Radioactivity and Its Adverse Health Effects: the Political Economy of Cost-Benefit Analysis

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Abstract

Access to relevant information in an understandable manner is highly important for decision makers in order to arrive at well-founded collective decisions, which might have far-reaching consequences, such as exposure to radiation. Explicitly throughout the thesis I stick to the assumption that the goal of any economic analysis is to supply the decision makers with sufficient and understandable information to make well-founded decisions. Cost-benefit analysis (CBA) aims to play a significant informational role in decision-making processes as a tool of policy analysis. Its capacity to achieve this goal is considered from two standpoints: (A) CBA as a tool to rank alternative projects according to their social desirability; and (B) CBA as an informational background for the democratic decision-making procedure. In this thesis I investigate whether CBA can improve on democratic decision-making processes which concern radiation-related projects and their adverse health effects. Nuclear power-related projects constitute a particular point of interest in this research. CBA turns out to be problematic to use in decision-making processes from both standpoints set above. As a tool of ranking the alternatives, CBA provides too aggregated information to judge about the social desirability of the projects because different decision makers have different political and ethical preferences. Applied CBA ignores distributional concerns, but if ignored, the very distribution of radiation-related risks to human life and health can be unfair. CBA rests upon monetary valuation of the project's effects, but putting prices on intangible values, such as life and health, is a highly controversial and demanding task. In addition, CBA appears to take improper account of risk and uncertainty, which are inherent in radioactivity. Besides, this thesis approaches CBA in the context of conflict. Initially some experts consider CBA as a measure to control proponents of risk regulation since the latter are perceived as powerful political groups and thus overregulate excessively. However, it may appear to be the case that rather the proponents of CBA themselves constitute well-organized politically powerful groups, which intend to manipulate the outcome and the use of CBA. The need for stronger public participation in democratic decision making is stated, and possible roots of weak public participation are addressed. Several alternatives to CBA are proposed as well.

Keywords: Cost-benefit analysis; Democratic decision making; Radioactivity; Nuclear power technology; Adverse health effects; Risk and uncertainty

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Of course, whatever I do in my life would not have been possible without my mum Valentina, whose love and warm emotional support mean more than everything to me.

I dedicate my thesis to my beloved friend Oleg who died from cancer in February 2011.

Contents

"Samfunnsøkonomer skal tenke mer enn telle."[1]

Introduction

Access to relevant, timely, and reliable information, provided in a convenient and understandable form, plays a crucial role in decision-making processes. The opportunity to have such information available seems to be particularly important in the fields where decisions might affect life and health of human beings, where possible consequences of decisions about projects and policies can be difficult to anticipate and assess properly due to risk, uncertainty, and extended time horizons. Evaluation of radioactivity-related projects and policies seems to be most demanding and challenging in this respect.

Since economic issues and policy making are highly interconnected and mutually influential, the economist is generally supposed to supply decision makers with results of an economic analysis of a project or policy proposal on the agenda. One of the tools of policy analysis available to the economist is cost-benefit analysis. In practice, cost-benefit analysis aims to provide information for decision-making purposes. Hence, it is important to verify that cost-benefit analysis properly fulfils its function in the provision of relevant information to decision makers when it comes to projects fraught with radiation adverse health effects. And an obvious criterion for the successful fulfillment of this function is likely to be decision makers' easier understanding of policy effects and risks involved.

The question I discuss is the following: Can cost-benefit analysis improve on decision-making processes concerning projects related to the risk of exposure to radiation and subsequent adverse health effects? Moreover, in order to specify the main question, I pose three sub-questions:

1. Can cost-benefit analysis be used to judge about the social desirability of a radiation-related project?
2. Can cost-benefit analysis be useful as a background for democratic decision-making processes, i.e. serve as an informational input in a democratic decision process, thereby facilitating such a process?

[1] The epigraph is just a phrase by someone from some discussion on www.facebook.com, remembered by me a few months ago. I was not able to find the roots and the author of it. The translation is: "Social science economists should think more than count."

3. Can the use of a cost-benefit analysis be endogenous to a decision-making process (i. e. Can CBA be deliberately chosen as a tool of policy analysis by those who are interested in its results)? If yes, what *implications* can this have for the *final* stage of decision making about a radiation-related project if weak public participation is in place?

In this thesis I mainly use a theoretical approach involving a review of the relevant literature. As an original motivation for this thesis, I refer to an ongoing Petersburg Nuclear Physics Institute's project aimed at advanced scientific research in neutron physics in Gatchina (Russia). They are going to put into operation an additional reactor, the so-called Reactor PIK. The project was frozen in the late 80s as a result of the Chernobyl disaster, then renewed, and today the Institute is about to go through with it (for a scientific review of the project see Serebrov and Okorokov 2000). The implementation of this project might worsen an unfavorable human health situation in the area as it is.

The thesis consists of seven parts. Part 1 points to the significance of information in decision-making processes. Part 2 outlines the theory of cost-benefit analysis. A simple mathematical model is set up and accompanied by brief descriptions of key concepts built in the cost-benefit framework and valuation techniques such as contingent valuation and hedonic pricing. Part 3 introduces risk into the cost-benefit framework. Part 4 takes up the specifics of radioactivity, which has to be taken into account when implementation of a project entails risk of exposure to radiation.

Due to several inherent weaknesses of cost-benefit analysis, its use as a tool of policy analysis may put obstacles in the provision of relevant and reliable information to decision makers. Cost-benefit analysis involves problems both on methodological and institutional grounds. Parts 5 and 6 are respectively concerned with methodological and institutional aspects of the tool. Among existing methodological issues of cost-benefit analysis, I pick up the following ones: distributional concerns in decision-making processes, limits to putting a monetary value on human health and life, and the flip side of nuclear power technology and the question of risk regulation. They are covered in turn in part 5.

Part 6 deals with institutional aspects of cost-benefit analysis. First, I check whether cost-benefit analysis satisfies criteria for democratic decision making. Then, I turn to an existing conflict of interests which has its roots in the presence of strong special-interest groups, on the one hand, and weak public participation, on the other. Part 7 provides possible alternatives to cost-benefit analysis in fulfilling an informational function for the purposes of making decisions about radiation-related issues.

1. Role of information in decision-making processes

In the information age, when access to knowledge is about to become instant, political decision makers still experience a lot of difficulty in receiving relevant information to make decisions about alternative policies. Because their decisions are so complicated and far-reaching, they cannot just browse the Web in the search of the only reliable solution. On the other hand, they do need a 'navigation system' to come by a well-founded decision. As Revesz and Livermore (2008, p 2) humorously depicted the state of affairs, "when policy makers make decisions without gathering all available information, looking at alternative courses of action, and anticipating the likely consequences of their actions, they are as foolish as someone who fails to consult a map when driving in unfamiliar territory." While "all available information" may be difficult to understand, information *sufficient* for well-founded decisions is crucial.

Decision makers may have their own ethical beliefs and make intuitive judgments about alternative projects or policies, but their decisions require to be well grounded in relevant and understandable information about the issues on the agenda. Therefore, scientific findings and recommendations play an important role in decision-making processes. However, decision makers encounter difficulties in making decisions because information available to them may not fulfill their requirements. This information may be either insufficient or abundant and difficult to process.

For instance, even in such well-studied fields as radioactivity, there are divergences of views among experts. In particular, scientists continue to disagree about the exact health impacts of low doses of radioactivity (Ackerman and Heinzerling, 2004, p 115). On the other hand, decision makers' mental capacity for processing a huge amount of available information is also not without limit. Like other human beings, decision makers "have a limited ability and time to receive and understand information. Providing too vast amounts of information may easily confuse decision makers rather than inform them" (Nyborg, 1996, p 94).

When information is incomplete or superfluous, time and budget constraints are in place, risk and uncertainty about the consequences of decisions are involved, a useful tool of policy analysis is needed to communicate health effects of radioactivity-related projects to decision makers. Moreover, ethical beliefs, judgments about policies, and preferred objectives of different decision makers are not usually absolutely congruent. They tend to diverge on a systematic basis. Hence, the tool of policy analysis has to be neutral in order to suit collective decision purposes.

Economists are usually called on to provide decision makers with economic results of policy analysis. In the light of the obstacles to receiving accurate and understandable information, mentioned above, it makes sense to suggest that the role of the economist should be to facilitate the information flow, rather than complicate it. Nyborg (1996, p 8) makes a basic assumption that "the aim of the economic analysis is to *inform participants in a political decision process*, in order to make their individual judgments as well-founded as possible." I stick to this assumption throughout the thesis.

Regarding the problem of policy analysis, Nyborg (1996, p 89) finds it "particularly useful to distinguish between the following two cases:

A. The purpose of the analysis is to arrive at a ranking of alternatives.
B. The purpose of the analysis is to facilitate *someone else's* (the decision makers') ranking of alternatives."

Thus purpose A is aimed at judging about social desirability of alternative projects. Purpose B deals with provision of background information to the decision makers to improve on the process of making decisions.

Cost-benefit analysis (CBA) as an economic tool of policy analysis is considered in this thesis. In the literature it is sometimes referred to as 'benefit-cost analysis' (BCA), but this fact does not entail any conceptual differences between the two terms (Perman et al., 2003, p 352). In what follows, wherever it is relevant, I distinguish between the two cases, A and B, proposed by Nyborg (1996), and specify the case under which CBA is being discussed. This is important because cases A and B are associated with sub-questions 1 and 2 respectively which have been posed within this thesis.

At this stage of the discussion, it makes sense to point out that the results of CBA for purpose A, i.e. when CBA serves as an output of a specific social welfare judgment, may be difficult or even impossible for a decision maker to use in combination with their own ethical or political views (Nyborg, 1996, p 89). Even among proponents of CBA there are those who recognize that this tool of policy analysis can only be used as one of the informational inputs into decision-making processes. For example, Zerbe and Bellas (2006, p 1) argue: "Care must be taken that unquantified or roughly quantified effects be given their proper weight. In doing this it is useful as well as politically realistic to regard BCA as an aid to discussion and to decision and not as the decision itself."

The acceptability of CBA as a neutral tool of policy analysis is only one side of the problem. The other side of the coin, no less complicated, relates to the third sub-question of the thesis. I restate it here: can the use of CBA be endogenous to a decision-making process? If yes, what *implications* can this have for the *final* stage of decision making about a radiation-related project if weak public participation is in place?

If some interests are underrepresented at the final stage of a decision-making process, methodological weaknesses of CBA can be deliberately abused by strong special-interest groups in their own favor, thereby distorting even further the quality of cost-benefit information provided to the decision makers. For example, Ackerman and Heinzerling (2004, p 92) argue, with regard to quantifying human health risks for the purposes of CBA: "(…) experience unfortunately shows that the science used in CBA can be manipulated to ensure results that work against regulation. The technical concepts involved, such as risk thresholds and dose-response relationships, have intimidated many observers, but they are important to understand: abuse of these concepts can make the real benefits of regulation magically seem to disappear."

Nyborg (1996, p 12) claims that if information on politically powerful groups is not provided to the decision makers, "politically powerful groups are presumably more than willing to provide information themselves; obviously having strong incentives to give biased information." Therefore, in my subjective opinion, it would be relevant to ask whether it may happen that CBA is endogenous to a decision-making process, i.e. deliberately chosen by those who may intend to play on the methodological weaknesses of the cost-benefit framework.

When democracy is assumed to be an ideal to strive for, all adult citizens should be included in a decision-making process at its final stage. Dahl (1989) argues: “The argument for the Strong Principle of Equality provides the grounds we need for a criterion of inclusion that a democratic process would have to satisfy: *the demos*[2] *should include all adults subject to the binding collective decisions of the association*” (p 120). I will discuss some aspects of public participation in part 6.

However, even though people tend to avoid risk from nuclear power radiation, and even if they have knowledge and opportunities to intervene in the management of nuclear power (Slovic, 2000, p 269), they hardly exercise their right to participate directly at the final stage of a decision-making process. Within the democratic premises, Dahl (2006) refers to ‘the law of time and numbers’: “The more citizens a democratic unit contains, the less that citizens can participate directly in government decisions and the more that they must delegate authority to others” (pp 58-59).

Zweifel et al. (2009, p 10) claim that when it comes to the monetary valuation of health, “the typical feature is that the individual does not weigh himself health against consumption. Rather, government or parliament decides on behalf of the citizens, and it is the task of health economics to provide these authorities with decision-making rules which are well-founded in welfare economics.” In my opinion, it seems reasonable to suggest that when public participation is weak and public interests are underrepresented at the final stage of a decision-making process, the weaknesses of CBA which are grounded in the results of welfare economics may be abused by politically powerful groups. Here we have returned to the task of economists to provide decision-makers with sufficient information for well-founded decisions. The economist is supposed to use their best judgments to provide information that the decision makers may demand to improve decision making.

As a starting point for further detailed discussion of the question whether CBA can improve on decision-making processes with regard to projects related to the risk of exposure to radiation and subsequent adverse health effects, it is reasonable to summarize the points about the role of information in decision-making processes. I do that by citing Nyborg (1996, p 97):

“(…) Decision makers (…) have ethical beliefs of their own, concerning what is good and bad for society as a whole, which may differ between decision makers. Furthermore, when they

[2] By *the demos* Dahl means the citizens, the people entitled to participate in governing.

decide which project to support in the political decision process, they choose in accordance with these subjective evaluations. But when regarding any specific project, they are only capable of taking a limited amount of data into account.

Our problem as economists, now, is to present background information to the decision makers in a way which fits into this decision process, so that they can make use of the provided information in a relevant manner. If we succeed in this, decision makers have at least had *the opportunity* to ensure that their individual rankings of projects are well-informed."

2. Cost-benefit framework: key concepts and accompanying techniques

Theoretical cost-benefit analysis has already been covered fairly enough in literature (see e.g. Drèze and Stern, 1987; Johansson, 1993; Perman et al., 2003). I will not discuss the methodology of cost-benefit analysis in great detail here, but for the purposes of this work, it makes sense to reproduce some relevant aspects and key concepts of the cost-benefit framework.

Cost-benefit analysis (CBA) is a tool of applied welfare economics which is intended to rank projects and evaluate government policy proposals according to efficiency criteria. The evaluation is conducted in monetary units. Stated quite simply, CBA involves weighing the expected benefits of a project against its expected costs. If the expected benefits exceed the expected costs, the project is defined as socially efficient. However, there are in-built concepts, assumptions, and techniques which underlie cost-benefit recommendations. They are therefore crucial for decision-making purposes.

It seems relevant to set up a simple mathematical model to make the description of the cost-benefit framework more precise. To this purpose, I use my background knowledge, in particular that I got from the course in Environmental Economics provided by K. Nyborg. As a background to the model, I take a hypothetical social decision maker who considers a project aimed at reducing the risk of adverse health effects due to exposure to radiation from a nuclear power plant situated in the area. Say, the decision maker intends to oblige the management of the nuclear plant to shut down one of the reactors. Implementation of this project can reduce risks of adverse health effects on n individuals living in the area, but it suggests decreased income that can be used by them for consumption purposes. Suppose that every affected individual has preferences for two goods: *X* – private consumption, and *H* – non-exposure to radiation. I choose money as a numéraire; X^i can be regarded as an individual *i*'s total income. *H* is a public good, which is meant to be the inverse of a public bad 'exposure to radiation'. For simplicity, the two goods are assumed to be substitutes. Utility is increasing in both X^i and H.

In this stage it must be admitted that although intertemporal issues are relevant to the problem at hand, they are beyond the scope of this work. Discounting can constitute a separate research work; thus time dimension is ignored throughout the thesis, and the mathematical model under consideration is *static*. The main focus of interest in this work is *risk*. For the moment (in this part) I disregard it for simplicity reasons. Risk will be introduced in part 3.

Every individual *i* maximizes their well-behaved ordinal individual utility function:

(1) $U = U^i(X^i, H), i = 1, \dots, n$

Suppose one takes a vector of small changes in the amounts of the goods (dX^i, dH). Totally differentiating the utility function in (1) gives expression for the subsequent change in utility:

(2) $dU^i = U^i_{X^i} dX^i + U^i_H dH$

where the subscripts denote partial derivatives of the i^{th} utility function with respect to goods H and X^i. Thus $U^i_{X^i}$ is the i^{th} individual's marginal utility of income.[3]

The use of CBA requires the availability of a *monetary* measure of this utility change that would follow from the implementation of the project, including the utility change from changed radiation exposure. As long as the goods are assumed to be substitutes, the latter can be calculated as a maximum sum of money dX^i individual *i* is ready to give up in order to get dH, which stands for a small increase in a public good 'non-exposure to radiation', say $dH = 1$, provided that the associated total change in utility remains constant, i.e. $dU^i = 0$. With these assumptions, (2) gives:

(3) $0 = U^i_{X^i} dX^i + U^i_H$

[3] Strictly speaking, it is a marginal utility of consumption. However, interpreting X^i as an individual's income allows considering $U^i_{X^i}$ as a marginal utility of income.

Rearranging (3) gives:

(4) $dX^i = MWTP^i = U_H^i / U_{X^i}^i$

Thus $MWTP^i$ stands for individual *i*'s marginal willingness to pay for a small increase in the provision of the public good 'non-exposure to radiation'. $MWTP^i$ measures thereby the net worth of this change to the i^{th} individual in *money* terms.

Willingness to pay (WTP) is a central concept built into the cost-benefit framework. It reflects the maximum amount of money the individual is willing to pay to get, or avoid, the proposed change. In the model the i^{th} individual's willingness to pay for a small increase in $H\ (dH)$ can be calculated as follows:

(5) $WTP^i = \left(U_H^i / U_{X^i}^i\right) dH$

According to the standard cost-benefit framework, the project at hand will be regarded as socially efficient (desirable) if the benefits aggregated across the affected individuals outweigh the aggregated costs, i.e. if the net benefits, NB^i, are positive:

(6) $\sum_{i=1}^{n} NB^i = \sum_{i=1}^{n} (WTP^i - C^i) > 0$

where C^i denotes the cost of the project individual *i* is supposed to cover.

The concept of *Pareto efficiency* is central here. "(…) a policy change is socially desirable if everyone is made better off (the weak Pareto criterion) or at least some are made better off (the strong Pareto criterion) while no one is made worse off. When the possibilities of making such policy changes are exhausted, we are left with an allocation of commodities that cannot be altered without someone being made worse off. Such an allocation is called *Pareto-optimal* or efficient" (Johansson, 1993, p 10). A gain by one or more persons without making anyone worse off is known as a Pareto improvement (Perman et al., 2003, p 107). In the model, the positive net benefits in (6) imply that the winners can compensate the losers; consequently, if such compensation occurs, the project yields a Pareto improvement. Moreover, disregarding actual payments, the project is said to be a *potential* Pareto improvement, i.e. the winners potentially can compensate the losers.

This simple idea about (potential) Pareto improvement underlies the so-called 'compensation tests' such as the Kaldor and Hicks (potential) compensation tests (for profound description and critics of such tests see e.g. Zerbe and Bellas (2006). These tests were devised to avoid explicit use of a social welfare function that I discuss below. The main argument against a social welfare function is that there is no generally agreed form of it.

However, a Pareto-optimal allocation is not unique and has little to say about the optimal distribution of welfare. We need some further criterion for judging which Pareto-optimal allocation is best from a social point of view, i.e. yields a social welfare improvement.

The concept of a *social welfare function* (SWF) is used for ranking alternative allocations. A SWF is an aggregation of individual utility functions. Varian (1992, p 333) states: “The most reasonable interpretation of such a function is that it represents a social decision maker’s preferences about how to trade off the utilities of different individuals.” However, there exists no single agreed-upon form of SWF. This result is due to Arrow’s impossibility theorem which implies that there exists no general quantitative rule to consistently aggregate individuals’ ordinal preferences into the results of democratic decision making (Persson and Tabellini, 2000, p 20). Every SWF expresses the views of a particular decision maker.

SWF is often assumed to satisfy convenient assumptions (Johansson, 1993, pp 15-16):

a. Social welfare depends only on the underlying individual utility levels.
b. Social welfare is increasing with each individual’s utility level, satisfying thereby the (strong) Pareto criterion. Moreover, if one person is made worse off, another one must be made better off so that the level of social welfare be maintained.
c. It does not matter who enjoys a high or low level of utility.

Sen (1987) argues that ‘the reach and relevance’ of welfare economics can be widened by incorporating other ethical considerations, rather than only individual utilities, into a SWF. He defines a simple aggregation of individual utility functions as ‘welfarism’ which requires that “the goodness of a state of affairs be a function only of the utility information regarding that state” (p 39). Therefore, he emphasizes that ‘consequentialism’ is another important requirement for utilitarianism to be regarded as a moral principle. According to Sen, ‘consequentialism’ requires that “every choice, whether of actions, institutions, motivations, rules, etc., be ultimately determined by the goodness of the consequent states of affairs” (p 39).

Later, I will return to implications of the narrowed 'welfarism'. Here I stick to it, for simplicity. Thus, the aggregation of individual utility functions gives a SWF that can be written as follows:

(7) $W = W\big(U^1(X^1, H), \dots, U^n(X^n, H)\big)$

A widely used particular form of SWF has social welfare W as a weighted sum of the individual utilities:

(8) $W = \sum_{i=1}^{n} w^i \, U^i\big(X^i, H\big)$

where $w^1, \dots, w^n$ are weights that reflect society's judgment about the relative emphasis to be put on each individual's utility (subjective welfare weights).

For the marginal project at hand involving dH on the benefit side and individual costs C^i, the total differential of SWF, dW, reflects a change in social welfare:

(9) $dW = \sum_{i=1}^{n} w^i (U^i_{X^i} \times \big(-C^i\big) + U^i_H \times dH)$

Dividing and multiplying simultaneously both sides of the equation in (9) by the marginal utility of income $U^i_{X^i}$ and substituting then for willingness to pay WTP^i, determined in (6), give the following equation for a social welfare improvement:

(10) $dW = \sum_{i=1}^{n} w^i U^i_{X^i} \big(WTP^i - C^i\big) = \sum_{i=1}^{n} w^i U^i_{X^i} NB^i$

Thus $w^i U^i_{X^i}$ is a welfare weight attached to individual *i*'s net willingness to pay for the project. Consequently, the net welfare gain of the project is a welfare-weighted sum of each individual's net willingness to pay.

Willingness to accept (WTA) is another available measure to estimate individual's net benefits from the project. WTP and WTA can be interpreted as two monetary measures of utility change associated with dH: compensating surplus (CS) and equivalent surplus (ES).[4] CS is the change in X^i that would *compensate* for a marginal change in 'non-exposure to radiation', dH. ES is the change in X^i that would be *equivalent* to the proposed dH. Defining

[4] The discussion of CS and ES here is based on Johansson (1993).

H^1 as a new amount of public good available, and H^0 as its initial amount, one can explain CS and ES mathematically in the following way:

(11) CS: $U^i(X^i - CS^i, H^1) = U^i(X^i, H^0)$

(12) ES: $U^i(X^i + ES^i, H^0) = U^i(X^i, H^1)$

In the model above dH is a *positive* change (a proposed small increase in ‘non-exposure to radiation), thus CS = WTP reflects an amount of money to pay in order to secure this change, while ES = WTA is a required compensation for this change not occurring. If dH was negative (for example, an additional nuclear reactor to be put into operation involving higher health risks), CS = WTA would reflect a necessary compensation for this change, while ES = WTP would be a sum of money to pay in order to avoid the change. Due to several problems the application of WTA involves, its use in practice is sometimes considered to be undesirable.[5] It does not matter which measure, CS or ES, to use if the project is marginal in the sense that MWTP in (4) can be considered constant. But if the project is large enough, the difference between CS and ES arises due to the fact that MWTP is no longer constant with respect to the project. Therefore in this case it is important which measure of the two to choose. Accordingly, a discrepancy between WTP and WTA takes place. Certain implications of the difference between WTP and WTA will be considered in section 5.2 under the discussion of monetary valuation of human life.

Since WTP is central to the cost-benefit framework, it has to be calculated because it is not directly available in the market. Different estimation techniques are therefore used to elicit it. The most widely applied methods, relevant for this thesis, are *contingent valuation* (CV) and *hedonic pricing* (HP) (for detailed discussion of these methods see e.g. Perman et al., 2003; Johansson, 1993; Carson and Hanemann, 2005; Rosen, 1974).

The CV is a method that involves directly asking people about their WTP. Preferences for a proposed policy change or a project, derived by means of this method, are thus called ‘stated’. The HP is an indirect method used to come by ‘revealed’ preferences. For example, the hedonic pricing method is used to calculate a monetary value of human life. In this case, the method involves implicit estimation of the wage increase demanded by workers to accept higher risk to their health.

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[5] See e.g. Carson and Hanemann (2005), Perman et al. (2003) for the discussion.

To conclude this part, it is reasonable to highlight some important points concerning the cost-benefit framework which imply certain consequences for the acceptability of CBA as a tool of policy analysis:

1. The use of CBA requires the monetary valuation of the impacts of a project to make its benefits and costs comparable. However, it might be difficult to put a price on some goods (such as human health and life) because these goods are not available in the market.
2. There is no suggestion that a SWF provides some kind of scientific measure of society's ‘well-being’; it simply represents the preferences of the planner (Drèze and Stern, 1987, p 933).
3. A SWF is not observable. There are at least two fundamental aspects of this problem to be faced in any application. First, the estimation of the welfare weights, w^i, in equation (10) above. Second, the unobservability of the individual utility functions (Johansson, 1993, p 21).
4. In applied CBA explicit welfare weights $w^i U^i_{X^i}$ consistent with the ethical views of a decision maker are rarely used (Nyborg and Spangen, 2000, p 84). $w^i U^i_{X^i}$ are usually assumed to be equal across individuals. Distributional issues are thereby ignored.
5. “There is no commonly accepted method of measuring cardinal, interpersonally comparable well-being; in particular, the problem of interpersonal comparisons seems difficult to overcome” (Nyborg, 1996, p 69). Consequently, decision makers using the recommendations of CBA have to accept WTP as a cardinal and interpersonally comparable measure of individual well-being.
6. An important ambiguity with the potential Pareto criterion is that it remains vague on whether a (potential) Pareto improvement will actually be implemented. “If no such guarantee exists, then the criterion is certainly unacceptable” (Drèze and Stern, 1987, p 957).
7. “In fact, the policy use of the Pareto criterion goes beyond welfarism and embraces consequentialism as well, since choices of actions, institutions, etc, are all required to satisfy Pareto optimality, so that consequentialism is implicitly but firmly demanded” (Sen, 1987, p 39).

3. Cost-benefit analysis: introducing risk

In practice the consequences of a radiation-related project are not known in advance, and the analyst deals with risk and uncertainty. I will draw the line between the concepts of risk and uncertainty in section 5.3. For the moment, I use them interchangeably. I also assume that probabilities somehow can be assigned to a complete list of alternative outcomes of the project. Let us now assume that in the model, introduced in part 2, each individual *i* faces an *uncertain* quality of the public good 'non-exposure to radiation'. Each individual's income is assumed to be known with certainty. Due to the presence of risk, monetary measures of utility change dU^i can thus be infinite in number. But for simplicity H is assumed to take on a finite number of values. The question arises how the analyst can come by a money measure of change in utility to use it in a CBA of the project.

I focus on the expected utility approach to the modeling of behavior under uncertainty. Following Johansson (1993, p 134), there is a probability distribution assigning probabilities $p^1, \dots, p^m$ to different states of nature $H^1, \dots, H^m$, with $p^j \geq 0 \; for \; j = 1, \dots, m$, and $\sum_j p^j = 1$. Thus instead of the function in (1), p.9, individual *i* maximizes their well-behaved expected utility function (for notation simplicity I drop the superscript *i*):

$$U^E = \mathrm{E}[U(X, H)] = \sum_{j=1}^{m} p^j \, U\left(X, H^j\right) \; for \; i = 1, \dots, n$$

where E is the expectation operator.

The following discussion, including the figure below, follows that of Perman et al. (2003, pp 448-449). As discussed in Perman et al., in practice the typical individual is assumed to be *risk-averse* because taking a risk is costly in utility terms. Figure 3.1 shows the main aspects of risk aversion. The shape of the utility function captures risk aversion behavior. Mathematically, $U_X > 0, \; U_{XX} < 0$, i.e. the expected utility is increasing in income (the first-order derivative is positive), but at a decreasing rate (the second-order derivative is negative).

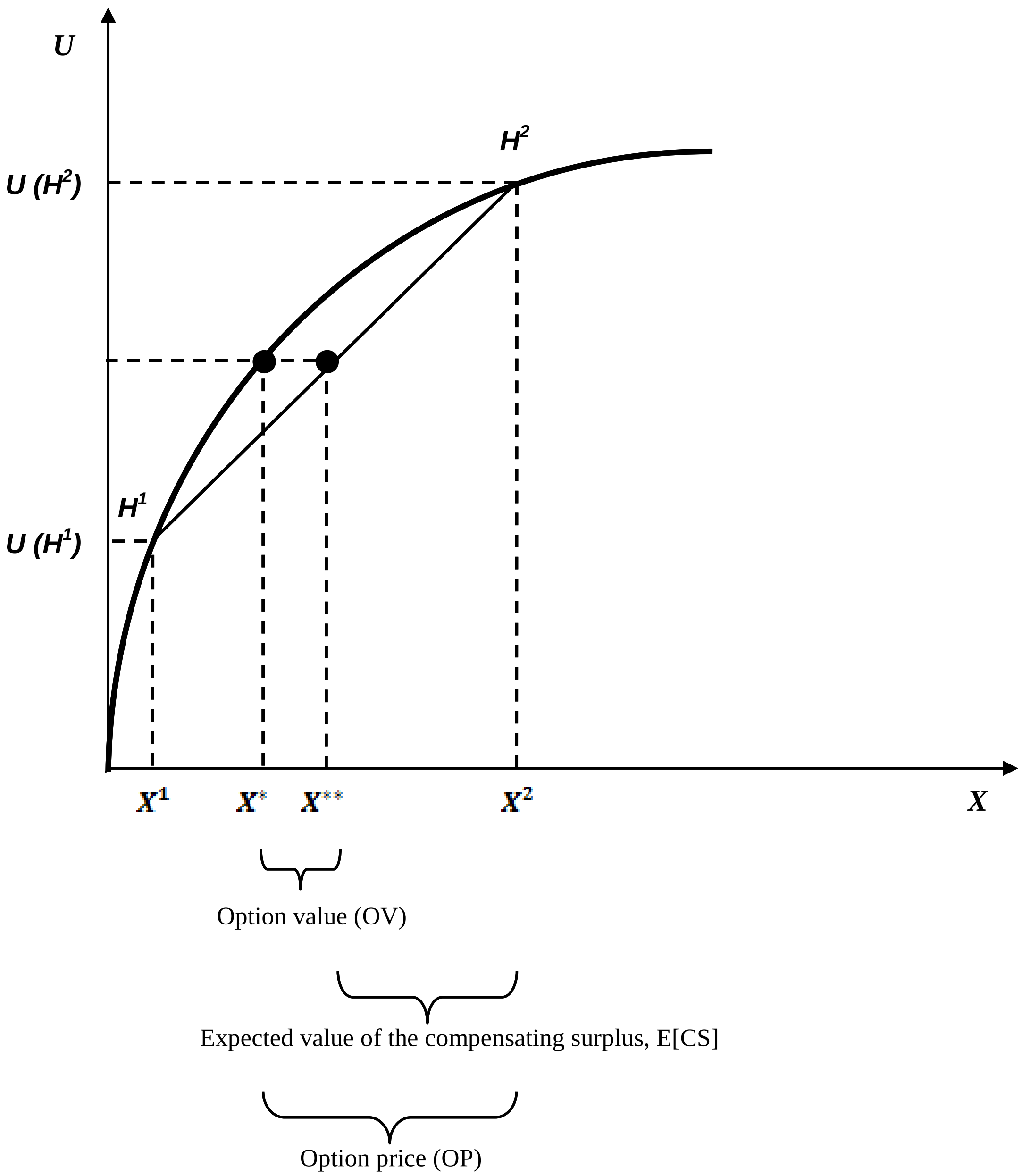

Figure 3.1 **Risk aversion**

Suppose now that there are only two possible states of nature: either a situation H^1 where the quality of the public good 'non-exposure to radiation' is high or a situation H^2 where the quality is low. However, it is not known for sure whether high quality will be available or not. The low quality of the public good 'non-exposure to radiation' H^1 happens with probability p^1; and the individual enjoys the high quality H^2 with probability $1 – p^1$. As Figure 3.1 is drawn, $p^1 = 0.5$. This probability determines the expected value of the individual's compensating surplus as willingness to pay for the higher quality:

E[CS] = $X^2 - X^{**}$

Thus X^{**} is the expected value of the outcome for the given probability, and X^* is its certainty equivalent. The amount of money $X^2 - X^*$is known as 'option price' (OP), the maximum WTP for an option which guarantees the high quality of the public good 'non-exposure to radiation'. The difference between X^{**} and X^* is thus an 'option value' (OV) which can be defined as a risk aversion premium. According to Johansson (1993, p 142), the expected value of the compensating surplus measure, as well as the concept of option value, must be used with great care in CBA because E[CS] alone would understate the benefits of the public good H since the risk-averse individual is willing to pay a risk aversion premium $X^{**} - X^*$ to avoid the risk. I will return to this point in section 5.2.

Concluding this part, it is reasonable to emphasize three important points. First, in practice the analysts encounter risk and uncertainty since the consequences of radiation-related projects cannot be treated as certain. Second, individuals are usually assumed to be risk averse. Third, under uncertainty and due to the presence of risk-aversion behavior, great care is needed to put a price on the non-marketed public goods such as 'non-exposure to radiation' for the purposes of CBA.

4. Specifics of radioactivity

Radiation has its specifics when considered as an economic good or service. On the one hand, nuclear power plants can generate huge amounts of relatively cheap and climate friendly energy, thereby improving on people's well-being by means of pushing up electricity provision, heat, employment, and progress. On the other hand, nuclear power plants are associated with adverse life and health effects connected to nuclear-waste repositories, radiation leak, and catastrophes. Ahearne (2000, p 769) states: "The use of nuclear reactors can ameliorate climate change and bring electricity to developing nations; but the associated waste problems will remain a nagging concern until publicly acceptable solutions are found. These may come about through improved technology, changed understanding of radioactive risks, or finding new disposal sites."

Hence, radioactivity can be perceived as either a good or a bad depending on whether it potentially improves or worsens individuals' well-being. Many studies have shown that public perception and acceptance of exposure to radioactivity is determined by the context in which radiation is used. I refrain from reproducing the numerous results of those surveys and refer to Slovic (2000, pp 264-269). But just to reveal the discrepancy between various perceptions of radioactivity it is relevant to give one result which has been obtained by many researchers. Medical uses of radioactivity (such as X-rays) are perceived in a very favorable way, while perceptions of nuclear power and nuclear waste are highly negative. Hence, in the former case radioactivity is believed to be a good (a benefit); in the latter case, it is perceived as a bad (a risk).

In what follows, I will stick to nuclear power as a source of energy, on the one hand, and a source of radiation exposure which is perceived to entail adverse health effects, on the other hand. This source of radioactivity is especially interesting because the views of technical experts often contrast greatly with the views of the general public. In most situations, the former attach a moderate and acceptable risk to the nuclear power and nuclear waste while the latter perceive the level of risk as extreme and unacceptable (Slovic, 2000, p 267).

As discussed in Slovic (2000), a lot of surveys, conducted to assess public attitudes and opinions regarding the management of high-level radioactive wastes, have resulted in an almost uniformly negative picture. In these surveys negative subcategories such as ‘dangerous/toxic, death/sickness, environmental damage, bad/negative and scary’ dominated significantly. A general category labeled ‘positive’ accounted for only 1% of the images. Other positive associations, ‘necessary’, ‘employment’, and ‘money/income’ amounted to only 2.5% of the images (p 278).

Moreover, public perceptions of technological hazards gave rise to such a phenomenon as ‘stigmatization of technologies’. The word ‘stigma’ denotes something ‘marked’ as deviant, flawed, spoiled or generally undesirable in the view of some observer (Slovic, 2000, p 270). Gregory et al. (1996) claim that technologies have become avoided by the public not just due to standard perceptions of risk, but because a positive condition or expectation has been overturned. Thus, they argue (p 216): “(…) stigma represents an increasingly significant factor affecting people’s perceptions of their health and influencing the acceptance of scientific and technological innovations.”

In addition, it must be mentioned that exposure to radiation might have adverse health impacts on human health. The special feature of many radiation-related health effects is that the target health risk can have a long latency period, i.e. decades can pass before the related disease manifests itself (such as cancer). One of the recent studies of nuclear workers in 15 countries has revealed that an excess risk of cancer exists even at the low doses of radiation (Cardis et al., 2005).

Furthermore, in the context of adverse health effects due to radioactivity, a normative question arises whether it is permissible to weigh the good health against other objectives such as money, consumption, etc. (Zweifel et al., 2009, p 10). In addition, some experts try to justify the application of CBA to radiation-related projects on the *rational* grounds, assuming that radiation risks are equivalent to risks from travelling by car (Dunster, 1973).

In my opinion, weighing health against money under the assumption of well-behaved individual utility functions may be problematic, when it comes to possible adverse radiation-related health effects. It may be hypothetically acceptable to apply CV techniques to elicit WTP provided that a person can *self* choose whether to sacrifice a certain amount of his health in favor of other goods, i.e. when substitution opportunities are open to this person. Just for example, a person can decide whether to buy cigarettes or to pay instead for medical treatment in order to get rid of smoking addiction. In this case one can regard health as a consumption good, which can be substituted for another good. And risk to health, imposed on the individual, can be considered as a *voluntary* one.

On the other hand, when it comes to such issues as radioactive contamination, the same person faces an *involuntary* risk to his health. He cannot avoid it by his own free will due to the fact that this risk comes as a possible negative external effect of decisions made by other people, and it is related to uncertain states of nature. In this latter case, health and consumption may *not* be substitutes. Rather, they may turn into *complements* because health fulfils a ‘production’ function, i.e. it determines person’s ability to produce consumption goods. Thus, it might be impossible to weigh health against other objectives.

Slovic (2000, p 269) argues that whether or not decision makers share public risk perceptions, they cannot be ignored. Thus, information about public risk perceptions of nuclear power radiation cannot be disregarded in decision-making processes. Whether or not CBA succeeds in providing decision makers with such information will be discussed below in section 5.3.

5. Methodological weaknesses of cost-benefit analysis and suggested improvements

Many critical remarks on CBA as a tool of policy analysis are conveniently summarized by Zerbe and Bellas (2006, p 17). For example, CBA rests on monetary values, it does not consider the income distribution, moral values are neglected, CBA is not voting, etc. As long as the list of methodological problems of applied CBA can be quite long, it is not possible to cover them all here. Therefore, I focus on a few problems particularly relevant to radiation-related projects. Distributional issues in decision making, limitations to the monetary valuation of human life and health, and the question of uncertainty, risk perceptions and risk regulation in nuclear power will be discussed in this part of the thesis.

5.1. Distributional concerns in decision making

In guidelines for preparing economic analyses, efficiency and distributional issues are usually approached separately. For example, USEPA (2000, pp 139-140) specifies that calculation of net benefits in CBA helps judge about efficiency of a project; two other ways – an economic impact analysis and an equity assessment – are aimed at providing information about the distributional effects of the project. The guidelines for social economic analyses applied in Norway state that "weighing of distributional effects and possible conflicts of interests is a political issue lying outside the social economic analysis" (Ministry of Finance, 2005, p 11).[6]

Economists tend to justify the disregard of distributional aspects in applied CBA by the separation of efficiency and equity considerations. As stated at the end of part 2 (p 13), explicit welfare weights aimed at incorporating decision makers' distributional concerns are not often used in applied CBA. Economists emphasize their responsibility for providing decision makers with recommendations on efficiency grounds (the potential Pareto improvement criterion), and leave distributional concerns to policy makers. As defined in Perman et al. (2003, p 116), "it is a separate matter, for government, to decide whether compensation should actually occur, and to arrange for it to occur if it is thought desirable."

[6] Throughout the thesis the translation from Norwegian into English is mine.

With this view taken for granted, economists focus on maximization of aggregate well-being based on several assumptions that allow ignoring distributional issues. In particular, they assume that costless redistribution of income is feasible. However, economic efficiency and equity considerations cannot be separated in a “second-best world” where government is not able to carry out non-distortionary taxation of the project winners in order to transfer these tax revenues to project losers adversely affected by the project (Loomis, 2011, p 3). Thus the assumption about lump-sum transfers has been recognized as implausible (Drèze and Stern, 1987; Loomis, 2011). Johansson-Stenman (2005) investigates whether introducing distributional weights into CBA is redundant, and whether it can imply large efficiency losses. He argues that such perceptions are incorrect and misleading, and shows that distributional weights are ‘second-best’ optimal to use.

Another assumption, used to justify the disregard of distributional issues, rests on the ethical grounds of utilitarianism. In applied CBA social welfare is often assumed to depend only on the underlying individual utility levels (‘welfarism’). According to Sen (1987), such narrowed ‘welfarism’ must be extended by ‘consequentialism’ considerations. Sen argues: “The case for consequential reasoning arises from the fact that activities have consequences. (…) To ignore consequences is to leave an ethical story half told.” (p 75) Intuitively, ignoring the distributional aspects of a project is conceptually the same thing as disregard for the rights of the affected people who may be particularly vulnerable to the consequences of the project’s implementation.

As long as CBA is grounded in a highly controversial task of measuring WTP (I will approach this question in section 5.2), its application to a radiation-related project can intensify the importance of distributional concerns if the implementation of such a project entails a biased distribution of negative health effects. Intuitively, the ignored problem of income inequalities may in its turn lead to an unfair distribution of radiation health risks. If the rich people enjoy higher WTP to avoid nuclear waste sites, nuclear waste repositories are very likely to be located in the areas populated by the poor people who have lower WTP to avoid them. To the point, Ackerman and Heinzerling (2004, p 150) argue:

> “It is no coincidence that pollution so often accompanies poverty. Imagine a CBA of siting an undesirable facility, such as a landfill or incinerator. Benefits are often measured by willingness to pay for environmental improvement. Wealthy communities are able and willing to pay more for the benefit of not having the facility

> in their backyards; thus the net benefits to society as a whole will be maximized by putting the facility in a low-income area. (Wealthy communities do not actually have to pay for the benefit of avoiding the facility; the analysis depends only on the fact that they are *willing* to pay.)"

Once the necessity to account for efficiency and distributional concerns in CBA simultaneously is recognized (Johansson-Stenman, 2005, p 349), the question arises how to do that. "In practice, developing a universally acceptable social welfare function is difficult because it requires explicit decisions to be made about society's preferences for the distribution of resources" (USEPA, 2000, p 141). However, it has been admitted that *potentially* a SWF can be used to evaluate efficiency-equity trade-off by incorporating the effects on distribution from economic impact analysis and/or equity assessment (USEPA, 2000, p 140). In particular, an equity assessment can provide information on how policies affect specific groups (sub-populations).

Nyborg (1996, pp 11-12) notes that providing information on groups can be useful only if decision makers agree that the welfare weights within each group are not significantly different. Moreover, she emphasizes that the main challenge for the analyst will be to decide on the considerations which are important to determine subjective welfare weights, i.e. $w^i U^i_{X^i}$ in equation (10) in Part 2. Nyborg believes that in any case, it is more useful to provide a distribution-concerned decision maker with group information than "simply a number telling her whether an analyst holds a project to be socially desirable or not" (p 84).

Loomis (2011, p 5) argues that "the more explicit the weights are, the more there is room for disagreement regarding the value judgments that underlie these weights." Therefore, he points out that the economists are supposed "to help steer decision makers away from obvious pitfalls that can arise with the use of weights. Some weighting schemes by being very explicit may be more controversial than others." He considers several approaches to incorporate distribution and equity concerns in CBA, such as implicit weighing by decision makers (on the basis of the benefits and costs disaggregated by group characteristics), explicit weighing of net benefits, Lorenz curve based approaches, etc. With regard to assigning different explicit weights to the net benefits of each group, Loomis emphasizes that it is useful to display the original benefits and costs as well for the purposes of sensitivity analysis. Showing weighted and unweighted net benefits together can facilitate the understanding of efficiency and distributional aspects of a project or policy. Monetary net benefits can in principle be weighted by some measure of marginal utility each group receives from its net benefits, for example, by the marginal utility of income.

However, Christiansen (1983) shows that the marginal utility of income, attached as weight to the net benefit of a particular individual, is not exclusively a function of utility levels. It can vary with other external factors, such as changes in relative prices. Thus once these external parameters change, weights change as well. Furthermore, provided two individuals have different sets of such external parameters, even if their utility functions are the same, their weights may differ.

In practice equal welfare weight w^i is assigned to all individuals' income changes on the assumption that individuals have the same marginal utility of income, even though the later assumption cannot be empirically verified (Medin et al., 2001, p 398). Furthermore, Nyborg (1996, p 18) states that if the rich people have a lower marginal utility of income, ignoring the use of explicit welfare weights can lead to the systematic bias towards the utilities of the rich people in applied CBA.

Further, in CBA the sum of individual net benefits which is regarded as the social net benefit is expressed in *monetary* units. An obvious argument for the choice of money as a numéraire may be the Pareto criterion: money allows the project winners to compensate the project losers. However, Brekke (1997) shows that when it comes to public goods, the numéraire matters, and that different numéraires will systematically give an advantage to different interest groups. He argues that the less valuable the numéraire to an individual, the more will their interest weigh in the sum of net benefits. Thus the choice of numéraire is equivalent to a particular choice of welfare weights. It is reasonable to suggest that a decision maker that regards some *natural* unit as the appropriate unit of aggregation will find CBA recommendations, which are based on a monetary evaluation of the social net benefit, hardly useful. Drèze (1998, p 485) emphasizes that the only plausible thing to do is to use appropriate welfare weights.

Medin et al. (2001) investigate further on the numéraire issue by using the information from different contingent valuation surveys. They find that the choice of numéraire turns out to be extremely important, i.e. the sum of net benefits appears to be highly sensitive to a particular way of comparing interpersonal utility changes. Supposing a public good is used as a numéraire, Medin et al. show that if one assumes equal marginal utility of the public good, instead of the conventional assumption of equal marginal utility of income, the sum of monetary net benefits is reduced by a factor of between 2 and 307 (p 406). Thus they conclude that making empirically unverifiable assumptions, such as equal marginal utility of income for everyone, introduces an element of arbitrariness into applied CBA.

On the grounds that the applicability of CBA to the monetary valuation of human health is limited, cost-effectiveness analysis is often proposed as an alternative to CBA to overcome the distribution problem.[7] For example, Ministry of Finance (2005, p 56) state: "It is more challenging to apply CBA, which is based on WTP, in the health sector (…) since this often leads to difficult ethical trade-offs. (…) The use of aggregated individual WTP as a decision-making criterion is ethically challenging when a distinct individual knows that he or she needs treatment. In this case, it is not clear whether the weight put on the WTP in the risk group should be higher than in the society on the whole. This problem becomes especially difficult to settle if the society also puts an emphasis on the distribution of health goods irrespective of the income distribution." Hence, the use of cost-effectiveness analysis is recommended in the health sector since the benefits of different alternatives are similar in kind, and the aim is thus to minimize the costs.

Cost-effectiveness analysis (CEA) ranks the alternatives according to lowest costs per unit of health gain, which is often measured in terms of quality-adjusted life years (QALYs) (for theoretical aspects of CEA and the concept of QALYs (see e.g. Zweifel et al., 2009; Nord, 1999). The derivation of QALYs is conducted in the following way. Using interviews, utility weights for the various health states are determined. For this purpose, the weight for the state of perfect health is calibrated to the value 1, while the state of death is assigned the value 0. Using these values, a year spent in the respective health state is weighted to obtain QALYs. The main attractiveness of CEA is that health benefits are expressed in *natural units* such as number of cases of disease prevented, number of lives saved, or number of life years gained, which most people can easily understand and intuitively accept as measures of value (Nord, 1999, p 4).

CEA is appropriate when the objective is that to maximize health, irrespective of how health benefits are distributed across individuals (Olsen, 1997, p 603). Wagstaff (1991, p 26) argues that even though QALYs are not based on individual's valuation of their health, health

[7] Here I am mainly concerned with the distributional issues. The aspects of monetary valuation of human life and health will be addressed in section 5.2 of the thesis.

maximization and utilitarianism are “close bedfellows”: like utilitarianism, health maximization entails reallocation of resources in favor of those who have a higher capacity to benefit from health. He investigates the issue of justifying the health maximization approach in literature. One of the explanations, he finds, states, for example, that since a QALY is regarded as being of equal value to everybody, the health outcome via QALYs is automatically equitable (p 27). However, such an assumption of ‘distributive neutrality’, as defined by Nord (1999), does not work because the distribution of health gains does matter (Ackerman and Heinzerling, 2004, pp 100-101; Nord, 1999, p 22; Olsen, 1997, p 603; Wagstaff, 1991; Zweifel et al., 2009, p 19).

As it was discussed above, Brekke (1997, p 117) argues that in CBA “the choice of money as a numéraire is systematically favorable to those who value money the least, relative to alternative numéraires.” Drèze (1998, p 487) confirms that this remark will be relevant to the social evaluation of different types of public goods, including health. Interestingly, Donaldson et al. (2002) in their turn show that income is an important determinant of non-monetary valuations of health outcomes, such as QALYs. Hence, “methods of valuation that incorporate non-monetary methods of valuing health consequences share the same ‘ethical concerns’ of WTP, even though they are usually overlooked in CEA studies” (p 66). Thus, they conclude that the choice of CEA as an alternative to CBA cannot be justified on the grounds of avoiding distributional concerns.

Ackerman and Heinzerling (2004, p 100) claim that “QALYs will never provide a good measure of the value of health or a reliable standard for shaping public health policy”, because the aim to maximize total health benefits (total QALY gains), regardless of how they are distributed, clashes with an important aspect of equity in health in at least three ways. First, it ignores the severity of the disease. According to Ackerman and Heinzerling, a comparative study found that QALYs give much greater importance to minor complaints, and relatively less importance to death, than other methods of valuation. Second, the QALY approach discriminates against the disabled by putting a lower value on their lives. Third, QALY calculations discriminate on the age grounds: to treat the elderly turns out to be generally “worth” less, because they have so few years left to be saved.

Revesz and Livermore (2008, pp 89-90) assert that it is wrong to ask healthy people, *ex ante*, to evaluate various health states. They emphasize a phenomenon – response shift or adaptation – that has puzzled the researchers, because people suffering from very serious diseases – like cancer – often continue to report relatively high qualities of life. According to Revesz and Livermore, the serious problem with the QALY approach is that it disregards the ability of people to adapt to negative health conditions. As a result, the quality of life of people with illnesses and disabilities appears to be systematically undervalued.

Nord (1999, p 22) states that QALYs can in principle be assigned equity weights to incorporate distributional concerns. However, he argues that under the QALY approach, it nevertheless may not be feasible to measure health benefits in terms of individual utility in the case of health improvements that either are of moderate size or consist in saving people's lives. To the point, Olsen (1991, 2000) suggests that there might be other preferences beyond those which are taken into account within the current health outcome measures (QALYs). He provides an example of preferences concerning the nature of the proposed health-related projects: Risk-averse people may prefer a life-saving project with a low probability of success to an alternative project with high probability and low gain, although the expected number of QALYs is lower for the former.

It seems useful to conclude section 5.1 by addressing cases A and B introduced in part 1 (p 4). The distributional concerns are explicitly ignored in applied CBA under the assumptions of costless lump-sum transfers and certain ethical considerations. However, these assumptions do not work in reality, thus efficiency and distribution cannot be treated on a separate basis. If we accept the assumption that the rich have a lower marginal utility of income, the disregard of explicit welfare weights favors the utilities of the rich people. In particular, ignoring welfare weights might result in an unfair distribution of health risks due to the implementation of a radiation-related project.

Once the necessity to incorporate distributional concerns into applied CBA is recognized, the question arises how to do that. On the one hand, the use of the marginal utility of income as a weight is difficult to achieve. On the other hand, the use of equal marginal utility of income across individuals appears to be empirically unverifiable. CEA, proposed as an alternative to CBA in order to deal with the distribution problem, does not improve on these grounds. Regarding case A, it seems reasonable to conclude that the separation of efficiency and distributional considerations does not allow judging about the social desirability of a radiation-related project on the basis of CBA recommendations. Similarly, for case B, decision makers will hardly regard CBA as a useful informational background for debates about the project and the consequences of its implementation.

With regard to case B, Nyborg (1996, p 19) in particular points out that the ignored distributional concerns do represent a problem for the use of CBA as an informational input. She also emphasizes that if equal weight on all income changes cannot be justified on the ethical grounds, the question arises whether decision makers will find the results of CBA useful at all.

5.2. Limitations to the monetary valuation of human life and health

For most people life is priceless (Zweifel et al., 2009, p 17). Ackerman and Heinzerling (2004, p 9) state that this idea does not mean that an infinite amount of money is needed to protect human life and health; rather, it is to say that translating life and health into money units is not a fruitful way to protect them. Irrespective of any ethical considerations, Broome (1978, p 92) notes that any attempt to attach a value to a human life is doomed to failure since "no finite amount of money could compensate a person for the loss of his life, simply because money is no good to him when he is dead." Willinger (2001, p 4) argues: "The technical debate about whether monetary equivalents are an appropriate measure is irrelevant if the viewpoint is taken that health or life cannot be valued. Such a position may be supported on the basis that rights to health and life are fundamental human rights. If environmental quality is a necessary condition for maintaining these rights, it is therefore itself a fundamental human right. Bargaining these rights in the market place, as CBA does, is then unacceptable".

Conducting CBA requires placing a monetary value on a human life in order to make the expected benefits of the project and its expected costs comparable. A skillful monetary valuation of human life and health is an extremely challenging task to perform because there are no prices of lives and health directly available in the market.

Following Johansson (1995, p 60), under the assumption that *no* income can compensate for the loss of one's life, it is impossible to detect a WTP such that a particular individual becomes indifferent between being alive (z_1) and being dead (z_0). This amounts to saying that the utility of being in state z_1 will always be higher than the utility of being in state z_0. Thus, if one introduces a variable *z*, for every individual *i* the following inequality can never be turned into equality:

$V^i(0, z_1) > V^i(X^i, z_0)$ *for* $X^i > 0$, where X^i is individual *i*'s income.

Since putting a price on the life of a particular individual is impossible, the analysts consider a marginal project of increasing probability of death, but they leave this probability in the open interval (0, 1). And under an additional assumption, $V^i(X^i, z_0) = 0$, the compensation needed to accept a reduction in survival probability thus becomes finite.[8]

The indicated assumptions make the valuation of a change in mortality (or morbidity) consistent with the concept of *statistical life* (Johansson, 1995, p 61). If there are *n* affected individuals and a project saves *b* lives, i.e. reduces the mortality risk by *b/n*, the value of a statistical life (VOSL) can be calculated in the following manner:

$$VOSL = \frac{\sum_{i=1}^{n} CS^i}{b}$$

where CS^i stands for the affected individual's marginal compensating surplus (equivalent to the individual's WTP^i for the risk reduction. Thus WTP for a proposed small change in risk is the key element to derive VOSL. For this purpose, as it was briefly discussed in Part 2, the two methods – hedonic pricing (HP) and the contingent valuation method (CV) – are used.

The HP – a method based on *revealed*-preference studies – is often considered as a 'gold standard' (Revesz and Livermore, 2008, p 93) due to the fact that it allows deriving CS from individuals' *actual* behavior. Namely, if the analyst considers wage differentials in jobs with different exposures to risk, the premium needed to induce workers to undertake jobs with a higher risk provides an estimate of monetary value of a marginal change in risk to health and life. One of the problems with the HP method is that the information about occupational risks, which is available to the workers, may be imperfect, i.e. the individuals may not be fully aware of the accident risks they actually face (Ackerman and Heinzerling, 2004, p 70; OECD, 2006, p 94). Consequently, the estimates of the value of a risk may be biased since the wage differentials do not reflect the individuals' true valuation of avoiding the risk. Another problem with the use of the HP method is that the study of wage differentials for long-latency diseases, such as cancer, is generally highly unreliable (Revesz and Livermore, 2008, p 99).

The CV method has been largely accepted for estimating the monetary value of non-market effects of projects and policies (OECD, 2006, p 123). The practical use of the CV method for eliciting WTP to determine VOSL is a rather controversial issue in itself; therefore, I refrain

[8] Profound discussion of evaluating changes in mortality can be found in Johansson (1995).

from discussing it here.[9] The CV method is regarded by some experts as most consistent with consumer sovereignty perspective[10] as compared to the QALY method (Olsen, 1997, p 604), which was introduced in part 5.1 under the discussion of cost-effectiveness analysis (CEA) as an alternative to CBA on the distributional grounds. Returning to CEA, it is relevant to emphasize that this method is considered to have an advantage in health-related issues thanks to the use of natural units, which allows overcoming the problem of monetary valuation inherent in CBA. The point is that CEA can only be used to compare projects with homogeneous outcomes (Zweifel et al., 2009, p 24). Therefore several attempts have been made to link WTP and QALYs for the purposes of economic evaluations on the basis of CBA (see e.g. Johannesson, 1995). However, other analysts assert that these attempts are implausible because CEA and CBA are based on fundamentally different ethical grounds (see e.g. Dolan and Edlin, 2002; Kenkel, 1997).

According to OECD (2006, p 196), there are three important aspects of VOSL: (1) the validity of VOSL; (2) the size of VOSL; and (3) the relevance of VOSL to all kinds of risks. The *validity of VOSL* relates to its sensitivity to underlying determinants. For example, OECD (2006, p 197) states that there might be some background (not policy-related) individual risks, which can interfere with the correct estimation of VOSL through their influence on WTP and which may be difficult to separate from the risk that individuals are asked about in a CV survey. Moreover, as it is pointed out in OECD (2006), the assumption that WTP varies proportionally to risk reduction does not work in reality. For example, Alberini et al. (2004) show that people with cancer are willing to pay even *more* for reduction in mortality risk. Krüger and Svensson (2009) found that the magnitude of option value (OV) (risk aversion premium discussed in part 3 of the thesis) is a significant determinant of VOSL. They demonstrate for a public policy investment in road safety, reducing mortality risk, that when in CV surveys uncertainty whether the risk reduction will actually take place or not is *explicitly* emphasized, the OV might become higher. Krüger and Svensson state that OV is of such a considerable magnitude that applied CBA cannot ignore it, which is generally the case, as they highlight it (p 564). This amounts to saying that E[CS] cannot necessarily be regarded as the maximum WTP for the proposed reduction in risk. Treich (2010) shows that ambiguity

[9] For the discussion see e.g. Perman et al. (2003), Carson and Hanemann (2005), OECD (2006).

[10] *Consumer sovereignty* means that every individual is the best judge of their own well being.

aversion that arises from scientific uncertainty, lack of information and other factors, increases the value of VOSL.

Regarding *the size of VOSL*, it is important to point out that the HP method usually produces higher estimates of VOSL than the CV method, mainly for two reasons: (1) occupational risks tend to be higher than public risks; and (2) the HP measures WTA, not WTP (OECD, 2006, p 201). Here I will touch upon the second point in the context of the discrepancy between WTP and WTA measures (theoretical aspects of this problem were considered in part 2 of the thesis). The main point is that WTA usually exceeds WTP. However, the choice of the measure might be significant for evaluation of risk-related projects.

Carson and Hanemann (2005, p 907) emphasize: "If total value, in an economic sense, can always be expressed in terms of WTP and WTA and the two measures differ substantially, either theoretically or empirically, the appropriate measure for a benefit–cost analysis depends upon the *property right*." It is equivalent to saying that if an individual is entitled to a reduction in risk, the relevant measure is WTA this reduction foregone; if there is no such entitlement, the suitable measure is WTP to secure this reduction in risk (Willinger, 2005, p 11). Strictly speaking, a property right to the *initial* situation is decisive. However, OECD (2006, p 158) states that the legal right could be assigned to the proposed *change* or to the future state of the environment, and that WTA to forego that right becomes thus the relevant valuation measure.

Imagine a hypothetical project that involves an additional reactor to be put into operation at the nuclear power plant in some area. If the project is implemented, the society of risk-averse people in the area face a potential risk of losing their future earnings as a result of an illness or death due to exposure to radiation. The affected people can be entitled to state their WTA an increase in risk, rather than WTP for risk reduction. Determining the property rights is not that straightforward in practice (OECD, 2006, p 158). However, in the age that left slavery behind, when developed democratic institutions are in place, every person has an inalienable "property" right to their life and health. A proposition like "no paper contract – no right" would hardly be appropriate here. Therefore WTA for the increased risk is likely to be a more relevant measure here.

Knetsch (1990) investigates the implications of the discrepancy between WTP and WTA for decision making. He points out that the choice of a measure is not that a question of property rights as such. He notes instead that the choice of an appropriate measure cannot ignore the fact that people ascribe different values to gains and losses: "(…) instead of comparing alternative end states, people usually evaluate gains and losses in terms of changes from some reference position. And they value losses from this neutral point much more than they do gains beyond it" (p 228). Knetsch emphasizes that there is a 'kink' in the utility function at the reference point, thus this function is not that well-behaved, as it is assumed. Knetsch argues that if a proposed change imposes losses on individuals, the welfare changes based on WTP will likely to be underestimated; consequently, the results of CBA will be biased: an accounting of the sums people are willing to pay to avoid the risk would likely greatly underestimate the costs (p 231).

Similarly, Willinger (2001, p 11) states that according to the psychological findings, large disparities between WTP and WTA are justified by individuals' 'loss aversion' behavior ('loss aversion' is discussed by Kahneman and Tversky 1979). Individuals are more inclined to minimize losses (with respect to a "reference point", discussed above) than to maximize gains. Willinger thus concludes that in the case of an increase in risk, an individual suffers a loss in their well-being as well as a loss in their initial entitlement to a reduced risk; consequently, an appropriate measure is WTA.

Regarding *the relevance of VOSL to all kinds of risks*, for the purposes of this paper it makes sense to point out that WTP to avoid cancer may be higher than other diseases, i.e. a cancer premia is required (OECD, 2006, p 215). According to one recent Canadian survey concerning water-related health conditions, the mortality risk reduction values appear not significantly different for cancer and microbials *only* for an equal spread of risk reductions (Adamowicz et al., 2011). When Adamowicz et al. introduce 25-year cancer latency, they find out that WTP to avoid cancer increases and it becomes significantly greater than WTP to avoid death from microbials. Thus VOSL for cancer-related risks might be higher.

The analysts often distinguish between '*ex ante*' valuation and '*ex post*' valuation. The *ex ante* view is prior to outcomes of the project; the *ex post* perspective is when the outcomes of the project are known (Perman et al., 2003, p 449). Broome (1978) claims that '*ex ante*' valuation cannot be justified because it deliberately and unfairly uses the individual's ignorance about a final outcome: it does not seem correct to fix different values on the death of a particular person (infinite value) and an unknown person (VOSL).

Similarly, Ackerman and Heinzerling (2004, p 68) state that the concept of VOSL unfoundedly replaces the concept of life itself: the analysts ignore the distinction between valuing risk and valuing life, and act as if they generate the latter. They also argue that reliance on VOSL does not allow making important decisions about priceless values, and that it is more reasonable to exploit one's intuitive judgments to find a correct policy choice (p 90).

Indeed, decision makers may find monetary values of non-marketed goods confusing and difficult to interpret. Nyborg (1998) provides the results of an interview with 16 members of the Norwegian Parliament concerning their attitudes toward the use of CBA in assessment of a road investment plan. According to the findings, 11 respondents expressed skepticism with respect to the possibility of measuring noise and accidents in monetary terms. Regarding case A, it is important to notice that none of the respondents considered CBA as a *final* tool of decision making, i.e. CBA recommendations turned out to be insufficient to judge about the social desirability of the project. Regarding case B, the answers were more "promising" for CBA: its results gave a signal to look closer at the project for 11 members of the Parliament. To sum up, 14 out of 16 respondents appeared to be sceptical about monetary valuation of non-marketed goods, in one or another manner.

As discussed by Ackerman and Heinzerling (2004, p 71), it is useful to collect quantitative data about the lives saved or human health improved through implementation of particular policies, but it is confusing and thus pointless to provide the decision makers with the information on lives in terms of money equivalents. Similarly, Nyborg (2000) points out that if the goal of economic analysis is to supply the decision makers with sufficient background information about the alternative projects for the purposes of democratic debates, the role of CBA is much less recognizable because the net social benefit derived in CBA is too aggregated information, given existing normative disagreements between the decision makers. Nyborg constructs a formal mathematical model to arrive at informational requirements for democratic decision-making processes and finds out that *physical* unit indicators appear to be more relevant in that respect than monetary value-based indicators.

CBA rests upon the monetary valuation of the impacts of a radiation-related project to make its benefits and costs comparable. As it was discussed in this section, the task of putting a price on a human life and health is a highly controversial and difficult to perform. Moreover, it may be considered ethically unacceptable if one takes into account the fundamental human rights. Well-founded decisions imply that information about the issue at hand is accurate and understandable to use. Monetary values of life can be rather confusing, while factual information in physical units is more likely to supplement the decision makers' own intuitive judgments. Besides, non-marketed values may be easily manipulated. The institutional aspects of CBA will be discussed in part 6.

5.3. The flip side of nuclear power technology: uncertainty, risk perceptions and risk regulation

The International Commission on Radiological Protection (ICRP) recommends CBA as a method of justifying radiation exposure practices and taking economic and social considerations into account (see ICRP, 1971; Ahmed and Daw, 1980). Thus when it comes to a nuclear power project, the analysts deal with technological risks, the monetary assessment of which they have to incorporate into CBA.

However, regarding nuclear power technological risks, it may be relevant to distinguish between risk and uncertainty. Following Perman et al. (2003, p 445), the implications of imperfect information about the future can be different. According to them, *risk* can be handled in some way due to enumerated states of nature and assigned probabilities. If it is impossible to assign probabilities to the possible consequences of a decision, the experts deal with *uncertainty*. *Radical uncertainty* in its turn implies that the decision maker becomes unable to come up with a list of alternative future states, let alone the distribution of probabilities.

Otway (1974, p 73) states that there has been controversy around emergency core cooling systems since in 1969 deficiencies were indicated in the evaluation models and computer codes used in their design. According to him, these systems have been extensively studied since then in order to establish new design criteria. However, today, in 2011, the cooling systems of Japan's Fukushima Daiichi nuclear reactors failed, and the situation seems to be almost uncontrollable (Watts et al., 2011).

Thus it is reasonable to suggest that nuclear power technological risks may be more relevant to discuss in the context of uncertainty or even radical uncertainty, rather than risk. For example, Stirling (1998, p 102) summarizes uncertainty concepts in a figure and provides suggested methods of dealing with risk, ambiguity, uncertainty, and ignorance. The first two presuppose firm or shaky bases for probabilities. Uncertainty, with no basis for probabilities, is equivalent to Perman's interpretation of uncertainty, and suggests scenario analysis as a relevant method to apply. Ignorance is similar to Perman's radical uncertainty, and it implies the use of the precautionary principle, according to Stirling.

Munda argues (2006, p 8): "Analytic techniques such as cost benefit analysis (CBA) lose a considerable amount of information in trying to reduce the environmental complexity to a unique and unidimensional value. The use of precise, quantitative data based on monetary valuations (such as market prices) where complexity and uncertainty are pervasive can be misleading."

Ackerman and Heinzerling (2004, pp 117-118) promote 'the precautionary principle' which "is calling for policies to protect health from potential hazards even when definitive proof and measurement of those hazards is not yet available". They argue (pp 118-119): "The precautionary approach is hard for the cost-benefit worldview to digest. Precautionary policy making rejects the quantitative formula of cost-benefit analysis, replacing it with a process of reasoning and deliberation that cannot be reduced to an alternative formula." By analogy with insurance, Ackerman (2004) asserts that, by analogy with insurance, the *worst* possible outcome must be taken into account in policy analysis.

Ayres and Sandilya (1987) point out that an optimal solution under utility maximization is based on a *finite* option value (OV), which fails to avert certain potential irreversible catastrophes, such as for example death of an individual. They state that an *infinite* OV should lead to catastrophe-averting decisions. Ayres and Sandilya thus develop the view that apart from any ethical considerations, the economic approach is unsatisfactory in case of a positive probability of irreversible catastrophes. This result is derived in Ayres and Sandilya (1986) where they show that the use of formal utility maximization leads to the choice of policies, which fail to avoid catastrophes. Namely, risk-averse decision making on the basis of CBA may select policies that fail to avert or even exacerbate avoidable disasters. Ayres and Sandilya (1987) emphasize the role of engineering analysis and simulation in the choice of a decision rule of policy making. On the basis of simulation techniques, Ayres and Sandilya demonstrate that a catastrophe can be avoided and that this can often be done at a modest or negligible cost.

There are also interesting results in decision sciences concerning how decision makers actually make decisions, in particular when they face risk and uncertainty. Kunreuther (2010, p 270) highlights the importance of taking into account the myopic behavior of decision makers, i.e. it is essential to recognize that in most cases decision makers tend to focus on short-term horizons. He argues therefore that to make them think long term requires an understanding of decision-making processes with respect to making tradeoffs between the costs of taking risk-reducing measures and the expected benefits from reducing future losses.

Keeney (2010), while consulting on numerous policy decisions, such as siting a nuclear waste repository, noticed that decision makers have contradictory value judgments and cannot express clearly all of their relevant objectives. For example, when in one short questionnaire approximately 100 participants were asked to rank economic cost of the clean-up of old hazardous waste sites, potential human life lost or sickness due to the hazard, and potential damage to the natural environment, every respondent but one gave priority to the potential life lost or sickness and ranked economic costs as least important. However, in the subsequent discussion, very few of these participants appeared to regard as worth a $2 billion increase in clean-up costs to avoid 20 people being sick due to the hazard (p 241).

Raiffa (2010, pp 248-249) points out that today the analysts act as "problem solvers" treating the issues independently and proposing decisions, which are based on utility considerations and individual attitudes toward risks. According to him, in the face of uncertainty, it is essential that the analysts instead would serve as "problem inventors", in order to consider causal relationships between different problems and foresee the joint consequences of the decisions.

Addressing the problem of evaluating alternative decisions involving uncertainty and potential fatalities, Keeney (1980) constructs a prescriptive model which aims to help decision makers to compare different alternatives and determine which one is the best. The model is based on the assumptions that allow using a well-behaved expected utility function for evaluation purposes. One of the crucial moments, emphasized by Keeney, is that in decision- making it is important to distinguish whether the potential fatalities result from voluntarily accepted risks or involuntarily accepted risks (p 190).

As it was discussed in part 4, radioactivity has its specifics. In particular, the question of risk perceptions arises with regard to nuclear power technology. The main features of these perceptions were covered in part 4, where it was stated that decision makers are supposed to take public risk perceptions into account, whatever they are. Different studies pose a question how risk perceptions affect risk regulation (e.g. Johansson-Stenman, 2008; O'Riordan, 1982; Salanié and Treich, 2009).

Salanié and Treich (2009) investigate what implications the biased risk perceptions have for risk regulation. They point out that risk regulators do respond to the distorted risk perceptions, either due to political opportunism or just because they share similar risk perceptions. Salanié and Treich formally examine the choices of a paternalistic regulator to answer the question whether the risk regulators' response to subjective risk perceptions is economically desirable. They arrive at a striking result: "One may provide an economic rationale for over-regulation of risks when people's beliefs about risks are distorted, no matter the direction of distortion, and absent any political economy" (p 677). Thereby they conclude that the paternalistic approach to risk regulation may justify risk overregulation, irrespective of either people overestimate the risk or underestimate it.

Johansson-Stenman (2008) considers the problem of perceived and objective risks in policy making. He argues that even though public risk perceptions are often systematically biased, they cannot be ignored because of the fear associated with the risk on the one hand, and due to their implications for decision making in the form of second-best adjustments, on the other. Among several measures of allowing for the perceived risks, Johansson-Stenman proposes risk-reducing investments and provision of costly information to reduce risk-perception biases. It is interesting that, according to his conclusions, under the second-best policy adjustments the optimal level of public safety investments is *ambiguous* as compared to the conventional efficiency rule (in terms of WTP) when people overestimate the risk (which is often a feature of nuclear power risk perceptions) (p 244).

O'Riordan (1982) tackles the decision making in nuclear energy and finds it appropriate to consider, in which direction the social-science approach to risk perceptions might move in the light of further changes both in the technology of risk reduction and in the method of resolving the social and political acceptability of risk. O'Riordan argues that the social and political dimensions have transformed the fairly precise technological approach to risk into a significantly more complicated issue (p 97). He expresses the hope that the fused risk analysis will be successfully incorporated into the decision-making processes without destroying the technological dimension (p 100).

The flip side of nuclear power technology implies: (1) real-life disasters and catastrophes reveal its uncertainty-related nature, rather than just its risky features, but CBA does not explicitly take uncertainty into account; (2) the decision makers may be myopic, disregarding thereby uncertainty considerations and choosing economic tools like CBA; (3) public risk perceptions diverge from the scientific assessments of nuclear risks, but these perceptions have to be regulated, even though this task appears to be very demanding.

6. Institutional aspects of cost-benefit analysis and suggested improvements

Cass Sunstein in his book *The Cost-Benefit State: the Future of Regulatory Protection* (2002, pp 26-29) argues that CBA has significant advantages on the democratic grounds. First of all, the use of CBA allows reducing the role of special-interest groups in risk regulation and promoting accountability and transparency. Furthermore, he emphasizes that CBA serves public interests when it comes to health-related adverse effects of projects and policies. Namely, his arguments for CBA run as follows:

> "We have seen that regulation of nuclear power plants, designed to increased safety, might create health risks if it increases people's use of fossil fuels, which create a range of environmental and health risks, including those from globe warming. "Health-health trade-offs" – and the introduction of substitute risks as a result of regulation – are omnipresent, and analysis of those trade-offs is important in its own right and a significant step in the direction of CBA, which puts the adverse health effects of regulation on the public viewscreen" (p 27).

At last, Sunstein (2002) argues that CBA is advantageous because it generates a "cooling effect" on exaggerated public risk-related emotions, i.e. its use helps to overcome cognitive problems the ordinary people face when they think about risks.

However, first, the very relationship between CBA and the democratic decision making has not been subject to enough explicit investigation in the literature. One of the exclusive attempts to do that will be addressed in section 6.1. Second, there is evidence on the endogeneity problem with CBA (Crespi, 2010). The clash of interests and the bias toward powerful special-interest groups will be approached in section 6.2. Third, the "democratic presumption" in CBA, i.e. the determining role of individuals' preferences in guiding social decision rules, is a matter for debate. As OECD (2006) states, this presumption turns out to be a weakness rather than a strength of CBA because it implies that counting of preferences is crucial, irrespective of the fact that the holders of these preferences might be badly informed (in particular, about the health-related risks due to nuclear power plants) (p 35). Moreover, OECD points out that under the “democratic presumption” it might be reasonable to distinguish between the individual’s preferences as a consumer, whose behavior is based on self-interest, and those as a citizen. In section 6.3 I address this problem with its possible implications for public participation in democratic decision-making.

6.1. Cost-benefit analysis and criteria for democratic decision making

In order to judge whether CBA meets criteria for democratic decision making, one must specify a set of such criteria. Robert A. Dahl, one of the most respected political scientists writing today, has supplied a number of requirements an ideal democracy has to fulfill (Dahl, 1989, pp 109-120; Dahl, 2006, pp 8-10):

Effective Participation: “Before a policy is adopted by the association, all the members of the demos must have equal and effective opportunities for making known to other members their views about what the policy should be” (Dahl, 2006, p 9).

Voting Equality at the Decisive Stage: “When the moment arrives at which the decision will finally be made, every member must have an equal and effective opportunity to vote, and all votes must be counted as equal” (Dahl, 2006, p 9).

Enlightened Understanding: “Within a reasonable amount of time, each member would have equal and effective opportunities for learning about the relevant alternative policies and their likely consequences” (Dahl, 2006, p 9).

Final Control of the Agenda: “The demos would have the exclusive opportunity to decide how (and if) its members chose which matters are to be placed on the agenda. Thus the democratic process required by the three preceding features would never be closed. The policies of the association would always be open to change by the demos, if its members chose to do so” (Dahl, 2006, p 9).

Inclusion: "Every member of the demos would be entitled to participate in the ways just described: effective participation, equality in voting, seeking an enlightened understanding of the issues, and exercising final control over the agenda" (Dahl, 2006, p 9).

Fundamental rights: "Each of the necessary features of an ideal democracy prescribes a right that is itself a necessary part of an ideal democratic order: a right to participate, a right to have one's vote counted equally with the votes of others, a right to search for the knowledge necessary in order to understand the issue on the agenda, and a right to participate on an equal footing with one's fellow citizens in exercising final control over the agenda. Democracy consists, then, not only of political processes. It is also necessarily a system of fundamental rights." (Dahl, 2006, p 10)

It is worth mentioning that in his book *On Political Equality (2006)* Dahl extended the original top five distinguishing features of an ideal democracy (Dahl, 1989) by the last item on the list. This last criterion is meant to emphasize that not only political processes of decision-making are to be judged on a democratic scale; a distribution of fundamental rights to take part in these processes also comes into play and has to be measured with regard to the democratic standards. This point is consistent with an assumption made by Dahl that the existence of political equality is a fundamental premise of democracy: "(…) the ideal of democracy presupposes that *political equality is desirable*. Thus if one believes in democracy as a goal or ideal, then implicitly they must view political equality as a *goal or ideal*" (Dahl, 2006, p 2). This point raises in particular a substantial issue the power of special-interest groups which may be particularly important when it comes to life- and health-related political decisions. I will return to this idea later in section 6.2.

Using the top four criteria, Nyborg and Spangen (2000) investigate whether CBA can be regarded as a democratic procedure for ranking alternative projects, on the one hand, and whether CBA can serve an informational input into democratic debate about collective decisions, on the other hand. They disregard the question of eliciting WTP for non-marketed goods, but taking this problem into account would only make the issue at hand even more prominent if CBA aims to be a decisive tool of policy analysis.

Regarding CBA as a mechanism for making final decision making on the project (case A mentioned in part 1, p 4), Nyborg and Spangen (2000) arrive at the following findings:

Effective Participation: At first sight, CBA does perform well in this respect because WTP of any member of a society is incorporated into CBA on the equal grounds. Thus it reduces the role of politically powerful groups that might influence the decisions in the final stage. However, due to the fact that utility functions are based on self-interest and individual preferences, CBA does not actually satisfy this criterion in a proper way. Effective participation is aimed at what is *best for society*, and no individual is ever asked about that in CV surveys. Anyway, if asked, aggregating such preferences and interpreting the result would be highly controversial, and hardly consistent with the theoretical underpinnings of CBA.

Voting Equality at the Decisive Stage: Assigning equal implicit weights to all individuals does not meet the principle of voting equality because CBA allocates more "votes" to the rich (this point relates to distributional aspects of CBA discussed in part 5.1, particularly concerning the choice of a numéraire).

Enlightened Understanding: Individual preferences incorporated into CBA are assumed to be exogenous to a decision-making process, while political and ethical preferences are actually endogenous to it. In Dahl's view Nyborg and Spangen (2000) thus emphasize that this criterion is irrelevant to CBA because preferences that are in-built in CBA cannot be shaped through public discussion.

Final Control of the Agenda: Since CBA focuses on the aggregated WTP, the range of concerns to be taken into account is restricted to efficiency considerations. Such issues as the distribution problem and rights cannot be controlled properly. Besides, an important requirement of this criterion for democratic decision making is that the citizens may withdraw efficiency considerations from the agenda if they find it appropriate.

Nyborg and Spangen (2000) point out that CBA as an informational tool to democratic debate (case B) is irrelevant to consider with regard to Voting Equality and Final Control of the Agenda. They thus make the following conclusions concerning the two remaining criteria:

Enlightened Understanding: The main requirement of this criterion is that a decision procedure has to supply every decision maker with the most important factual information in order to be regarded as a democratic procedure. However, CBA presupposes that most citizens share its normative foundations (they were listed at the end of part 2 of the thesis). If some citizens consider such premises unacceptable, which might obviously be the case due to the fact that existing interests are rarely congruent, they hardly arrive at a well-founded evaluation of the issue at hand taking into account their own political and ethical judgments.

Effective Participation: Since the outcome of a CBA is too aggregated, CBA does not provide decision makers with equal and effective opportunities to express their preferences about the issue at hand. This point is clear when it comes to a health-related project: the aggregate net benefit derived in CBA does not communicate any descriptive information on specific adverse health effects of the project.

Nyborg and Spangen (2000) conclude that CBA is inconsistent with Dahl's criteria for democratic decision making. As a decisive rule, CBA allocates more "votes" to the rich. As an informational background, CBA appears to be not politically neutral. Consequently, those who apply the CBA methodology may enjoy the most influence. This fact can hardly be justified on the democratic grounds. According to OECD (2006, p 285), since CBA is non-participatory (non-voting), its result cannot play that significant role which some experts assign to it.

6.2. Clash of interests. Special-interest groups

As it was discussed above, in practice CBA ignores the distributional concerns and allocates more "votes" to the rich. In this section and in the next one I address the third sub-question of this thesis: Can the use of CBA be endogenous to a decision-making process (deliberately chosen as a tool of policy analysis by those who are interested in its results)? If yes, what *implications* can this have for the *final* stage of decision making about a radiation-related project if weak public participation is in place?

To begin with, it makes sense to specify a democratic decision-making procedure, at least in a simplified form. I refer to the democratic decision process used by Nyborg (2000, p 349):

1. The alternatives are specified and described.
2. Each decision maker makes their subjective judgment about the various alternatives, based on the information from step 1 and their own ethical or political views.
3. Decision makers' individual judgments are aggregated to yield a collective choice.

The first two steps have been more or less addressed above in this thesis. Regarding steps 1 and 2, I have discussed to what extent applied CBA may be a problematic tool to specify and describe the effects of a radiation-related projects due to its inherent methodological weaknesses, on the one hand; on the other hand, decision makers may experience difficulty using the result of a CBA if they do not accept its normative foundations. Moreover, it has been demonstrated that standard CBA does not meet the criteria for democratic decision making. Now, I introduce a conflict of interests into the three-step democratic process, and ask whether those who are favored by CBA can choose this tool of policy analysis and deliberately incorporate it into the decision making process. I guess that powerful interest groups, dominating in step 3 and interested in the results of CBA, may intentionally support the choice of CBA as a tool of specifying alternative policies in step 1. My strategy here is *not* to discuss how a clash of interests may be incorporated into CBA, rather to look at how CBA can be used in the context of conflict.

While proponents of CBA, like Cass Sunstein, promote this tool as a measure against powerful interests in risk overregulation, it may happen that the situation is just the opposite, namely that it might be the case that the groups favored by CBA are politically powerful and thus exploit this tool to their own interests.

Dahl (2006, p 51) emphasizes that political resources, information, skills, and incentives are distributed unequally. Among other things, political resources include money, information, and votes, which can be used to influence the behavior of other people. Dahl claims that the unequal distribution of political resources produces inequalities in the capacity of different citizens to employ their votes effectively to protect and advance their interests. Thus, on the one hand, those who enjoy greater political resources might be the most powerful. On the other hand, CBA allocates more “votes” to the rich, as it was discussed in the previous section. Consequently, the most powerful groups might deliberately choose CBA to exploit its weaknesses in their own favor.

Revesz and Livermore (2008, p 164) argue that environmental and consumer protection groups are less likely to organize themselves into effective lobbying blocks, and that the industry, with fewer players and more at stake, will have the advantage. Similarly, in the public choice literature it is emphasized that groups with the largest stake in a particular project are more likely to become organized and have higher influence on policy making (Persson and Tabellini, 2000, p 61). Ackerman and Herzberg (2004, pp 87-89) exemplify the situation by the famous experience with the Ford Pinto and its exploding gas tank. In the 1970s Ford lobbied intensively against the gas tank safety regulation, using CBA as one of their lobbying efforts. According to Ackerman and Herzberg, the society's value of a statistical life was then manipulated in Ford's favor.

The choice of an appropriate decision mechanism used in step 3 of the democratic procedure thus seems to be very important. If the decision mechanism rests upon the results of a CBA, even Sunstein (2002) recognizes that there is no assurance that this tool of policy analysis will not be misused by the interested groups (p 29).

Returning to Arrow's impossibility theorem, a SWF cannot translate aggregated ordinal individual preferences into democratic policy choices. As discussed in Persson and Tabellini (2000, p 21), one of the important implications of the impossibility theorem is that the majority rule fails to produce a well-defined stable policy choice, i.e. it may not lead to a transitive binary relation between policy alternatives. This failure, known as the Condorcet paradox, gives rise to infinite voting cycles unless the agenda is restricted, i.e. unless it involves voting only in a finite number of steps. Restricted agendas in their turn give incentives for strategic agenda manipulation, either of the agenda itself or of the preferences revealed in the voting process (p 31).

The *agenda-setter model* is one of the ways to deal with unfavorable implications of Arrow's impossible theorem (Persson and Tabellini, 2000, p 32). The premises of the model imply that representatives have well-defined policy preferences and presuppose the presence of the political institution, which imposes a particular procedure for decision making. In this model the policy decision constitutes the outcome of a game with a well-defined extensive form. Persson and Tabellini state that there are often specific politicians who exert a great deal of influence on the alternative political decisions. They note that successful positive modeling of political decisions have to take this influence into account (p 37). It is reasonable to suggest that being powerful these politicians can get access to the agenda setting and choose the preferred decision rule. In the light of the institutional aspects of CBA (in particular, that this tool is non-participatory in the final stage of collective decision making), it might be the case that the powerful interest groups control the agenda and use CBA as an agenda-setter tool.

Nyborg (2002) argues that the *goal* of project analysis is decisive when one chooses to translate *all* possible consequences in money units. According to her, it might be the case that the experts, who claim that placing price on environmental goods is essential for well-founded political decisions, implicitly consider *ranking* as the goal of project analysis (p 11). Nyborg's conclusion is highly consistent with how Dunster[11] (1973) justifies the 'essential need for CBA' as a tool of policy analysis for U.K. nuclear power technology. At the outset he argues (p 192):

> "Some form of *deliberate*[12] but *rational* simplification is almost always needed if the process of reaching decisions is to avoid being purely intuitive." In the way to the 'deliberate rational specification' he provides three separate stages of CBA application: "(…) to decide if a proposal is likely to be beneficia*l* or otherwise; to optimize procedures within that proposal with the aim of achieving a maximum net benefit; and to compare several optimized proposals and choose the best." With regard to safety considerations, Dunster assumes that people rationally give priority to their personal everyday objectives, like travelling by car or swimming, before they reveal safety concerns. Thus he claims that 'no one actually puts safety first – we cannot afford to' and thereby rejects the criticism of CBA application for the nuclear power technology in an absolutely striking manner: "(…) we conduct *intuitive cost-benefit analyses* to choose those risks which we will accept for ourselves or *impose on others* and those which we will not. All that the formal process of cost benefit analysis does is to offer us a tool to help us make these decisions rationally and consistently."

I interpret Dunster's justification of CBA in nuclear power technology as follows: first, the deliberative choice of CBA as a tool of policy analysis in U.K nuclear power technology has the aim to rank the alternatives, rather than to supplement the democratic decision-making process with sufficient background information to make well-founded collective decisions. Second, Dunster makes it explicitly clear that someone can give a good reason for imposing risks on other people, if this someone finds it beneficial according to his or her rational weighing of benefits against costs; and CBA is a helpful tool to do that formally. Indeed, CBA might be a convenient tool to apply by those who most benefit from its result because CBA is aimed at a final ranking of the available alternatives; it is an output of some specific views and preferences, and it is non-participatory.

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[11] John Dunster (1922 – 2006) served as deputy director general and director of nuclear safety of the U.K. Health and Safety Executive and later was director of the National Radiological Protection Board (NRPB).

[12] The use of italics here is mine.

Dahl (2006, pp 85-86) claims that the cumulative advantages in power, influence, and authority of the more privileged strata may become so overwhelming that even if the less privileged constitute a majority of citizens they are simply unable, and perhaps even unwilling, to make the effort to overcome the politically powerful forces. If the most powerful are so powerful and might exploit their preferable tools, the question arises whether there exists some way to balance the conflicting interests, to select an appropriate decision rule in the final stage of the decision-making process, and to choose a politically neutral tool of policy analysis. This seems to be rather significant, especially when the consequences of policy choices might be far-reaching, as in case of nuclear power.

As emphasized by O'Connor and Wenger (2010, p 255), most of the time policy change is slight and incremental because the distribution and relative power of interest groups are stable. Wilson (2000) considers the role of different 'stressors', such as a catastrophic event or an information leak, that provoke questions about the legitimacy of the existing arrangements, stimulate pressure for policy changes and create strategic advantages for groups promoting an alternative policy agenda. He provides an interesting non-incremental shift in U.S. organizational and policy goal changes:

> "Originally nuclear energy policy operated in a closed system (…) in which corporate, political, and technocratic elites advocating nuclear power had privileged access to the most insulated and centralized interiors of the policy process. Several factors contributed to the dissolution of this policy monopoly and policy change: the defection of a few technical Atomic Energy Commission (AEC) staff members who questioned the safety of nuclear energy; the expansion of the issue as AEC scientists leaked information to other initially excluded organizations such as the Union of Concerned Scientists; the dramatic increase of negative media attention; the change of the image of nuclear energy from positive to negative" (pp 249-250). "The old AEC gave priority to promoting nuclear energy. The new NRC (the Nuclear Regulatory Commission) was given primary responsibility for safety. The dismantling of the AEC and the formation of the NRC reflected the growing power of the anti-nuclear movement and the ascension of a new, more negative image of nuclear energy. For example the old paradigm that promoted nuclear energy as cheap and safe was replaced by a new paradigm that emphasized the dangers of melt-downs and radiation leaks and the problems of disposing of nuclear waste materials" (p 265).

In the light of the example, it might be the case that one way to stimulate policy changes and shift the power from the most powerful is “stressors”. Today, the evidence of this link between a “stressor” and policy change comes from Germany, which intends to abandon nuclear power: “The transition was supposed to happen slowly over the next 25 years, but is now being accelerated in the wake of Japan's Fukushima Daiichi nuclear plant disaster, which Chancellor Angela Merkel has called a "catastrophe of apocalyptic dimensions" (Baetz, 2011).

However, in order to arrive at a non-incremental policy change, the counter groups have to be in place to promote this change. If the counter groups are poorly organized or absent, even a strong ‘stressor’, like a catastrophe, may not work. Moreover, stronger and more organized public participation might be needed to counterbalance powerful interest groups. Revesz and Livermore (2008, p 5) claim that on the one hand CBA is biased against regulation, and on the other hand environmental and other progressive groups reject to participate in political processes concerning CBA. The resulting asymmetry in political participation may give rise to the misuse of CBA, according to Revesz and Livermore. They emphasize that more active participation of the ordinary citizens is essential as well to neutralize the conflict of interests around CBA. However, citizens may not participate for certain reasons, which I address in the following section.

Concluding this section, it is reasonable to suggest that the outcome of CBA, which can favor powerful political groups, may be endogenous to the final stage of a decision-making procedure and thus to the procedure itself. Having access to this final stage, where collective decisions are made, politically powerful groups may manipulate introducing CBA as a decisive tool of policy analysis. Different “stressors” and more active public participation might add to possible positive changes of the situation.

6.3. Roots of weak public participation

As it was mentioned in part 1, p 8, within the democratic premises the Strong Principle of Equality implies the inclusion of all adult citizens into a decision-making process. However, due to the ‘law of time and numbers’ (see part 1, p 9), in practice the democratic procedure is representative, i.e. the citizens delegate policy choices to the elected representatives. This law might serve as an obvious technical reason for weak public involvement in collective decisions making.

In January 1991 Frank Hahn made several interesting predictions for the next hundred years, which concerned the future role of the economic theorems and axioms prevailing in the economic theory, such as for example the axiom of rationality. Hahn (1991, p 47) believes that “theorising of the ‘pure’ sort will become both less enjoyable and less and less possible.” He predicts that computer simulations will replace theorems, and that psychological, sociological, and historical postulates have loomed on the horizon to displace simple transparent economic axioms. Hahn does not entirely reject the role of the economic method; rather, he states that theoretically useful results are a combination of different approaches to a problem at hand.

Indeed, today many scholars have realised that the key to improving economic decision making implies the careful empirical study of how people *actually* make decisions (Michel-Kerjan and Slovic, 2010, p 5). As a result, new multidisciplinary fields (e.g. economic psychology, behavioral economics, neuroeconomics, etc.) have emerged to integrate theories and results from different sciences. My aim here is to point to some possible explanations of the weak public participation with the help of an interdisciplinary approach. What seems to be important is that the roots of weak public participation may lie somewhat deeper than simply be explained by ‘the law of time and numbers’.

One possible explanation is ‘human drives’, as defined by Dahl (2006). In describing what drives people in their struggle for greater political equality, Dahl emphasizes the role of human feelings and emotions, rather than the role of human reason. He exemplifies this point by the powerful role of envy in strengthening the practice of competitive consumption, and claims that the culture of consumerism exerts much higher influence on individuals’ behavior than, as Dahl defines it, ‘the culture of citizenship’ (pp 88-90). Thus many individuals may prefer to raise their ever-rising private consumption, rather than participate in society-related issues.

There is evidence that once people have achieved a rather modest level of consumption, further increases in income and consumption no longer generate an increase in their sense of well-being or happiness (see e.g. Wilkinson and Pickett, 2010, pp 5-10). Dahl (2006) argues that this aspect of human nature may promote a positive shift from the prevailing culture of consumerism toward the culture of citizenship: the greater a number of people in the rich countries who experience this aspect, the more people evolve from consumers into active citizens (pp 106-107).

It is noteworthy that for the people in poorer countries the effect of increasing income and consumption on well-being or happiness is clearer (Layard, 2003, p 17). Taking into account Dahl's argument above, it is reasonable to suggest that poorer people, who are more concerned with consumption needs, may participate less actively in public issues. According to Maslow's hierarchy of needs (see e.g. Boeree, 1998), preferences on higher levels hardly motivate a person lest their lower-lying needs stay unsatisfied. In particular, Boeree points to the following: "If you are living through an economic depression or a war, or are living in a ghetto or in rural poverty, do you worry about these issues, or do you worry about getting enough to eat and a roof over your head?" Then Boeree states referring to Maslow's theory: "(…) much of the what is wrong with the world comes down to the fact that very few people really are interested in these values – not because they are bad people, but because they haven't even had their basic needs taken care of!"

In my subjective opinion, according to Maslow's pyramid of preferences, the transformation of the consumer into the citizen is likely to happen somewhere on the bridge between the third and forth levels of the hierarchy. I guess that a person will hardly actively participate in society-related projects if their bottom individual preferences are kept unsatisfied or even if satisfaction of these primary needs falls substantially behind that of other members of the society.

Concluding this section, I would like to point out that possibly my subjective point of view on the roots of weak public participation can be argued, and the true range of such roots is different to those I considered in this section. My aim was to make a humble attempt to apply an interdisciplinary approach to this problem. The point is that the problem of weak public participation might be significant in the context of the dominating special-interest groups. The misbalance of interests in the final stage of a decision-making process might intensify the misuse of such non-participatory tools of policy analysis as CBA. For such complicated issues as radiation-related projects, this may be fraught with far-reaching negative consequences, such as increased risks of adverse human health effects.

7. Alternatives to cost-benefit analysis

As an alternative to CBA, other decision-making procedures are proposed. Most of them are covered for example in OECD (2006, pp 269-276). OECD (2006) states that most of the existing alternatives vary in degree of comprehensiveness and rather narrow; and none of them are at least as comprehensive as CBA. The only exception among them is multi-criteria analysis, which may be even more comprehensive than CBA once goals beyond efficiency are considered.

I will refrain from returning to cost-effectiveness analysis (CEA) since it was to a relatively large degree considered above. Instead, I will address briefly two other existing alternative methods, which may be used in assessment of the radiation-related projects. Besides, it is reasonable to compare any recommended alternative to CBA according to some criterion. The basic assumption throughout the thesis, stated at p 4, was that the goal of the economic analysis is to inform participants in a decision-making process, in order to make their political and ethical judgments as well-founded as possible. Thus I will look at the alternatives to CBA from this perspective.

Multi-Criteria Analysis (MCA) is in many respects similar to cost-effectiveness analysis (CEA), but it involves multiple indicators of effectiveness. The available options get ranked on the basis of various criteria that are regarded as relevant. The distinctive feature of MCA is that it uses the preferences of decision makers, not the population's preferences as CBA. Like CEA, MCA is proposed as an alternative to CBA when it comes to the consideration of criteria which cannot be easily expressed in monetary terms. The procedure of MCA is rather complicated to discuss it here and involves many steps; therefore I refer to Zopounidis and Pardalos (2010) for the profound discussion of MCA. Here, it is more interesting to look at the importance of MCA results in a decision-making process.

OECD (2006, p 276) emphasizes that MCA tends to be more transparent than CBA because objectives and criteria are clearly stated, rather than assumed. Munda (2000, p 17) argues that since MCA allows taking into account conflicting, multidimensional, and uncertain effects of decisions, this technique may be a promising tool of policy analysis under conditions of complexity.

Gamper and Turcanu (2007) investigate the development of the potential of MCA to be used as an effective tool of policy analysis. They conveniently summarize several strengths and weaknesses of using MCA for public decisions (see their Table 1, p 300). In particular, they emphasize the advantage of MCA in stimulating discussions, its ability to tackle qualitative and intangible factors, and its support of broad stakeholder participation. On the other hand, MCA does not protect against possible information bias from certain groups to strengthen their power. Gamper and Turcanu come to the conclusion that MCA can improve on the final judgment about the desirability of a project both on the efficiency and distributional grounds. A difficult point is information sharing, because on the hand it is a demanding task to make technical information understandable to decision makers, and on the other hand to make technical specialists become aware of the social and political dimensions of the problem at hand. MCA provides final decision makers with reliable information about the affected people's preferences, and structures this information in the light of policy objectives and options to achieve them, according to Gamper and Turcanu.

However, according to Perman et al. (2003, p 383), the relevant way of making decisions is rather through the *deliberations* of citizens, than the preferences of the decision makers. Moreover, like CBA, MCA can be considered as an output of some specific incorporated preferences, rather than an input into a democratic decision-making process.

Cost-Impact Analysis (CIA) was introduced by Ministry of Finance of Norway in 1998 as an alternative to CBA and CEA, in case information in physical unit indicators may be more useful for decision-making purposes, than that in money terms (Ministry of Finance, 1998, p 11). This tool of policy analysis is recommended especially for the health sector when the benefits of different projects are not necessarily similar in kind (as it is the case for CEA). The costs are expressed in money units; while the benefits are interpreted in best available units and can be accompanied by descriptive information on the aspects, which may be difficult to quantify (Nyborg 2002, pp 7-8).

Nyborg (2000, p 394) states that the possibility of separating factual information from normative foundations is a necessary condition for a democratic debate. CIA meets this requirement because it is not initially meant to rank available alternatives in one way or another. Rather, factual information about the project is provided to the decision makers who in their turn judge about the social desirability of the project on the basis of their ethical and political views (Nyborg 2002, p 8). Thus, CIA succeeds in supplying background information into a democratic decision-making process, when the purpose of policy analysis is case B. Since information in physical units can be crucial for intuitive understanding of a project's welfare effects, Nyborg (2002, p 37) argues that there may often be sufficient grounds for the choice of CIA as a tool of environmental policy analysis, instead of CBA.

Consequently, both MCA and CIA help to overcome the problem of monetary valuation of non-marketed goods. However, MCA is similar to CBA in the sense of being an output of preferences of particular decision makers, and thus MCA does not facilitate the democratic debate about a project. CIA improves on providing relatively sufficient background information into democratic decision-making processes.

Conclusion

The central question approached in this master thesis was formulated as follows: Can cost-benefit analysis improve on decision-making processes concerning projects related to the risk of exposure to radiation and subsequent adverse health effects? To answer it, I explicitly kept to one simple assumption throughout the discussion of the issue at hand: The role of an economic analysis is to supply the decision makers with sufficient and understandable information to make well-founded political decisions.

In order to find an answer to the main question, three sub-problems were formulated. Time has come to highlight the solutions to them.

1. Can CBA be used to judge about the social desirability of a radiation-related project?

As long as there is no single agreed-upon form of SWF, the results of a CBA can be regarded as an output of some specific normative judgments and preferences of a particular decision maker. Putting prices on non-marketed goods, such as human life and health, turns out to be a highly controversial and demanding task on the methodological grounds. The separation of efficiency and distributional considerations in applied CBA limits its applicability as a tool of policy analysis on the one hand, but on the other hand, it is difficult to incorporate appropriate welfare weights into applied CBA to account for distributional concerns. The uncertainty-related nature of nuclear-power technology and public risk perceptions of radioactivity are not explicitly taken into account in CBA. Such methodological background allows to judge about the social desirability of the project only to a limited extent because the social net benefit in monetary terms does not reflect all possible consequences of the project.

2. Can cost-benefit analysis be useful as a background for democratic decision-making processes, i.e. serve as an informational input in a democratic decision process, thereby facilitating such a process?

The highly aggregate result of a CBA might be difficult to understand and process, and it is an output of preferences of a particular decision maker. Those decision makers who do not share the normative foundations of CBA can find its result less useful as an informational input. Since *neutral* normative basis is important for a tool of policy analysis, but such neutrality is problematic for CBA, CBA can supply decision makers with information which can be easily misinterpreted, and thus it appears to be inappropriate for debate purposes in a decision-making process.

3. Can the use of a cost-benefit analysis be endogenous to a decision-making process (i.e. can CBA be deliberately chosen as a tool of policy analysis by those who are interested in its results)? If yes, what *implications* can this have for the *final* stage of decision making about a radiation-related project if weak public participation is in place?

CBA does not meet the criteria for democratic decision making, neither as a measure of social desirability nor as an informational input. Strong special-interest groups can possibly manipulate the outcome of a CBA, particularly if decision makers do not receive information on these groups. Moreover, the use of CBA may to be endogenous to the decision procedure, i.e. powerful groups that enjoy huge political resources and have access to the final stage of a decision-making process may manipulate introducing CBA as a decisive tool of policy analysis. The misbalance of interests in the final stage due to weak public participation might intensify the misuse of CBA because CBA has a non-participatory nature.

It might be the case that the main concern related to the nuclear power technology is that of uncertainty, rather than risk. Several real-life disasters, such as the recent catastrophic situation with Japan's Fukushima Daiichi nuclear reactors, point to the radically uncertain nature of radiation. If it is the case, this could make CBA less suitable than some other alternatives. How CBA is conducted (the methodological aspects), and how it is used in the context of conflict (the institutional aspects), put severe obstacles in its way to improve on decision-making processes, especially in such fields where the consequences of decisions might be far-reaching or even irreversible, like radiation with its adverse impacts on human health and life.

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