

CHAPTER 1

The key steps in cost–benefit analysis of environmental health interventions

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1.1 Introduction

The main principle behind cost–benefit analysis (CBA) is simple: if the total costs are outweighed by the total benefits, the intervention can be implemented. Nevertheless, CBA may appear complex and intimidating given the many types of possible interventions. A common problem in CBA of Environmental Health Intervention (EHI) is its timing: policy makers require fast responses, their power is limited to their political mandate, and during emergencies a CBA approach is considered time consuming. This chapter helps making the process of conducting a CBA more manageable by dividing the analysis into seven main consecutive steps: (1) specifying the decision problem, (2) quantifying the benefits, (3) assigning monetary values to each benefit, (4) quantifying the costs of the

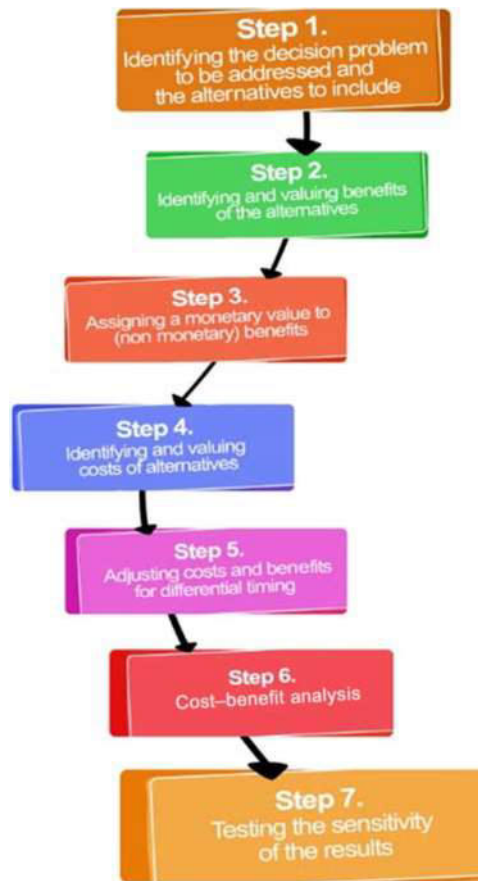


Figure 1.1 The key steps in cost–benefits analysis of EHIs.

intervention, (5) including considerations of the life span for costs and benefits and reexpressing these as present values, (6) comparing the estimated costs with the benefits, and (7) performing uncertainty analysis to assess the robustness of the study results (OECD, 2006a, 2006b). The remaining part of this chapter will focus on a brief overview of each step with special focus on Step 1 which is not covered in the remaining chapters of this book (Fig. 1.1).

1.2 Step 1: Identifying the decision problem to be addressed and the alternatives to include

The first step in CBA requires the analyst to make key decisions about the objective and the main components of the economic evaluation. The

most important decision is to identify the question(s) being answered and more specifically: (1) specifying the problem and (2) the policy alternatives, including nonaction, considered in the analysis. Answer to these questions requires an assessment of the pollutants/hazards that are causing the problem and (3) the medium (e.g., air, soil, water) through which the exposure is taking place.

Once the environmental data have been gathered and assessed, it is possible to select the range of alternatives. The selection of the policy (ies) or intervention(s) included in the economic evaluation depends on their availability and feasibility but is also based on political factors (OECD, 2006a). The rationale for choosing the alternatives (and excluding others) should be clearly provided in the analysis. All alternatives included should be described in sufficient detail to assess the relevance of the analysis. In general, it is advisable not to include more than six possible alternatives. It has been shown that the advantages of a larger set would be offset by the cognitive and analytical burden of considering a larger number of options.

The form of evaluation (CBA) should be clearly stated with a clear justification of the chosen evaluation approach in relation to the question being addressed.

Another important preliminary decision for the first stage of CBA is the selection of the relevant viewpoint (OECD, 2016; HM Treasury, 2018). According to the selected perspective, different costs/benefits (e.g., health service, societal, employer) may or may not be considered in the analysis. For example, if the Minister of Health perspective is adopted, the benefits in terms of visibility improvements associated with air pollution interventions will go unaccounted. According to Hutton (2008), given the broad range of possible benefits, the best approach is to estimate the costs and benefits for all relevant perspectives and to present them separately in the results to leave the most relevant perspective decision to politicians. However, this approach is both challenging and time consuming, and in practice, the perspective is likely to change according to the type of selected intervention. A societal perspective, for instance, is useful if the intervention has a wide range of benefits/stakeholders (OECD, 2016). Alternatively, a narrower perspective (e.g., employer) is commonly adopted where the application of the intervention is sector-specific, such as improving ventilation and thermal control in an office building.

In general, three are the possible perspectives to adopt when conducting a CBA: private/business, institutional, and societal perspective.

These perspectives correspond to three types of CBA:

1. **Financial:** This type of CBA meets the criteria of private assessment regardless of the subject involved. The objective is to chime with the maximization of profit according to the criteria of financial efficiency.
2. **Economic:** This CBA meets public evaluation criteria that vary according to the nature of the subject involved (e.g., Minister of Health or Education or Transport). In this case the objective is the maximization of the social well-being according to the criteria of economic efficiency. This CBA considers all possible determinant effects of the intervention beyond “market prices.”
3. **Societal:** This CBA meets public evaluation criteria but also takes into account the effects of the investments on equity and income distribution. The reference parameters for this analysis are social prices, that is, those established on the basis of the references of public decision makers with the aim of improving temporal and spatial distributions of income. This is the most comprehensive but also the most challenging type of CBA.

The first stage of CBA should also set out which benefits and costs will be included in the analysis. This issue “standing” will be discussed later and in further detail in [Sections 1.3 and 1.5](#) of this chapter and in Chapter 5, Health benefit analysis: monetization of health impacts and its use in environment and health, and Chapter 7, Discounting benefits and costs.

Once the perspective for the analysis has been selected, it is essential to identify the target population, namely, the population affected by the range of interventions. The final beneficiaries of EHIs may include specific subgroups of individuals, for example, motorways users, a population located in a geographical area, for example, individuals living close to an industrial site, or an entire nation, for example, a new regulation on national air quality standards.

The health effects on the target population change according to the types of pollutants and media of exposure, but they are also affected by individual characteristics such as age in which exposure is taking place (e.g., low birth weight due to air pollution exposure during pregnancy) and the gender of the exposed individual (e.g., the risk of dying from cancer in proximity to toxic waste disposals may differ between females and males).

Thus, it is essential, especially for large CBA analysis, to gather information on the age distribution and gender composition of individuals

affected by the policy. In addition to the demographic characteristics, economic indicators may also be relevant for the analysis. Equity and efficiency cannot be separated, especially when the objective of the policy is to reduce health inequalities of disadvantaged groups. The issue of weighing the monetary values in CBA to account for distributional concerns will be discussed in [Chapter 12](#), Conclusion.

Finally, in the first stage of CBA, the analyst should determine how long the impacts of the proposed interventions should last. According to the [HM Treasury \(2018\)](#), 10 years is suitable as a base case scenario for many interventions. Similarly, the EU Guidelines for CBA recommend a long-term outlook ranging from 10 up to a maximum of 30 or more years.

The relevant time period depends on the characteristics of the intervention as there are no predefined rules. For infrastructures such as roads and ports, the typical time span ranges between 30 and 50 years [[European Commission \(EC\), 2014](#)]. In the case of polluted sites, excavation eliminates the hazards forever, but capping the contaminated land has a shorter life span ([Environmental Protection Agency, 2014a, 2014b](#)). Importantly, if the project is expected to last many years, it is important to consider elements that change over time such as the demographic dynamics, the expected GDP growth, the labor market conditions, and the unemployment trend. For large interventions (e.g., new air pollution regulations), these elements likely play a significant role in the valuation of intervention consequences. [Table 1.1](#) presents a useful checklist of the actions required in Step 1.

1.3 Step 2: Benefits analysis

There are many types of benefits besides the health outcomes when undertaking a CBA of EHIs. The total benefits can be divided into three categories: (1) human health improvements (mortality and morbidity risk reductions); (2) ecological improvements such as improvements to market products (e.g., harvest of food), recreational activities (e.g., wildlife viewing), valued ecosystem functions (e.g., biodiversity), nonuse values (e.g., ecosystems communities etc.); and (3) finally “other benefits” such as visibility improvements or reduced damage to monuments ([OECD, 2006a, 2006b](#); [HM Treasury, 2018](#)). As suggested by the EPA Guidelines for CBA, this list is not exhaustive, but its broad categories can easily

Table 1.1 Checklist for step 1 appraisal.

Issue	Question
General	<ol style="list-style-type: none"> 1. Is the type of analysis adopted clearly stated? 2. Has an incremental approach been adopted? 3. Is the counterfactual credible? 4. Are all the possible interventions considered? 5. Is a clear justification for the intervention(s) included in the analysis provided?
Presentation of the context	<ol style="list-style-type: none"> 1. Is the social, institutional, and economic context clearly described? 2. Has the impact area been identified? 3. Have all the most important socioeconomic effects of the intervention(s) being considered in the region, country, or sector concerned? 4. Are these effects actually attainable given the context? 5. Are there any major potential constraints to intervention(s) implementation?
Definition of objectives	<ol style="list-style-type: none"> 1. Does the intervention constitute a clearly identified self-sufficient unit of analysis? 2. Have the final beneficiaries of the intervention(s) been identified? 3. Whose costs and benefits are going to be considered in the economic welfare calculation? 4. Are all the potentially affected parties considered?

Source: Adapted from European Commission (EC), 2014. Guidelines to cost–benefit analysis of investment projects. Economic appraisal tool for cohesion policy 2014–2020. <https://ec.europa.eu/inea/sites/inea/files/cba_guide_cohesion_policy.pdf>.

accommodate any benefits [Environmental Protection Agency (EPA), 2010a, 2010b, 2010c].

Principal among all direct benefits arising from EHIs are those to the human health. In most CBAs the baseline number of health outcomes attributable to pollution exposure is determined using a dose–response function. This function is “an estimate of risk per unit of exposure to pollutant.” The dose–response functions can have different shapes. They can be linear, meaning that any change in the pollutant concentration produces a corresponding change in the health outcome, or they can be nonlinear, meaning that health outcomes increase proportionately to pollutant concentrations, but then level off, and/or they can present a threshold dose, meaning that there is a level of pollution at which health outcomes become apparent [Environmental Protection Agency (EPA),

2010a, 2010b, 2010c]. Where the health outcomes attributable to pollution exposure result from a single pollutant (e.g., asbestos), the population attributable proportion (PAP) or, in other words, the number of cases that would have not occurred in the absence of pollutant can be estimated using the following formula (Hurley et al., 2002):

$$\text{PAP} = (p - (\text{RR} - 1)) / (1 + p * (\text{RR} - 1))$$

where RR is the relative risk of developing the health outcome given the pollutant concentration and p is the proportion of the population exposed (e.g., workers only).

In most cases, identifying the individual pollutants responsible for the health effects in the exposed population is problematic. As in the case of landfills or illegal waste disposals, impacts are likely to result from different compounds discharged in the same site. Thus the PAP is estimated using primary epidemiological data according to the following formula:

$$\text{PAP} = \text{Observed number} - \text{Observed number} / \text{SHR}$$

where SHR is standardized mortality/hospitalization ratios (SMR, SHR), which are estimated by dividing the observed cases (e.g., individuals with lung cancer) by the expected cases. SHR and SMR are adjusted for population characteristics such as socioeconomic class and other risk factors (e.g., prevalence of smokers). This step will be described in further detail in Chapter 4, Monetary analysis of health outcomes.

The ecological improvements associated with EHIs can be classified into four main subgroups: market products, recreational activities and esthetics, valued ecosystem functions, and nonuse values. Market products are easier to quantify and price as traded in the market. In the last decades, there has been an increased number of studies including other ecosystem services. Markandya (2015) documents an exponentially increasing number of published articles on ecosystem services. As for the human health benefits, once the pollutant(s) and their corresponding dose–response function are identified, it is possible to quantify the potential improvements using the same formula of health outcomes. Further details on this step are reported in Chapter 4, Monetary analysis of health outcomes.

1.4 Step 3: Assigning a monetary value to (nonmonetary) benefits

The human capital and the willingness-to-pay (WTP) approach are the two main methods for placing a monetary value on changes in health

(Bateman et al., 2002). The human capital approach assumes that an individual's life can be valued in terms of future production potential. As its name suggests, the WTP approach measures how much individuals are willing to pay to reduce the likelihood of an adverse event.

Within human capital approach, the cost of illness (COI) method is a measure of the monetary loss due to a negative health outcome (e.g., case of an asthma exacerbation) (Bateman et al., 2002). COI has several advantages over WTP. COI is straightforward. It is an objective measure of direct monetary costs of a given health outcome. In other words, it does not depend on personal preferences. However, COI also tends to underestimate the true value of a health outcome and does not consider the intangible aspects associated with illness such as stress, pain, and suffering. Moreover, given that COI values can be estimated only a posteriori, it is impossible to elicit the values that individuals assign to future environmental health risk reductions.

As a result, the most popular approach adopted in CBAs is the WTP approach. The WTP method can be divided into two main categories: revealed and stated preferences. The revealed preference method derives values from the observed actions of individuals (Bateman et al., 2002). The stated preference method elicits valuations by asking individuals how much they are willing to pay to reduce the risk of a given health outcome (Atkinson and Mourato, 2008).

It has been suggested that revealed preference techniques provide the most reliable indicator of preferences because estimates are based on actual decisions than on individual choices under hypothetical scenarios. In many cases, however, WTP information cannot be inferred from the market. Sometimes markets do not yet exist for the effect or cost being evaluated. Or, where EHIs target children and the elderly, the subjects are outside the workforce (OECD, 2006a, 2006b; OECD, 2018).

Another limitation of the revealed preferences method is that it does not consider the risk context (OECD, 2006a, 2006b). The revealed preferences approach does not allow valuations of different types of risk (mortality risk) and may lead to biased WTP estimates (OECD, 2006a, 2006b). Several studies report that individual WTP for averting cases of immediate death (road traffic accident) is lower than for chronic degenerative disease, given the fear and pain associated with long-term illness (Alberini and Scansy, 2011; Sunstein, 1997). For example, empirical studies have found that the WTP for avoiding cancer is higher than other diseases provided the dread and pain effects associated with this particular

pathology (Alberini et al., 2009a, 2009b; Van Houtven et al., 2008). To account for the “cancer premium,” the European Commission recommends that cases of cancer should be inflated by 50% (DG Environment, 2002). Finally, revealed preference techniques assign a monetary value to immediate risk reductions or that will occur quite soon. Especially in the context of environmental-related health effects, the risk reduction (e.g., cancer risk) is observed years after the implementation of the policy.

For these reasons, stated preference methods provide a more flexible tool with which to elicit individual WTP. Under this method, individuals are directly asked how much they would be willing to pay for an improvement in their health status or their willingness-to-accept values for an increased risk. Compared with the COI, stated preference approach has the advantage of taking into account the intangible consequences like premature death and the suffering from an illness. In addition, stated preferences methods can also be used to elicit WTP estimates from individuals who are not in the labor force and can easily account for different types of risk context.

There are two stated preference techniques for estimating WTP for environmental health risk reductions: contingent valuation (CV) and discrete choice experiments (DCEs). The CV approach asks respondents to make a monetary evaluation of the change in health risk. Among the many methodologies for eliciting WTP/Willingness to Accept (WTA) values from CV studies the most common methods are dichotomous choice and open-ended and payment card format (Bateman et al., 2002). All the elicitation formats have certain advantages and disadvantages. For example, compared with dichotomous choice and payment card format, the open-ended format has several major advantages, which include avoiding starting point bias, range bias, and anchoring bias (Bateman et al., 2002). However, this method is rarely used given its wider cognitive demands, which often produce nonresponse or a high proportion of protest and zero answers (Bateman et al., 2002). The payment card elicitation method presents respondents with a series of ordered amounts (from the smallest to the largest) and usually asks respondents to indicate the maximum bid they would likely pay for the health risk reduction (Bateman et al., 2002). But the payment card is also subject to bias because it requires the analyst to make assumptions about the range and the number of price bids. Another disadvantage of the payment card approach is that it cannot readily be used in telephone interviews. Compared with open-ended and payment card formats, the single and

double-bounded elicitation methods are less cognitively demanding. However, both these approaches also have weaknesses. Close-ended formats leave less freedom to the respondents to select the exact amount they are willing to pay (Ryan, 2009). However, approaches are subject to anchoring bias (Bateman et al., 2002).

Unlike CV studies that directly ask respondents the amount they are willing to pay for a specific change (e.g., in health risk), DCEs present respondents with a number of choice sets in which alternatives, described as a set of attributes, are mutually exclusive. The alternatives presented in each choice set vary in one or more attribute levels. The selected combination of attributes is used to infer indirect information on individual preferences about the parameters considered. Compared with the CV technique, DCEs are able to describe a choice situation with a range of attributes that reflect the different characteristics of the particular good being valued, and when the cost factor is included, they allow WTP estimates to be made for changes in different attributes (Ryan, 2009). The methodologies and issues related to this step will be discussed in greater details in Chapters 5 and 6.

1.5 Step 4: Cost analysis

To evaluate a priori the cost of EHIs is as difficult as evaluating its benefits. An additional difference in the cost valuation is that there is no uniform approach to costing environmental health interventions.

According to OECD (2006a, 2006b), for instance, there are three major cost components to consider in CBA of environmental interventions: the compliance, the regulatory, and the damage cost. The compliance costs include the resources necessary for policy implementation such as the cost of remediating a polluted site, including both the capital and the operating cost. Given the information asymmetries between the intervention provider (e.g., government) and supplier (e.g., contractors in charge of the remediation activities), initial compliance costs estimated a priori may be overestimated or underestimated compared with the final cost incurred to implement the policy [OECD, 2006a, 2006b; European Commission (EC), 2014; Environmental Protection Agency (EPA), 2010a, 2010b, 2010c]. Estimating ex ante the compliance cost is even more difficult when the intervention is new and/or, as in the case of large projects or regulatory interventions there are significant spillovers in different economic sectors (HM Treasury, 2018).

The second cost component to consider is the regulatory costs, which are the costs to the government of implementing the policy. Regulatory costs are often substantial, particularly where the project involves a large area (e.g., European regulation) or a large number of industries (OECD, 2016). The transaction costs associated with new regulations involve the cost of gathering, implementing, and monitoring the new regulation [Environmental Protection Agency (EPA), 2010a, 2010b, 2010c]. Sometimes the new regulation may even require the creation of property rights for previously nonmarketed goods (e.g., emission trading in California) and an establishment of institutions to control the newly created markets [Environmental Protection Agency (EPA), 2010a, 2010b, 2010c]. Finally, additional regulatory costs may be incurred as a result of changes to the institutional and legal system to create the new policy [Environmental Protection Agency (EPA), 2010a, 2010b, 2010c]. The third cost to consider is the damage cost or environmental loss arising from the intervention. The monetary value of environmental loss is quantified using the different approaches described in the benefits section. Once this cost is quantified, it must be subtracted from the total economic value attached to the intervention.

There are no specific guidelines for costing EHIs in CBA, and the different guidance developed for CBA recommends different approaches to costing. Regulatory, compliance, and damage costs are briefly discussed in this section, but depending on the type of intervention, the perspective adopted in the analysis, and the number of markets affected, there are potentially more types of costs that need to be considered. For further details on this costing approach see Chapter 8, Quantifying uncertainty in environmental health models.

1.6 Step 5: Time adjustment for cost and benefits

The cost and benefit of EHIs may materialize over lengthy periods. Thus discounting plays a crucial role in estimating the value of future costs and benefits (HM Treasury, 2018). Where different types of interventions are compared, discounting future costs and benefits to present values renders them more easily comparable. Discounting implies that the further in the future the benefits and the costs occur, the lower the weight that should be attached to them.

The general formula of discounting is the following:

$$W_t = 1/(1+s)^t$$

where W_t is the discount factor for time t and s is the discount rate.

Thus the conversion of future benefits to a present value can be estimated with the following formula (OECD, 2006a, 2006b):

$$\text{Present Value} = \sum \text{Future Value}_t \times W_t$$

where economists use discounting to adjust the value of costs and benefits occurring in the future, the standard approach is to assume a constant discount rate common to both costs and benefits (OECD, 2016). For example, since 1992 the US discount rate suggested as the base case for CBAs was fixed at 7% for both cost and benefit estimates [Environmental Protection Agency (EPA), 2010a, 2010b, 2010c]. A 3% discount rate was also suggested for sensitivity analysis [Environmental Protection Agency (EPA), 2010a, 2010b, 2010c]. The European Commission recommends the use of a discount rate of 4% for environmental CBAs and a lower discount rate of 2% for sensitivity analyses (DG Environment, 2002). However, there has been extensive discussion of whether the discount rate for health benefits should be lower than that applied to monetary costs. Also, where the effects under consideration are long-lived, a case has been made for discount rates declining over time (OECD, 2006a, 2006b). There is also an ongoing debate whether the normative discount rate should account for the discount rate estimated directly from individuals in stated choice studies (positive discount rate). Previous studies suggest that individuals' discount rate is not fixed but varies over time (Cairns and Van der Pol, 1999). Economists are paying increasing attention to hyperbolic models that reflect time inconsistent models of discounting. According to Cairns, hyperbolic models present two major advantages over traditional exponential models: they seem to reflect real individual time preferences and, compared with a constant discount rate, do not attach very low weight to benefits occurring in the distant future. For example, Viscusi and Huber (2006) found that the discount rate shown for improvements in environmental quality do not follow the standard discount utility model; rather its pattern is consistent with the hyperbolic model. Also, Alberini et al. (2009a, 2009b) found that discounting rates for saving lives in the hazardous waste context are not constant over time. For time spans longer than 10 years, in particular, they found that the discount rate was decreasing. For policy that displays health benefits occurring in a distant

future, there is a strong incentive to consider intergenerational equity. Indeed, using a constant discount factor would highly depreciate benefits occurring in the distant future. Given the uncertainty surrounding the future discount rate, and also the necessity to ensure intergenerational equity, UK government departments introduced new guidelines recommending the use of time-varying discount rate (HM Treasury, 2018).

Time lags between the policy and its related benefits are also an important issue (HM Treasury, 2018). When a policy is implemented, there may not be immediate reductions in the number of health outcomes (e.g., cancer cases). Following this “cessation lag,” there will be a gradual (proportional/nonproportional) decline in the effects of reduced emissions on health up to the point where the number of health outcomes is the same as observed in the general population.

The following formula can be used to account for both the discounting and the latency of benefits (Guerriero and Cairns, 2009):

$$\text{Present value of benefits} = \lambda * X_a * 1/(1 + d)^l * (1 - 1/(1 + d)^t)/d$$

where X_a is the number of health endpoints averted by the intervention, t is the number of years over which the benefits accrue, and d is the discount rate. λ is the WTP for the health outcome and latency period l , which is the time occurring between the reduction of the exposure and the improvement in population health.

1.7 Step 6: Cost–benefit analysis evaluation

The objective of CBA is to provide transparent evidence on the net benefit associated with an environmental intervention versus the do nothing scenario. If more than one intervention is available, CBA allows to compare the net benefit of competing options. Summary measures of net benefits are the outcomes of CBA. They should include the net present value (NPV) of benefit, the benefit–cost ratio, and the results of sensitivity analyses.

The main condition for the adoption of EHIs is that the present value of the benefit (PVB) exceeds the present value of the cost (PVC), or that the $\text{NPV} > 0$ (OECD, 2006a, 2006b). The NPV rule is usually adopted to decide whether to accept or reject an option, to rank different projects, and to choose between mutually exclusive projects. An equivalent feasibility test is the benefit–cost ratio test:

$$\text{PVB/PVC} > 1.$$

Table 1.2 Generic appraisal summary template.

	Do nothing scenario	Option 1	Option 2	Option 3
Present value of benefits				
Present value of costs				
Net present value				
Benefit–cost ratio				
Switching values				
Time horizon and reason				
Significant unmonetized Costs/Benefits				

However, there are differences between the two tests. The first evaluates the excess in benefits and is a more direct way of measuring the social benefits of the intervention. The second evaluates the benefits per dollar of cost incurred. For example, a cost ratio of 2.2 means that for each dollar invested, \$2.20 of social benefit is realized. There is general agreement that benefit–cost ratio can be misleading when used outside the rationing context (when only one project should be evaluated).

A modified version of the Appraisal Summary Table as recommended by the UK Green Book is shown in Table 1.2. The table provides a comprehensive summary of the main outputs of CBA. Each column of the table is associated with an intervention appraisal including the do nothing alternative which should be presented in absolute terms. The first four rows report key CBA measures such as the PVC, PVB, the NPV, and the benefit–cost ratio. One-way sensitivity analysis results (switch values) can be reported only for the preferred option.

The table also allows to summarize the key assumptions of the analysis, including time horizon used and the unquantified values of the analysis. Whenever possible, the table should be completed by graphical representations of the uncertainty around the CBA estimates [e.g., cost–benefit acceptability curves (CBACs) and tornado diagrams].

1.8 Step 7: Risk and uncertainty

As with economic evaluations of healthcare interventions in cost–utility and cost–effectiveness analyses, extensive sensitivity analyses address the

lack of certainty and also allow an assessment of the robustness of economic evaluations and their comparability (OECD, 2006a, 2006b). As mentioned above, costs and benefits are difficult to ascertain a priori. As a consequence, they are associated with high degrees of risk and uncertainty. Risk denotes the possibility of attaching a probability to costs or benefits that are not known with certainty. Uncertainty denotes a case in which the probability distribution is not available, but in which crude end points, like the minimum and maximum values, are known. Despite the importance of addressing risk and uncertainty in CBA, there is still a lack of core methodologies for conducting uncertainty analysis to facilitate the comparison between CBA results (Drummond, 1993).

If the objective of sensitivity analysis is to assess the degree of uncertainty associated with single-model parameters, deterministic sensitivity analysis and one-way or multiway sensitivity analyses can be used (Drummond, 1993).

One-way deterministic analysis tests the sensibility of the expected NPV to changes of a single variable in the model (Drummond, 1993). Alternatively, multiway sensitivity analyses test the effect of changes to two or more variables on the expected NPV of the EHIs.

The main advantage of deterministic sensitivity analysis is its easy computational abilities. It allows assessments of which specific parameter value the expected NPV changes. The main disadvantage, however, is that deterministic sensitivity analysis does not account for cases where variables change simultaneously. Monte Carlo analysis is a computational method that uses statistical sampling and probability distributions to show how parameter uncertainty affects model results. In CBA of EHIs, Monte Carlo simulation can be used to model the effects of key variables such as policy associated health risk reduction on the NPV of a given proposal (Doubilet et al., 1985). Compared with crude deterministic methodologies that generate a single point estimate, Monte Carlo method can be used to account for parameter variability and uncertainty. Monte Carlo simulation is carried out in two consecutive steps: first, it requires the analyst to select and assign a probability distribution to the variables used for the NPV calculation; second, it requires the simulation of a large number of draws, usually between 1000 and 10,000 simulations from the distributions selected. The most difficult task in performing Monte Carlo simulation is the selection of the appropriate probability distribution, which depends on the characteristics of the variable (e.g., bounds of the variable and symmetry of the distribution) and also on information available about

the variable. According to [Briggs et al. \(2008\)](#), the choice of the appropriate distribution for the model parameter depends on the parameter characteristics, and also on the information available about the parameter.

For example, the authors suggest the adoption of a beta distribution for binomial data, such as proportion and probabilities, as these are naturally bounded between 0 and 1. The gamma probability constrained between 0 and positive infinite is the perfect candidate for simulating uncertainty in the cost parameter for cost parameters ([Briggs et al., 2008](#)).

Once the Monte Carlo simulation results have been obtained, they can be presented using CBAC. CBACs are a modified version of the cost-effectiveness acceptability curves used in healthcare decision-making that have been employed to represent uncertainty within economic evaluation of healthcare technologies ([Fenvick et al., 2006](#)). In pure healthcare decision-making, CEACs indicate the probability that an intervention is cost-effective compared with the alternative(s), given a range of λ WTP values (e.g., for an additional quality of life year gained). In the case of CBA of EHIs, both cost and benefits are reported in monetary values. Thus the condition for the pollution control policy to be implemented is the following ([Lothgen and Zehraeus, 2000](#)):

$$\text{NPB} = \text{PVB} - \text{PVC} > 0$$

where NPB is the net present benefit and PVB and PVC are the present values of benefits and costs associated with the intervention.

An application of the CBAC to describe uncertainty in CBA results has been provided in Chapter 12.

1.9 Conclusion

This chapter provides a brief description of the main steps involved in estimating the costs and benefits associated with EHIs. In particular the chapter describes the main steps for assessing the health benefits and costs associated with EHIs. The first step in conducting CBA consists of identifying the decision problem and specifically determining the perspective and time span for the analysis along with the relevant types of benefits and costs. The second step of CBA quantifies the benefits arising from the intervention using different sources of data including environmental, demographic, and epidemiological statistics. Once these benefits have been quantified, the following steps consist of assigning a monetary value to the quantified nonmarketed benefits. Monetization of the health

benefits is probably one of the most challenging step in CBA. The most commonly used method for assigning monetary value to environmental health benefits is the stated preferences technique. However, WTP estimates elicited using this approach are associated with a high degree of uncertainty, because they are calculated on the basis of respondent answers to hypothetical scenarios rather than real decision-making. The fifth step of CBA is to assess the cost of the intervention. Depending on the type and size of the intervention, its potential for cost can vary significantly. For this reason, ascertaining a priori costs can be difficult. Further, establishing costs and benefits arising from EHIs require analysts to fix a period of time in which these are expected to occur. And if the relevant time horizon is longer than 1 year, discounting can play a crucial role in the CBA as it allows translating both future costs and benefits to their present value. Once the costs and the benefits have been reported to their present value, the sixth step of CBA compares the total cost with the total benefits and ranks the assessed alternatives from the most to the least cost-effective. Given the uncertainty associated with estimates of benefits and costs, the last step of CBA requires the conduct of deterministic and/or probabilistic sensitivity analyses.

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