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Towards improved handling of uncertainty in cost-benefit analysis: addressing the 'price-quality' and 'communication' dilemmas

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An important limitation of Cost-Benefit Analysis (CBA) is the inherent uncertainty in estimations of future welfare effects. In this paper, we argue that consideration of the 'price-quality' dilemma and the 'communication' dilemma is useful to explain and improve the handling of uncertainty in CBA. The 'price-quality' dilemma refers to the trade-off between the quality of welfare effect estimations and the costs of providing these estimations. Instruments to produce good quality effect estimates (including uncertainties) can be expensive both in monetary terms and time. We discuss the application of probabilistic traffic models as a promising example of how the 'price-quality' dilemma can be solved. The 'communication' dilemma refers to the observation that both a poor communication and a too prominent communication of uncertainties can cause problems for decision-makers. We argue that cognitive psychological theory provides useful perspectives to solve this dilemma, by providing a psychological framework which might help to explain why different types of people process CBA information differently. The results of this research may enhance first insights into the questions how the two dilemmas can be solved.

Keywords: *cost-benefit analysis, probabilistic dynamic traffic modelling, social psychology, transport appraisal, uncertainty*

1. Introduction

Cost-Benefit Analysis (CBA) has been an important tool for transport planners for several decades, in particular for evaluating and ranking transport infrastructure investments (e.g. Eliasson and Lundberg, 2012; Grant-Muller et al., 2001). Despite its popularity, CBA has often been criticised for several reasons, most of them related to the insolvable limitations when it is applied in practice. One important insolvable limitation is that estimations of future project effects are inherently very uncertain (e.g. Flyvbjerg et al., 2003; Naess, 2006; Naess and Strand, 2012). The topic of uncertain impact estimations in CBA is addressed in recent literature. For

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example, Nicolaisen (2012) states that a systematic ex-post evaluation programme needs to be established to facilitate a better learning process from experiences in past projects, which should result in more accurate effect estimations. Eliasson and Fosgerau (2013) point out that learning from ex-post evaluation results should be carried out carefully to avoid that methodological issues (in their case: selection bias) explain the main differences in ex-post and ex-ante effect estimates of projects instead of real 'estimation' problems. Furthermore, in their paper they demonstrate that the benefit–cost ratio turns out to be a robust selection criterion in the sense that the average benefit–cost ratio of the selected projects greatly outperforms random selection even for large uncertainties in benefit and cost estimates. Börjesson et al. (2014) seem to come to more or less the same conclusion. The key result of their study is that CBA rankings for 479 transport investments that were shortlisted for possible inclusion in the National Transport Investment Plan for Sweden 2010-21 are robust when different key assumptions (e.g. traffic safety benefits, emission benefits) are adjusted. Salling and Banister (2009) suggest to present interval results to decision makers instead of single point results to enhance decision makers' understanding of uncertainties. In this paper we take a different view on handling uncertainty in CBA. We argue that two dilemmas – the 'price-quality dilemma' and the 'communication dilemma' – impede a proper handling of uncertainty in current CBA practices. In this paper, we discuss both dilemmas and – more importantly – for each dilemma we propose a solution that aspires to be a first step towards solving the dilemmas. The main scientific contribution of this paper is that we attempt to use cognitive psychological theory to provide insights into how uncertainty *could* be communicated, based on individuals' reactions towards the communication of uncertainty in CBA reports. This is, to our knowledge, the first time that this theory is explored to see if it is useful in the field of CBA. It should be noted that we do not provide definitive answers in this paper. We hope that our paper inspires people for further research in this area. The paper is organised as follows: section 2 discusses both dilemmas in more depth. Sections 3-5 discuss the solutions. Section 6 provides concluding remarks.

2. Problem definition

We label the first dilemma as the 'price-quality dilemma'. CBA practitioners often make a trade-off between the quality of the estimation of welfare effects and the costs in time and money of providing these estimates. Cost-Benefit Analyses are intended in the decision-making process to provide decision makers with high quality information with regard to the welfare effects of infrastructure projects. CBA practitioners may aspire to provide effect estimations that are as accurate as possible and in realistic intervals (see below) based on empirical information, for instance. However, in most CBA practices, private consultants have to compete for a CBA tender. To win a tender the price-quality ratio of their offer must outperform the offers of the competing private consultants. Hence, it is important that their offer is not too expensive. Moreover, CBA Guidelines emphasise that costs of the appraisal should be proportionate to the costs of the infrastructure project under scrutiny in the CBA study. See for instance the UK WebTag (www.dft.gov.uk/webtag/) 1.4.2: *'it is expected that appraisals will be comprehensive but proportionate.*' And WebTag 2.1 '*careful consideration should be given, before resources are committed to data collection and model building.*' Also, supplements to the Official Dutch CBA Guidelines (e.g. Ministry of Transport, Public Works and Water Management, 2004) emphasise that the resources that would have to be devoted to preparing estimates of welfare effects should not be disproportionate. This results in gathering data of varying degrees of quality, applying causal explanations with varying degrees of validity and robustness, making assumptions and selecting certain approaches, all to limit the inquiry (e.g. Beattie, 1995). A group of scholars argues that the accumulation of assumptions and shortcuts leads to biased results and take this as an argument to oppose the use of CBA in the decision-making process at all (e.g. Ackerman and Heinzerling, 2004; Naess, 2006).

Naturally, a lower quality estimate is not a problem in itself if the analyst presents this result as a kind of interval estimate (i.e. the lower quality estimate 'x' lies somehere between a < x < b). By doing so, the analyst clearly shows the uncertainty to the decision-maker which they then can take into account in their decision (see Salling and Banister, 2009; Manski 2012). However, producing realistic intervals is not easy and often more time-consuming compared to just giving a more or less 'quick-and-dirty' point estimate (the 'x'). We define the 'price-quality dilemma' as follows: on the one hand CBA practitioners might want to produce high-quality interval effect estimates. However, because instruments to produce realistic intervals can be expensive, CBA practitioners are not inclined to produce these, because this could make their tender too expensive to win.

We label the second dilemma as the 'communication dilemma'. There is much literature on the poor communication of uncertainties in CBA reports. Naess and Strand (2012) state that the high degrees of uncertainty are often not displayed in reports. According to Welch and Williams (1997), CBA outcomes are usually presented as if they are endowed with considerable accuracy, although estimations of traffic models, for instance, are very uncertain. From an analysis of decision-support documents of 78 Norwegian and Danish projects, Nicolaisen (2012, p.7) finds that: *'uncertainties are often toned down or ignored in the decision support prepared for policy makers.'* Annema et al. (2013) have analysed 106 Dutch transport CBAs published in the period 2000 – 2012 and found, amongst other things, that in only 25% of the projects evaluated the CBA results were presented with a clear bandwidth to the decision-makers, in the other 75% just point estimates were given in the main results. To which extent is a poor communication of uncertainties problematic? Nicolaisen (2012) finds that improper communication makes impact appraisals appear more accurate than warranted, which causes distrust towards the results among policy makers. Based on a survey of 86 key individuals in the Dutch CBA practice for spatial-infrastructure projects Mouter et al. (2013) discuss that a poor communication of uncertainties leads to two problems. On the one hand politicians, civil servants and other stakeholders that use CBA assign too much value to the CBA because they are not aware of the uncertainties in CBAs and, as a result, use it as a holy grail ("we decide positively only if the benefit-cost ratio is above 1"). On the other hand poor communication of uncertainties enhances suspicion by sceptical actors, which leads to a situation where these actors assign too little value to the CBA ("I don't trust instruments that produce false certainties and are not honest about the limitations of the results"). Some Dutch key individuals even consider a poor communication of uncertainties so hazardous, that they think it can lead to the 'collapse' of the CBA in the decision-making process.

Is a very prominent communication of uncertainties then the solution? Mouter et al. (2013) find that a group of key individuals in the Dutch CBA practice for spatial-infrastructure projects perceives that a too prominent communication of uncertainties eventually leads to 'the collapse' of the instrument in the decision-making process. These key individuals perceive that politicians will not use a CBA report that communicates an uncertain message because politicians will not consider this as useful information and certainly not as a solid basis for decision making. In addition, a Review of the Norwegian Cost-Benefit Analysis Guideline (Hagen et al., 2012, p. 85) advises against the use of more than one estimate of welfare effects: '*since the approach will not provide one estimate, but several different estimates, for net economic benefits for the entire lifespan of the project, this approach may result in a more complex and equivocal basis for making decisions.*' Also, Manski (2012) discusses that the public, politicians and policymakers reward economic consultants who offer simple analyses leading to unequivocal policy recommendations. Therefore, the dilemma is that both a poor communication and a too prominent communication of uncertainties cause problems.

Before we suggest some steps to solve the dilemmas it is important to note that uncertainty is discussed to a very limited extent in this paper. In order to keep this paper manageable we only

discuss improved modelling for travel time gain estimates (in hours saved) in relation to uncertainty as an example to possibly solve the 'price-quality dilemma' (see section 3). Other sources of uncertainty in CBA are ignored. One important example of another source of uncertainty in CBA are the Value of Time (VOT) estimates (uncertainty in general, but also related to small versus large time savings, time losses versus gains, and so forth, see, e.g., Mackie et al., 2001; Fosgerau et al., 2007, Fowkes, 2010). Also estimates for environmental impacts of projects and their monetary values in CBA are highly uncertain (e.g., Atkinson and Maorato, 2008). A final example of high uncertainty is the much debated issue of the 'proper' discount rate to be used in CBA (e.g., Harrison et al., 2010 and for long-term and irreversible environmental impacts, Pearce et al., 2006).

3. A first step towards solving the 'price-quality dilemma'

In this section we propose a solution that aspires to be a first step towards solving the 'price-quality dilemma'. The general idea is to develop models or calculation tools which practitioners can use in order to make more accurate estimations without substantial extra costs (time and money) compared to current models and tools. Below, we discuss the probabilistic dynamic traffic model INDY-MonteCarlo as a promising example of how the 'price-quality dilemma' can be solved. This model applies efficient Monte Carlo sampling which makes it possible to estimate welfare effects more accurately against approximately the same time and costs (approximately 4 extra man-days, and 10 days extra running time for computers).

In CBAs for infrastructure projects the transport effects (such as travel time gains) are for financial reasons estimated based on a model simulation of a representative day, almost without exception. The representative day contains the average of the applicable capacity and traffic demand values for a scenario. The underlying assumption made is that even though traffic demand and capacity vary over the year – for instance, as a result of weather, lane closures, special events and incidents – the outcomes for the representative day can be extrapolated to a yearly value, presuming that the capacity and demand in the representative day are good averages. Conducting a CBA applying this assumption is obviously far less expensive than conducting a CBA for which the transport effects for all days in a year are estimated separately. The question is to which extent this assumption makes the estimation less accurate.

In a real-world case study, we investigate this topic by applying an advanced Monte Carlo traffic model, called INDY-MonteCarlo (see Calvert et al., 2014) for new rush-hour lanes on the A9 highway in Amsterdam (the Netherlands). As a result of the new rush-hour lanes the 2x2-lane road was expanded to a 2x3-lane road during peak hours (see figure 1). It was one of the thirty projects in the Dutch Roadworks Priority Program. Supplying extra road capacity was expected to relieve congestion on these critical motorway stretches. The lack of capacity typically caused congestion at the Diemen junction going in the direction of Amstelveen/Schiphol in the morning, and in the opposite direction in the evening.

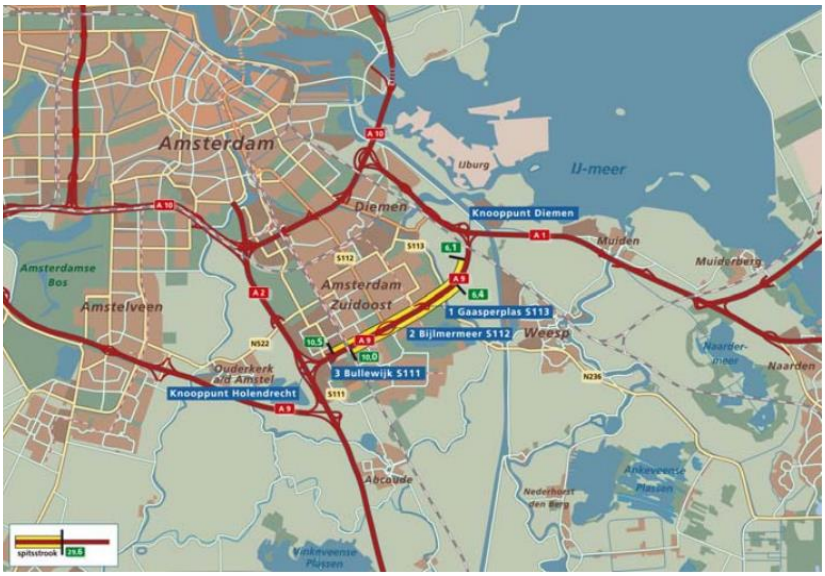

Figure 1. South East Amsterdam (the Diemen – Holendrecht stretch is colored yellow)

3.1 Application of stochastic variation in modelling the case study's travel time savings

In our case study we consider the stochasticity of road capacity and traffic demand while modelling the traffic effects of the project. Applying variation in the modelling process using stochastic input through Monte Carlo simulation is performed in this study through the approach that is introduced by Calvert et al. (2014). Firstly, in this approach, the traffic network is constructed with associated empirical information about road capacity and traffic demand. These distributions of stochastic variations of capacity and demand[2] result in probability distributions of capacity and demand. The underlying information for the probability distributions is derived from real traffic data from the A4 and A12 highways in the Netherlands during weekdays. Calvert et al. (2014) further indicate that the distributions found can be generically applied to most highways, "as the distributions are constructed as a relative factor rather than absolute capacity values." The resulting cumulative distribution functions of the road capacity and traffic demand factor are presented in figure 2.

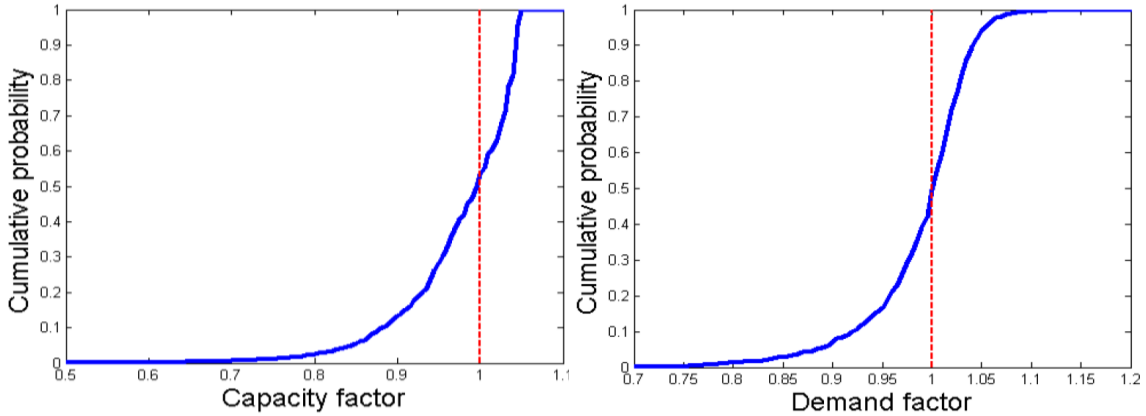

Figure 2. Cumulative distribution function of the road capactity and traffic demand factor

[2] Stochastic variation in traffic is a result of weather, lane closures, special events, incidents, and shifting demand patterns, for example. In this study, stochasticity is applied by using probability distributions indicating variations in road capacity and in traffic demand (i.e. adjustments from the average). For example, if the average ('base') demand for a particular road section is 1800 vehicles/hour, then an adjustment factor of 1.05 yields a demand of 1890 vehicles/hour, and a factor of 0.80 yields a demand of 1440 vehicles/hour.

Secondly, from these distributions a random sample is taken using Monte Carlo simulation, which is applied as input for the traffic model. In this study, 100 values are drawn for capacity and 100 values for demand. One important aspect in this study is that, in order to reduce the variance between individual samples and thereby to reduce the number of required sample iterations before an adequate level of performance is reached, Latin Hypercube Sampling (LHS) is applied in the Monte Carlo simulations in this study, in line with Calvert et al. (2014) and Salling and Banister (2009).

Thirdly, a traffic model simulation is run with 100 iterations for both the project situation and the reference situation in 2010, 2020, 2030 and 2040 for two social-economic development scenarios that differ in traffic demand development (Global Economy or Regional Communities; Huizinga & Smid, 2004), in which the samples drawn are applied as adjustment factors over base capacity and demand. Induced traffic, as a consequence of changes to the traffic network, is also included in the projections of traffic demand from the social-economic development scenarios. It is therefore implicitly considered in the model without further need for explicit consideration. The traffic model applied in this study is INDY. INDY is a dynamic macroscopic traffic model (Bliemer et al., 2004), which uses the Link Transmission Model (LTM) implementation by Yperman (2007) for traffic propagation.

The 100 outcomes of the simulation are expressed as a reduction in the total network delay of traffic in the project situation compared to the reference situation for each year of the time horizon using linear interpolation. Furthermore an assumption is made of the number of relevant days that the situation applies to per year of 210 days a year. These are generally the non-holiday weekdays in which congestion usually occurs. The result of the model simulation is multiplied with this number of days to give a yearly value, presuming that the given capacity and demand values are valid on all days. Finally, the travel time savings are expressed in monetary terms and are discounted to the base year (in this case 2010; discount rate is 5.5% in the Netherlands) in order to estimate the Net Present Value (NPV).

3.2 Resulting distributions and conclusions

The steps described in section 3.1 result in outcomes for the whole time horizon, in both scenarios. In the Global Economy scenario, the mean value of travel time benefits as approximated by INDY-MonteCarlo is 133 million euro, with a standard deviation of approximately 0.7 million euro. The deterministic mean, in which a single simulation is performed with a representative day, returns a considerably higher value of 141 million euro. In this scenario the mean is therefore overestimated by six percent if deterministic traffic model input is used. Figure 3 shows the distribution and the means in the GE scenario.

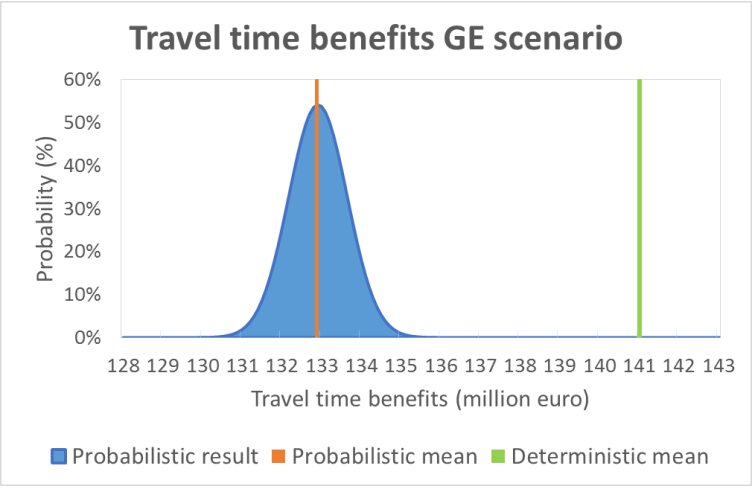

Figure 3. Uncertainty in estimations of travel time savings in the GE scenario

In the Regional Communities scenario, the mean value of travel time benefits is 73 million euro, with a standard deviation of approximately 0.8 million euro. The deterministic mean, in which a single simulation is performed, returns a much lower value of 60 million euro. In this scenario the mean is therefore underestimated by seventeen percent if deterministic traffic model input is used. Figure 4 shows the distribution and the means in the RC scenario.

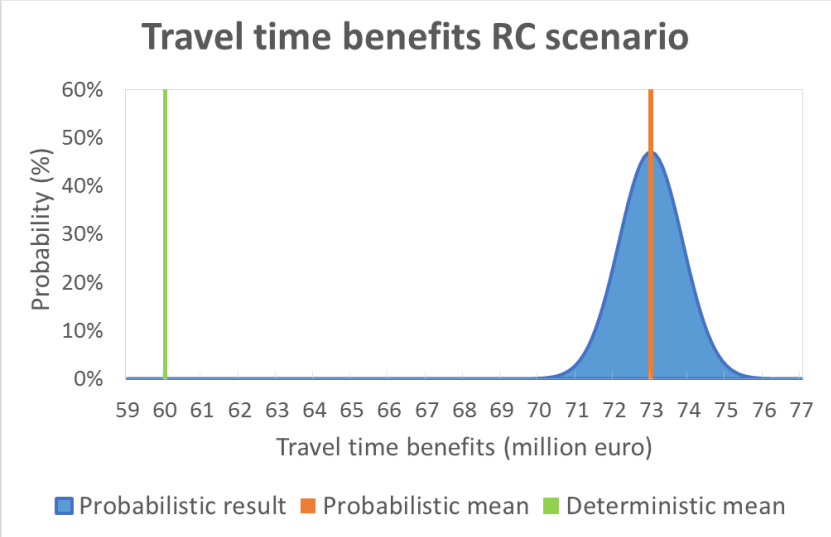

Figure 4. Uncertainty in estimations of travel time savings in the RC scenario

Figures 3 and 4 demonstrate that modelling traffic with the assumption that the capacity and demand in the representative day are good averages will lead to biased CBA outcomes. The results show that considering uncertainty with regard to demand and capacity over the year results in deviations from 6% and 17% compared to merely considering a 'representative day' for the model simulation in this test case. These values are also comparable with deviations found elsewhere in literature (van Lint et al, 2012; Calvert et al, 2012). A second notable observation, found from the results shown in figures 3 and 4, is that the bandwidths that were found around the probabilistic mean are small. Moreover, figures 3 and 4 show that uncertainty which originates from estimating effects with two social-economic development scenarios is much larger than uncertainty that results from estimating traffic effects with a probabilistic traffic model for demand and capacity. Hence, we conclude that – when CBA practitioners aspire to effectively communicate uncertainty surrounding effect estimations in the CBA report – it is paramount to estimate welfare effects with two economic development scenarios. Furthermore, these estimations will be more accurate if a model such as INDY-MonteCarlo is used, which makes it possible to estimate these welfare effects more accurately compared to estimating the effects assuming a representative day.

Now that we have more information with regard to the level and shape of uncertainty surrounding effect estimations the question is: how to communicate uncertainty in the CBA report? For instance, it is not yet clear how prominently uncertainties should be communicated in the CBA report, such that different types of individuals have a better understanding of the uncertainty. This topic is addressed in the next chapters.

4. Explanations for controversy about communication of uncertainty from a psychological perspective

As discussed in section 2 the dilemma is that both a poor communication and a too prominent communication of uncertainties are mentioned as potential causes for 'the collapse' of CBA in the

decision-making process for spatial-infrastructure projects. We argue in this and the next section that cognitive psychology may provide a promising perspective to solve this dilemma. Based on insights from cognitive psychology, we scrutinise the extent to which individuals have different attitudes towards uncertainty. Based on this, a cognitive psychological theory is developed that helps to explain the controversy about the communication of uncertainty in CBA reports. This theory also provides insight into how uncertainty *should* be communicated, based on individuals' reactions towards the communication of uncertainty in CBA reports. Furthermore, based on cognitive psychological theory measures arise that may stimulate the motivation of CBA users whose attitude towards the communication of uncertainty in CBA reports is expected to be problematic. Although the results of this study may not necessarily provide a final answer to the question of how uncertainty should be communicated in CBA reports in an appropriate manner, the results may enhance insights into the question of how – and most of all how prominently – uncertainty in welfare effect estimations should be communicated in CBA reports so that users with different personality and social psychological characteristics are able to understand the information and still evaluate the information as useful input in the decision-making process.

To address this topic, this section first discusses the dual-process theory of reasoning. This widely recognised theory clarifies how individuals receive and process information and explains that individuals can process information systematically or heuristically (section 4.1). Secondly, we discuss the fact that one result of a heuristic way of processing a CBA report that prominently presents point estimations is that uncertainties are poorly understood and argue that one should present uncertainty in a very prominent way (section 4.2).

4.1 The dual-process theory of reasoning

The dual-process theory of reasoning basically argues that individuals may *theoretically* employ two modes of thinking when processing information: individuals can process messages via 'System 1' or via 'System 2'.[3] System 1 is characterised by the reliance on simple inquiries and environmental characteristics of the message (O'Keefe, 2008), such as credibility of the author, appearance of the text or clarity of illustrations, whereas System 2 is characterised by accurate balancing of all specific information before judging, extensively relating the information to knowledge already possessed (O'Keefe, 2008). In other words, System 1 tends to process information heuristically, via subconscious cognitive 'shortcuts' that act as automatic programs to reduce complex decision tasks to simpler judgmental information, whereas System 2 tends to process information systematically (Kahneman et al., 1982; Shah and Oppenheimer, 2008). System 1 is always active (unintentionally) and is influenced by experiences, emotions and memories, whereas System 2, which is influenced by facts, logic, and evidence, is only active if an individual perceives that System 1 does not reach realistic conclusions and intentionally chooses to employ System 2 (Kahneman, 2011). Furthermore, literature indicates that individuals will only choose to employ System 2 if they are sufficiently motivated to assign cognitive resources to the task of information processing, if they have the ability, i.e. the competences or skills, to accurately interpret and understand a message, and if they have the opportunity to do so (e.g. Andrews, 1998).

Meyers-Levy and Maheswaran (2004) suggest that if decision-makers process a message systematically (typical of System 2), there will still always be some heuristic processing, to some extent (typical of System 1). In other words, even if individuals are highly motivated to thoroughly assess information in a systematic way, heuristic processing will always occur to a

[3] See e.g. Stanovich and West (2000), Kahneman (2011). Other labels for this theory and the associated modes of thinking are 'Elaboration Likelihood Model' (ELM; Petty and Cacioppo, 1986) and 'Heuristic-Systematic Model of Information Processing' (HSM).These theories refer to the same phenomenon and are conceptualised in similar terms (Evans, 2009). Therefore, it seems justified to assume that findings that apply to ELM, HSM or System 1 and 2 are also applicable to the others.

certain degree. Based on this observation and the occurrence of heuristic processing in other fields of research and policy making, it is considered likely that the use of heuristics in the processing of CBA reports is common, even if individuals are highly motivated to thoroughly assess all the information in a systematic way. Letson et al. (2001) state that before risks, uncertainties and limitations can be effectively communicated, scientists need to comprehend the 'mental models', which essentially refers to actors' use of framing and heuristics when they evaluate the information. Therefore, the next passage focuses on the most important heuristics that are relevant to the present study.

4.2 When point estimations are presented prominently, individuals will not consider the uncertainty

In this section, the relationship between the use of heuristics and the communication of CBA uncertainty is discussed. The heuristics that are taken into consideration explain why individuals are not able to understand uncertainties sufficiently when point estimations are presented in a prominent way.

Availability and anchoring-and-adjustment heuristics

There are various types of heuristics. Two of the most common and important heuristics are the *availability* heuristic and the *anchoring-and-adjustment* heuristic (e.g. Tversky and Kahneman, 1974).

The *availability heuristic* makes it more likely that people will consider the events which are easier to recall or bring to mind. For example, Tversky and Kahneman (1974) indicate that people tend to overrate the danger of air travel (relative to car travel), because of the dramatic nature of aircraft calamities and the subsequent lasting impressions of these accidents. Next, the *anchoring-and-adjustment heuristic* is the fundamental decision-making heuristic in events where values need to be estimated (Epley and Gilovich, 2006). In essence, this heuristic refers to starting from an initial value - the 'anchor' - which is based on a simple feature and then to adjust this number to arrive at the final answer (Tversky and Kahneman, 1974). But typically, the adjustments made to these anchors are insufficient (Lichtenstein and Slovic, 1971; Epley and Gilovich, 2006), meaning that different initial values lead to different estimates that are biased towards the initial values. For example, when asked to estimate the percentage of African countries in the United Nations, the median estimations were 25 and 45 for two distinct groups that had 10 and 65, respectively, as suggested initial values (Tversky and Kahneman, 1974). The anchor biased their final estimate. Furthermore, Yamagishi (1994) suggested that anchoring-and-adjustment also leads to biases in evaluations of risk and uncertainty, the same as the other heuristics and biases.

The availability heuristic and the anchoring-and-adjustment heuristic may be important causes for ineffective communication of uncertainties when CBA practitioners prominently present 'point estimates'. Considering the availability heuristic; this heuristic leads individuals to relate the numbers presented to the ease with which they can imagine such outcomes. Since individuals have far less difficulty in imagining a single number as the outcome than in imagining a range or a probability distribution as the outcome, presenting a single number results in an overconfidence in this number. In other words, as soon as individuals are given a single number as the outcome, they are likely to put so much emphasis on this number that they will subconsciously accept that number as decisive, irrespective of the presentation of uncertainties surrounding the estimation. For the anchoring-and-adjustment heuristic: this heuristic leads individuals to assume that the actual effect cannot differ that much from the starting estimation, or the 'best estimate'. So, individuals would subconsciously underestimate the possibility of different outcomes (outliers) and overestimate the confidence with which outcomes are likely to be close to the initial single point estimation. In other words, if a CBA report communicates a specific value for a social benefit or a social cost of a project, the report may still present

uncertainties surrounding the estimations, but CBA users remain relatively unaffected by this 'late' presentation of uncertainties.

5. Prominent communication of uncertainties: problems and solutions

From section 4 we conclude that it is important to prominently communicate all uncertainties and limitations in a CBA report. However, this does not serve heuristic message processing. Actors are not enabled to reach conclusions immediately, but will have to consider the uncertainties and ambiguous clues. In this study we distinguish two possible types of 'heuristic individuals' who we think will have trouble with processing information on uncertainty.[4]

Firstly, we believe that the communication of an uncertain and equivocal message will be problematic for the 'flamboyant heuristic individual'. By making decisions, this type of individual will heavily rely on his intuition. Hence, this individual is a priori relatively sceptical towards the added value of research reports. This type of individual will almost exclusively use System 1 to process information. If this individual decides to process the information of a report at all, he will process the information in an extremely heuristic way. When a research report communicates an uncertain message this commands the flamboyant individual to activate System 2. Chances are high that the individual will not decide to activate System 2 and will just focus on information that is possible to grasp using System 1 solely or will rely on his intuition. In conclusion, if a CBA report first communicates point estimations, a 'flamboyant heuristic individual' will probably consider the point estimations and not the uncertainties. However, when uncertainties are presented first, it is likely that this individual will not consider the information of the CBA report at all. Hence, prominent communication of uncertainties results in diminishing use of information.

Secondly, we think it is likely that a prominent communication of uncertainties is ineffective for the 'stubborn heuristic individual'. In spite of the prominent warning that effect estimations are uncertain, this individual still wants to find a definite and unambiguous conclusion in the CBA report. This type of individual will consider a report that conveys an equivocal message useful. However, this individual will ignore the uncertainty and eventually believe to have found conclusive evidence in the report to support or not support the project.

To enhance our understanding of the two types of individuals' difficulties to process ambiguous messages, we first need to discuss the relationship between individual differences and motivations to use the CBA report (section 5.1 – 5.3). Moreover, we will discuss psychological characteristics of the so-called 'stubborn heuristic individuals' and the 'flamboyant heuristic individual' (section 5.4) and provide solutions for managing their problems of processing uncertain messages (section 5.5).

5.1 Different Motivations (orientations)

Individuals can have different motivations for using a CBA report in the decision-making process (Mouter et al., 2013). For instance, individuals use the CBA to contemplate the usefulness, necessity and design of a project, use it strategically (either to kill or support the project), use it in an Absolute way ("if the score is positive we decide positively and vice versa). The first three motivations will from now on be called (1) Challenge orientation, (2) Strategic orientation and (3) Absolute orientation. We have conceptualised Challenge orientation as the tendency to view

[4] We are aware of the fact that considering a report that communicates an uncertain message can be troublesome for other types of individuals as well. Hence, the two possible types of heuristic individuals should be seen as examples of individuals for whom we consider it certain that possible drawbacks of prominently communicating uncertainty can arise. Further research should clarify which other types of individuals may have trouble with processing information on uncertainty.

information as being useful or needed to think about the usefulness, necessity and design of the project, and to be likely to question assumptions in the CBA, for the sake of making better decisions. Strategic orientation has been conceptualised as individuals' tendency to value and apply information according to their own liking, for the sake of serving their political or personal interests. Absolute orientation has been conceptualised as the tendency to overrate or absolutise information because of a conviction that it is imperative to base the final decision on this information. Within this orientation, the accent is not on searching out the limitations and assumptions of the research, which is the case in the Challenge orientation, but on 'simply' trusting that the information provides the right (final) answer.[5]

In sub-section 5.3, we discuss a conceptual model for the hypothesised relationships between cognitive styles and the three motivations for processing CBA reports. First (in sub-sections 5.2), we need to explain the cognitive styles that are relevant, related to the processing of uncertainty-related CBA report content.

5.2 Cognitive styles

Cognitive styles are defined as individuals' "chronic motivations that principally determine the initiation, course, and cessation of information seeking and processing" (Thompson, 2008; Thompson et al., 2001). In other words, cognitive styles are individual differences that directly influence information seeking and processing preferences. Individual differences are defined as psychological traits or chronic tendencies that "convey a sense of consistency, internal causality and personal distinctiveness" (Carver and Scheier, 2000). These individual differences are assumed and demonstrated to be relatively unrelated to situational induced differences: individual differences are considered to "play an elemental role in how people generally react across the situations they encounter" (e.g. Thompson, 2008). In other words, individual differences, as they are understood in psychology, are presumed to describe individuals' general orientations and motivations across domains.

Three cognitive style variables are discussed which can be related to the processing of uncertainty-related CBA report content. These are: Need for Cognition (NC; Cacioppo and Petty, 1982), Personal Need for Structure (PNS; Thompson et al., 1989, 1992), and Personal Fear of Invalidity (PFI; Thompson et al., 1989, 1992).

Characteristics of Need for Cognition (NC)

Cacioppo & Petty (1982) conceptualised Need for Cognition (NC) as "an individual's chronic tendency to engage in and enjoy effortful cognitive activities." To measure individuals' NC, generally, the scale validated by Cacioppo et al. (1984) is used. This scale consists of 18 items, such as "I would prefer complex to simple problems"; "I find satisfaction in deliberating hard and for long hours"; "I only think as hard as I have to" (reverse scored). Positive correlations have been found, amongst other things, between NC and *Objectivism* (the tendency to base one's judgements and beliefs on empirical information and rational considerations, Leary et al., 1986; see Cacioppo et al., 1996, for a review of studies concerning NC)[6].

[5] Strong support for these conceptualisations is found in the study of three distinct motivations in the field of religion: it was found that Challenge, Strategic and Absolute orientation are highly similar to 'Quest', 'Means' and 'End' orientation in religion (see e.g. Barrett et al., 2005). It is, however, beyond the scope of this research to discuss the convincing similarities between the motivation to be involved in religion and the motivation to use the CBA report.

[6] Note that the conceptualisation of the social-psychological concept 'Objectivism' deviates from the philosophical concept 'Objectivism' established by Ayn Rand in The Fountainhead, amongst others.

Hypothesised relationships between NC and the motivations in the processing of CBA reports
Challenge orientation clearly indicates individuals' inclination to systematic processing of the more cognitively complex and less explicit content. Consequently, it is hypothesised that there is a positive relationship between NC and Challenge orientation.

Since NC was found to be positively related to Objectivism, indicating that individuals high in NC are more open to change their opinion – perhaps even their strategic (self-centred or political) opinion – if empirical or rational information demands so, it is to be expected that NC and Strategic orientation are inversely related.

Absolute orientation has been conceptualised as the tendency to overrate or absolutise the CBA because of a conviction that it is imperative to 'simply' trust the outcomes of the CBA report and base the final decision on its results. Nicolaisen (2012) found that individuals with a higher education tend to perceive results of a research report with more scepticism than people with a low education. From the findings of Spotts (1994) we derive that level of education and Need for Closure (a motivated tendency of an individual to desire for a firm answer to a question and an aversion toward ambiguity) are positively related as well. Consequently, it is hypothesised that there is a negative relationship between NC and Absolute (vs. Relative) orientation.

Characteristics of Personal Need for Structure (PNS)
PNS is designed to "assess preferences for structure and clarity in most situations, with ambiguity and grey areas proving troublesome and annoying" (Thompson et al., 1989) and was indicated by Neuberg et al. (1997) to serve "to capture the chronic preference for cognitive simplicity and structure". Thompson et al. (1992) furthermore indicate that PNS "reflects individual differences in preferences for structure and clarity in one's thinking and one's life". To measure individuals' PNS, generally the scale validated by Thompson et al. (1989) is used. This scale consists of items (such as "I become uncomfortable when the rules in a situation are not clear" "I hate to be with people who are unpredictable"; "I don't like situations that are uncertain." Negative correlations have been found, amongst other things, between PNS and *Openness to experience*, and *Need for Cognition* (Neuberg and Newsom, 1993). Furthermore, it should be expected that people high in PNS prefer simple informational messages over complex ones, which require more cognitive effort to understand (e.g. Van Hiel and Mervielde, 2003).

Hypothesised relationships between PNS and the motivations in the processing of CBA reports
PNS is expected to be negatively related to Challenge orientation. Basically, this is because high PNS is indicative of rigid or inflexible thought, whereas Challenge orientation is conceptualised as showing flexibility in changing one's thoughts for the sake of making better decisions. Individuals high in Challenge orientation are likely to start processing a CBA report in an open-minded way.

Strategic orientation is hypothesised to be positively related to PNS. The reason is that high-PNS individuals will *need* to act strategically more than low-PNS individuals in order to be able to maintain their more circumscribed convictions.

Absolute orientation is hypothesised to be positively associated with PNS. It may be expected that absolutising a message in the context of a decision-making process requires people to freeze their judgments and then to remain relatively uncritical about their opinions, which are characteristic of high PNS.

Characteristics of Personal Fear of Invalidity (PFI)
Personal Fear of Invalidity (PFI) refers to the tendency of individuals to seek alternatives and avoid making an explicit choice between them because of a fear of being incorrect (Thompson et al., 1992), and to the extent to which individuals are concerned with the cost of committing errors

(Thompson et al., 1989). To measure an individual's PFI, typically, the scale validated by Thompson et al. (1989) is used. This scale consists of 14 items, such as "I prefer situations where I don't have to decide immediately"; "I rarely doubt that the course of action I have selected will be correct" (reverse scored). Thompson et al. (1992) indicate that individuals high in PFI were found to be concerned about the possible consequences of a choice, that they are indecisive, that they were found to be likely to feel discomfort when they receive feedback indicating that they have made a mistake, and that they are likely to embrace cognitive structures to reduce ambiguity. It can be suggested that there are positive relations between PFI and the amount of information acquired prior to making decisions (Wichary et al., 2008). Negative relations may be expected between PFI and reliance on incomplete information and confidence in one's own judgment (Kruglanski and Fishman, 2009).

Hypothesised relationships between PFI and the motivations in the processing of CBA reports

It is conceivable that PFI is positively associated with Challenge orientation. Whereas Challenge orientation refers to a motivation to study the CBA exhaustively, individuals high in PFI are likely to study reports exhaustively as a result of a fear of making an error harmful to themselves or harmful to society.

Strategic orientation is hypothesised to be unrelated to PFI. Whether individuals have a high or low fear of making errors seems to be orthogonal to using the CBA outcomes strategically in order to serve their personal or political interests.

The relationship between PFI and Absolute orientation is expected to be positive. It might be expected that individuals high in PFI will want to minimise their personal responsibility of being wrong, whereby they are conceivably more likely to rely on the outcomes of underlying research reports. By doing so, in a sense, they absolve themselves of their personal responsibility.

5.3 Conceptual framework

Overall, section 5.2 provides support for the hypothesis that broader cognitive orientations might have a systematic influence on actors' motivations in the processing and use of CBA reports in decision-making processes. We display the hypothesised relationships between NC, PNS, PFI and Strategic, Absolute, and Challenge orientation discussed in the previous section in a conceptual framework (figure 5). Note that the assumed causalities in this conceptual framework cannot be empirically underpinned yet. We explore possible relationships.

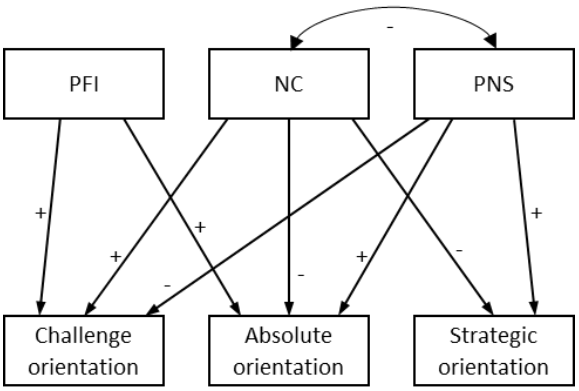

Figure 5. A conceptual framework of the hypothesised relationships between Personal Need for Structure, Need for Cognition, Personal Fear of Invalidity and Strategic, Absolute and Challenge orientation in the processing of CBA reports

The conceptual framework results in the following observations[7]:

- Individuals who are high on Strategic orientation should be expected to be low on NC, high on PNS, and either high or low on PFI;
- Individuals high on Absolute orientation should demonstrate high PNS, high PFI and low NC;
- Individuals who are high on Challenge orientation are expected to show high NC, high PFI and low PNS.

5.4 Relate psychological characteristics of flamboyant heurist and stubborn heurist

Looking at the conceptual framework (figure 5) we assume that the 'flamboyant heuristic individual' will have a low NC and low PFI. The flamboyant individual tends to rely on intuition. For this individual it is not necessary to process research findings to come to a decision. Hence, his NC is low. Moreover, the PFI of a flamboyant individual can assumed to be low. This individual will trust that his intuition is right, even when the outcomes of a research report contrast his intuition. At best, this type of individual will read the top page of a research report and will use the results of the CBA report in a strategic way. When the report supports his intuition, he considers the information in the report as valid. When the report does not support his opinion he might marginalise the validity of the report. Here, it should be noted that in this paper we take a purely psychological view. Naturally, also politicians self-interests (see, e.g. the school of Public Choice, Buchanan and Tullock, 1962) can play a role in marginalising the validity of a report. For example, a politician might want to realize a project just because he thinks that it increases the probability that he will be re-elected. A report showing to the politician that this project is not the best idea ever might even be in accordance with his own intuition but out of self-interest the politician still might marginalize the report.

It is likely that the 'stubborn heuristic individual' is high on PNS. Although the CBA report prominently communicates that the welfare effect of the project is highly uncertain, this individual wants to know if the outcomes mean that the project should or shouldn't be supported. It is either black or white. This type of individual will not consider it problematic to process the report systematically (use System 2), as long as he can find conclusive evidence for a 'go' or 'no go' decision. Although uncertainty is communicated prominently, this individual will not consider the uncertainty.

We hypothesise that the result of the prominent communication of uncertainties (as recommended in 4.2) is that the 'flamboyant individual' will not use the CBA report at all, whereas the 'stubborn heuristic individual' is likely to ignore the uncertainty, even though the uncertainty is communicated in a prominent way.

5.5 Solutions to enhance systematic processing

In this section we discuss some possible remedies to enhance motivation of the flamboyant heurist and the stubborn heurist to simultaneously understand uncertainty and perceive the CBA report as useful input for the decision-making process (thus, some remedies for solving the dilemma). For both individuals it is not easy to achieve our double objective. However, our theory indicates that increasing the Personal Fear of Invalidity might help both individuals to consider the results of the CBA report in a more in-depth way. Accordingly, a solution could be that decision makers are held personally accountable for their decisions (e.g. Bruzelius et al., 2002). When these individuals know in advance that the consequences of a wrong decision will be severe (for their income or reputation), this might be an incentive to process the CBA report

[7] We would like to emphasise that the assumed relationships in the conceptual framework need to be tested in further research.

more systematically, even though the main conclusion of the CBA report is that the welfare effect of the project is uncertain. Flyvbjerg et al. (2003) propose a number of instruments to improve accountability. There are, however, a number of dangers with the introduction of such a measure, moral hazard being the most important (Cantarelli, 2011). We furthermore expect that presentation of the report by a prominent and credible author ('the expert in the field') functions as a situational factor that heightens the salience of the CBA's message, and thus stimulates individuals' need for cognition (cf. Lockwood, Jordan and Kunda, 2002).

Another remedy to enhance systematic processing of information of a CBA report is to enhance the *Ability* and *Opportunity* of individuals, by training, for instance. It may be assumed that the *Ability* of individuals to work with research reports that communicate an uncertain message will be enhanced anyhow when all CBA reports communicate uncertainty. Eventually individuals get more used to it. *Opportunity* of individuals may be enhanced by customising the environmental characteristics of the message (O'Keefe, 2008), such as appearance of the text or clarity of illustrations. This means that it is more likely that the flamboyant individual will process the information of the CBA report in a systematic way when the lay-out of the report (that presents uncertain results) is very persuasive. Because the flamboyant individual is forced to use System 2 to process the uncertain message of the CBA report it is paramount to make sure that the individual solely needs to use System 1 to process the rest of the information. More specifically, jargon should be avoided at all cost, the report should be very easy to read, persuasive infographics should be used etc. We display the hypothesised relationships between solutions to enhance systematic processing and motivation, ability and opportunity discussed in the previous section in a conceptual framework (figure 6).

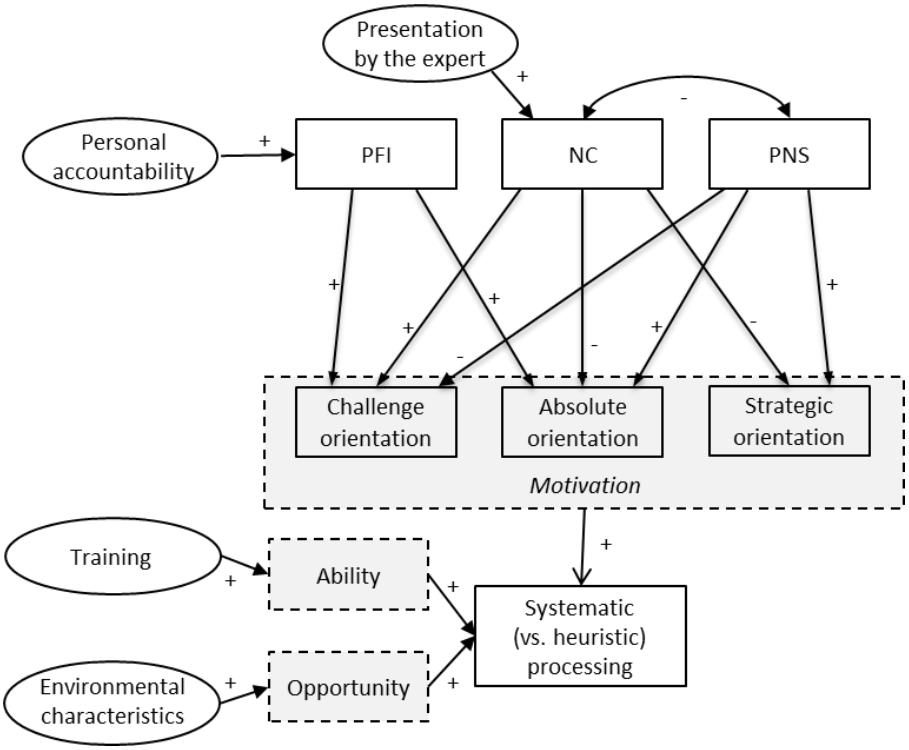

Figure 6. A conceptual framework of the hypothesised relationships between various solutions to enhance systematic processing

Although we do not necessarily provide a definitive answer to the question of how the 'communication dilemma' can be solved, we conclude that uncertainty should be communicated very prominently before point estimates in order to make sure that CBA users understand the

uncertainty. However, one simultaneously should apply the actions that are discussed in this section to make sure that decision makers still perceive the CBA as useful information. We recommend scrutinising which of these actions is most effective in future research.

6. Concluding remarks

In this paper we discuss solutions that aspire to be a first step towards solving two dilemmas with respect to handling uncertainty in the CBA and the decision-making process in which the CBA is used. The 'price-quality dilemma' and the 'communication dilemma'.

Regarding the handling of uncertainty in CBA studies, we derive three main conclusions. Firstly, in addressing the 'price-quality' dilemma there is a need for models in CBA which can more accurately estimate project impacts without substantially increasing time and monetary costs compared to the current models. The INDY-MonteCarlo method is an example of such a model. Secondly, if uncertainty is considered in CBA studies, and if it is desirable that different types of users are given a better understanding of the uncertainty, the uncertainty should be presented very prominently. Cognitive theory shows that the negative consequences of using heuristics when processing the CBA report (i.e. using outcomes strategically or absolutise or marginalise the report) can be diminished when CBA practitioners first communicate the uncertainty surrounding welfare effect estimations, such as bandwidths, ranges, and chances of outliers, and only then carefully give some indications to what could be plausible outcomes. Thirdly, if uncertainty is considered in CBA studies, CBA practitioners should be aware that communicating uncertainty (and, thus, even very large uncertainty) in a prominent way can lead to problems for individuals that process information heuristically. In this study, we developed a cognitive psychological conceptual framework of motivation to use the CBA report in the decision-making process. Based on this conceptual framework we identify remedies for the problems caused by a prominent communication of uncertainties. We argue that increasing heuristic individuals' Personal Fear of Invalidity might stimulate them to consider the results of the CBA report in a more in-depth way. One way of achieving this is by increasing personal accountability for a negative outcome of a decision. Another remedy is to enhance the presentation of the results. It is important that 'the expert in the field' presents research reports that communicate an equivocal message to heuristic individuals. Optimising environmental characteristics of the message, such as appearance of the text, clarity of illustrations, less jargon, etc., ensures that the individual does not have to make high cognitive effort to understand other information included in the report than the uncertain message, which enhances the opportunity that the individual will make the cognitive effort to understand the uncertainty. Lastly, training that enhances the ability of individuals to process CBA reports that communicate an uncertain message might result in a more systematic way of processing the information.

We would like to emphasise that the aim of this contribution was to contribute to our insight into handling uncertainty in CBA in a more optimal way. This was done by considering the result of giving uncertainty a more prominent place in the analysis and in the communication of results in a CBA report. Several items in this study have not been empirically demonstrated. This study contains the first exploration of these relationships and further research is needed to test the validity of the hypothesised relationships. We distinguish three relationships that need further research. Firstly, the fact that CBA users make use of heuristics in the processing of CBA reports has not been tested. Theoretically, it may be expected that this is indeed the case, but the extent to which this is the case for decision makers processing CBA reports remains unclear. Secondly, based on existing literature regarding cognitive psychology, we suggest that uncertainty is better understood if communicated very prominently in the CBA report, but the extent to which the understanding increases has not been tested. Thirdly, the relationships between broader

cognitive motivations and motivations in the processing of CBA reports have not been examined before.

Other possible avenues for future research based on the results of this study include the following. Firstly, which format communicates uncertainty in an optimal way? In this study we found that – based on cognitive theory – CBA users understand uncertainty better if uncertainty is presented prior to point estimations. However, we did not analyse which format is the most appropriate to present uncertainty in CBA reports so that users with different personality and social psychological characteristics are able to understand the information and evaluate the information as useful input in the decision-making process. Secondly, our study did not discern between the communication of conventional uncertainties – which can be communicated with business-as-usual scenario's such as the Global Economy and Regional Communities scenario used in the Netherlands – and uncertainties that are the result of unconventional changes such as major ICT developments, terrorist events and pandemics (see Van Cranenburgh et al., 2012 for an overview of unconventional changes). It would be interesting to scrutinize the extent to which conventional and unconventional uncertainties should be communicated differently to users of CBA studies in further research.

Thirdly, which social-psychological factors explain the position of CBA in a group decision-making process, and what does this mean for the way uncertainties should be communicated in CBA reports? The background of this question is that decisions with regard to spatial-infrastructure projects are usually made in group processes, not by individuals. This study, – at least, in the discussion of the 'communication' dilemma – is focused on individuals. Fourthly, in practice CBA reports are 'translated' by senior civil servants to politicians. Hence, one can argue that not the politicians but the senior civil servants should be encouraged to process and communicate uncertainty. Does the fact that results – and uncertainties – are usually communicated via a senior civil servant to a politician have any effect on the way uncertainties should be communicated in CBA reports?

Finally, we would like to point out that problems with uncertainty in CBA outcomes might be different for practices where CBA is predominantly applied to rank different project proposals against each other (e.g. Sweden) compared to practices where CBA is used as information for decision making with regard to the extent to which funding will be approved for specific project proposals (e.g. the Netherlands). If CBA is only used to rank proposals and the rankings turn out to be highly robust (Börjesson et al., 2014) it is not highly urgent to prominently communicate uncertainty. If a CBA is used as input for 'go/no go' decision making for an individual project a prominent communication might be more desirable since communicating to a decision-maker that the BCR ratio is between 0.7-1.2 instead of communicating a point estimate of 0.9 possibly leads to different outcomes.

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