

Integrated approaches to health

A handbook for the evaluation of One Health

edited by:

Simon R. Rüegg

Barbara Häslér

Jakob Zinsstag



**Network
for Evaluation
of One Health**

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who work together with passion,
respect and vision to achieve
sustainable health for all.**

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Chapter 6

The economic evaluation of One Health



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Abstract

This chapter provides an overview of the main methods and techniques available for the economic evaluation of One Health initiatives to introduce scientists and professionals from backgrounds other than economics to key considerations and implications of such assessments. The first part of the chapter describes the main analytical tools currently used in economic evaluations and discusses their potential and limitations when applied in a One Health context. A critical assessment is provided in particular to issues dealing with complexity of interrelations between human and animal health, and effective management of environmental resources. The second part of the chapter introduces and describes a range of pragmatic approaches to economic evaluation which have been inspired from the need to deal with and account for such complexity. It also investigates how systems approaches and methods used in One Health can enhance the capacity of economic evaluations to support informed decision making. With this chapter we are making a contribution to develop One Health economics as a scientific trans-disciplinary topic and stimulate further economic evaluations of One Health activities from a broader range of disciplines.

Keywords: One Health, economic evaluation, economic evaluation methods, economics and complexity, systems transdisciplinary approaches

6.1 Introduction: brief rationale behind economic evaluations of One Health initiatives

The initiatives to promote human, animal and environmental health have direct and indirect economic implications through the consumption of scarce resources and the generation of outcomes. Economic evaluations intend to understand these implications and support decisions on the implementation of interventions. The general motivation for economic evaluations is that resources are limited and can be devoted to different competing uses: a systematic analysis and comparison of the costs and the outcomes associated with an intervention can inform the decisions on the most efficient allocation.

In this chapter, we describe the main methods that can be used for the economic evaluation of One Health initiatives. With this text we aim to introduce researchers and professionals involved in One Health from backgrounds other than economics to the basics of economic analysis. The text should help to improve their awareness about the multifaced implications of an economic evaluation process, by showing and discussing the main theoretical and operational tools available, their potentials and their limitations. The development of economics as a discipline has not been straightforward. The theoretical constructs of this branch of knowledge have been affected by dogmatism, and the tendency to methodological reductionism, although inspiring pragmatic approaches to economic analysis, has narrowed its capacity of seizing complex phenomena. The recognition of such limits, confronted by the One Health vision, has highlighted the need in economic evaluations to account for the complexity of interrelations between a sound environmental resource management and human and animal health. Thus, we explore how the fields of systems approaches and methods can enhance the potential of economic evaluations to support informed decision-making

through the same analytical tools that One Health scientists and practitioners commonly use. We think that this specific feature should characterise One Health economics and its development as a scientific trans-disciplinary topic (e.g. Zinsstag *et al.*, 2015a). We also hope that researchers and professionals from other disciplines working in One Health initiatives will be motivated to conduct practical economic evaluations for their One Health activities.

After this introduction, Section 6.2.1 presents the main concepts and theoretical aspects of economic evaluations and Section 6.2.2 is dedicated to the cost-benefit analysis (CBA), a method that translates all the effects of an initiative into monetary values by exemplifying most of the problems connected to economic assessments: e.g. the identification of the initiative's effects (Section 6.2.2.2), the attribution of values and their monetization over time (Section 6.2.2.3-6.2.2.5), and the choice of appropriate indicators for decision making (Section 6.2.2.6). The following sections show other methods that find wide application in health-related studies (Section 6.2.3), i.e. the cost-effectiveness, the cost-utility, and the cost-consequence analysis, and the issue of uncertainty in economic evaluations (Section 6.2.4). Next, Section 6.2.5 summarizes the limitations and challenges of economic evaluation techniques in the context of One Health, by introducing the subject of Section 6.3: the trade-off between One Health complexity and the reductionist approaches of economists. After showing how the economic thought evolved to deal with complex phenomena (Section 6.3.2), the final sections present a variety of methods and models, mainly of systemic type, that can contribute to account for the diversified and intangible values, and added values, created by One Health initiatives.

One Health is a wide concept and the related initiatives can vary in terms of complexity, context, characteristics, and objectives, and there is no 'one size fits all' for economic evaluations (Häsler *et al.*, 2012): each assessment must be context-specific. Nonetheless, One Health itself has been defined as 'any added values in terms of health of humans and animals, financial savings or environmental services achievable by the cooperation of human and veterinary medicine' with respect to the approaches of the two medicines working separately (Zinsstag *et al.*, 2015b). This definition of One Health has a strong economic connotation that takes the shape of technical achievements producing monetizable benefits, for example: reduced loss of lives and reduced suffering for humans and animals, reduced time of disease detection, full assessment of disease burden, increased awareness of cross-sectoral costs of diseases and cross-sectoral benefits from disease control, shared costs of health interventions, capacity to identify interventions of higher leverage, easier access to health care, improved food security and ecosystem services (Zinsstag *et al.*, 2015c).

A classification of economic evaluation for different types of One Health initiatives, whether possible, is beyond the scope of this work, but in Box 6.1 we provide a brief outline of few examples that illustrate the complexity of the effects and how far economic evaluations can reach through an adequate set of concepts and tools. We will refer to them throughout this chapter to illustrate specific aspects of the economic evaluation of One Health initiatives.

Box 6.1. Examples of One Health initiatives.

- A. Human and animal vaccination delivery to remote nomadic families, Chad (Schelling *et al.*, 2007):
The implementation of a joint vaccination program for humans and cattle led to considerable cost savings while also increasing uptake in humans, particularly among nomadic populations, women, and children. The cost per immunised children or women is calculated, in comparison to a non-integrated intervention.
- B. Integrated surveillance for the prevention and management of *Escherichia coli* cases (Elbasha *et al.*, 2000):
This study evaluates a surveillance mechanism for the detection and management of *E. coli* cases. The authors take a cost-benefit approach, attempting to value all costs and outcomes in monetary terms. They then calculate the net benefits depending on the number of cases prevented, compared to a scenario with no surveillance mechanism, where emergent cases are individually traced back.
- C. Health, agricultural, and economic effects of adoption of healthy diet recommendations (Lock *et al.*, 2010):
The assessments of policies aimed at improving health and reducing greenhouse gas emissions through reduced livestock consumption estimate the potential impact of diminished meat consumption on human health and gross domestic product, both in Brazil and the UK, considering the consumption patterns and trade links involved. The impacts are further disaggregated by sector by acknowledging the relevance of the geographic and sectoral distribution of the impacts.
- D. Comparison of human post exposure prophylaxis (PEP) versus a mass dog rabies vaccination and culling policy to control human rabies (Zinsstag *et al.*, 2009):
This study assessed the economic impact of using PEP versus a mass dog rabies vaccination in the capital of Chad. The results show that a mass dog rabies vaccination is more cost-effective over a six year period than PEP alone.

6.2 Tools for economic evaluation

6.2.1 What do we understand by economic evaluation?

6.2.1.1 A definition of economic evaluations

According to a definition very popular in the field of health economics, the economic evaluation of an intervention is ‘the comparative analysis of alternative courses of action in terms of both their costs and consequences’ (Drummond *et al.*, 2005). An economic evaluation is then subject to two main conditions:

- a comparison between two or more alternatives, and no action could be one of the alternatives examined;
- the identification, measurement and valuation of the costs and consequences (or outcomes) of each alternative examined.

Drummond *et al.* (2005) also indicate a typology of evaluations for health interventions based on the partial or full compliance with such conditions, as shown below:

- Partial evaluations:
 - Only one course of action is examined:
 - Only consequences are examined: outcome description.
 - Only costs are examined: cost description.
 - Costs and consequences are examined: cost-outcome description.
 - Two or more alternatives are examined (no action could be one of the alternatives):
 - Only consequences are examined: efficacy or effectiveness evaluation.
 - Only costs are examined: cost analysis (CA) or cost minimisation analysis (CMA).
- Full economic evaluations:
 - Two or more alternatives are examined (no action could be one of the alternatives):
 - Costs and consequences are examined:
 - Cost-effectiveness analysis (CEA).
 - Cost-utility analysis (CUA).
 - Cost-benefit analysis (CBA).

Such a setting is related to the scarcity of resources and the need to optimise choices for their use: hence, the main objective of economic evaluations is to inform decision making.

6.2.1.2 Optimisation of resource use and social choices: welfarist and extra-welfarist approaches

Optimisation of resource use is connected to the notion of efficiency, which is rooted in the marginalist-neoclassical economic theory, the mainstream current of thought in economics, and represents its first goal: e.g. ‘The problem of Economics may [...] be stated thus: Given, a certain population, with various needs and powers of production, in possession of certain lands and other sources of material: required, the mode of employing their labour which will maximise the utility of the produce’ (Jevons, 1871); ‘Economics is the science which studies human behaviour as a relationship between ends and scarce means which have alternative uses’ (Robbins, 1932).

Utility is a concept of economics that indicates the satisfaction gained by individuals from the consumption of goods and services. The maximisation of utility, through an optimal use of scarce resources, depends on individual preferences and individual choices, but interventions in the health sector, as in many other sectors, are mostly determined by decisions involving whole communities of citizens at different levels: local, national, global, etc. Social choices are a topic of welfare economics. For this branch of the marginalist thought, social choices should be driven by the concept of Paretian dominance or Paretian efficiency, in which one solution is preferable to another if it provides a better off for someone without implying any worse off for someone else (Pareto, 1894). An extension of the Paretian principle, the so-called Kaldor-Hicks compensation, which is more usable in the practice of economic evaluations, is based on the hypothesis that if a solution implies the outcome of gainers and losers and the gainers may compensate the losers and also maintain some benefit, then this solution is Pareto efficient (Hicks 1939, 1943; Kaldor, 1939).

The Paretian approach and the Kaldor-Hicks compensation have been severely criticized, as well as other major elements of the welfare economics' theory (e.g. Arrow, 1951; De Scitovszky, 1941; Samuelson, 1942; Sen, 1970, 1999). Extra-welfarist approaches focus on societal objectives as separated by maximisation of subjective utility of individuals and enable the optimisation of resource use within the framework of socially relevant outcomes: e.g. to impose additional taxes for the improvement of the public health system beyond the utility of those single individuals that could prefer to keep these resources for other personal uses. The judgement on the relevance of the outcomes might be indicated by the affected individuals as in the welfarist approach, but also by a representative sample of the general public, by an expert or by an authoritative decision-maker, and may integrate ethical considerations (Brouwer *et al.*, 2008). In particular, the decision-maker approach emphasises the function of decision makers in defining societal objectives and relevant outcomes, by acting as representatives of the individual members of society (Coast, 2004; Sugden and Williams, 1978). Within this approach, the definition of societal goals can also be achieved through transdisciplinary initiatives engaging with stakeholders to find consensus for problem solving (Schelling and Zinsstag, 2015).

6.2.1.3 Economic evaluations in health interventions and the One Health approach

The last four methods listed in Section 6.2.1.1 (CA or CMA, CEA, CUA, and CBA) are the most common approaches in the economic evaluation of health interventions. All four methods assess the cost of interventions in monetary values but differ in the ways outcomes are measured. In cost analysis or cost minimisation analysis (CMA) comparison of cost is made between two or more alternative interventions implying different costs but producing equivalent outcomes. Cost-effectiveness analysis (CEA) compares two or more alternatives that produce the same type of effect, but to a different extent: the comparison has to be made in terms of monetary cost per unit of effect measurable in natural metrics, for example: number of cases treated appropriately, lives saved, life years gained, days free of pain or symptoms, cases successfully diagnosed, etc. (Robinson, 1993). In cost-utility analysis (CUA) the effects are measured by indicators of the utility provided to patients in terms of health-related life quality along the time: e.g. quality-adjusted life years (QALY) or disability-adjusted life years (DALY). With respect to CEA, the CUA approach is broader, since it allows comparing treatments that produce different effects in terms of both mortality and morbidity on patients, as well as the costs and the outcomes of health programmes targeting completely different objectives.

Both CEA and CUA are based on extra-welfarist/decision-maker approaches. CBA is rooted in welfare economics and aims to evaluate, in monetary terms, all the possible effects, i.e. both the direct and indirect benefits and costs, of two or more alternative interventions, to identify the one which provides the highest net benefit to society. The use of a single parameter, the monetary value, for the assessment of any kind of outcome makes CBA potentially adaptable to economic evaluations in any sector of human activities and to comparisons between and across sectors. Furthermore, the CBA of an intervention in one specific sector, e.g. health, can also consider all the indirect costs and benefits affecting other sectors involved. This feature can be particularly suited for the evaluation of One Health initiatives, which in general have wide cross-sectoral impacts involving areas such as human, animal and ecosystem health,

agricultural and livestock production, food industries and services, etc. (e.g. Häslar *et al.*, 2014; Roth *et al.*, 2003).

The use of money as single parameter in CBA evaluations is however greatly discussed (Ackerman and Heinzerling, 2005; Anderson, 1988; Hansson, 2007; Kelman, 1981; Sagoff, 1988; Sunstein, 2005). On the one side, this implies to attribute monetary value to goods and services that are not tradable in the market (also defined as intangible goods and services), while the market price is the main reference to establish the actual economic value of goods. On the other side, the monetary appraisal of many intangible goods, like absence of pain and suffering, human health and lives, biodiversity conservation, protection of endangered species, integrity of ecosystems, animal welfare, etc., raise significant ethical concerns. The latter issue seems to be the main reason why CBA has not found extensive application in the human health sector (Coast, 2004; Drummond *et al.*, 2005). CEA and CUA in part avoid the problem, but they limit the possibility to take into consideration the cross-sectoral benefits of an intervention. Recent contributions have however tried to widen the potential of CEA and CUA techniques in animal health evaluations with promising results (Shaw *et al.*, 2017; Torgerson *et al.*, 2018).

In other sectors, including industry, infrastructures, public services and utilities, and the environment, CBA has been increasingly recommended and adopted by government and international institutions to assess projects and programmes of public interest, despite concerns for monetisation of intangible goods and the criticisms against its welfarist background. This contradictory outcome has been explained with the lack of effective competing approaches and evaluation methods within mainstream economics and with the fact that the criticisms were not so relevant for the ordinary practice of economic evaluations and for the needs of the real-world decision makers (Pearce *et al.*, 2006).

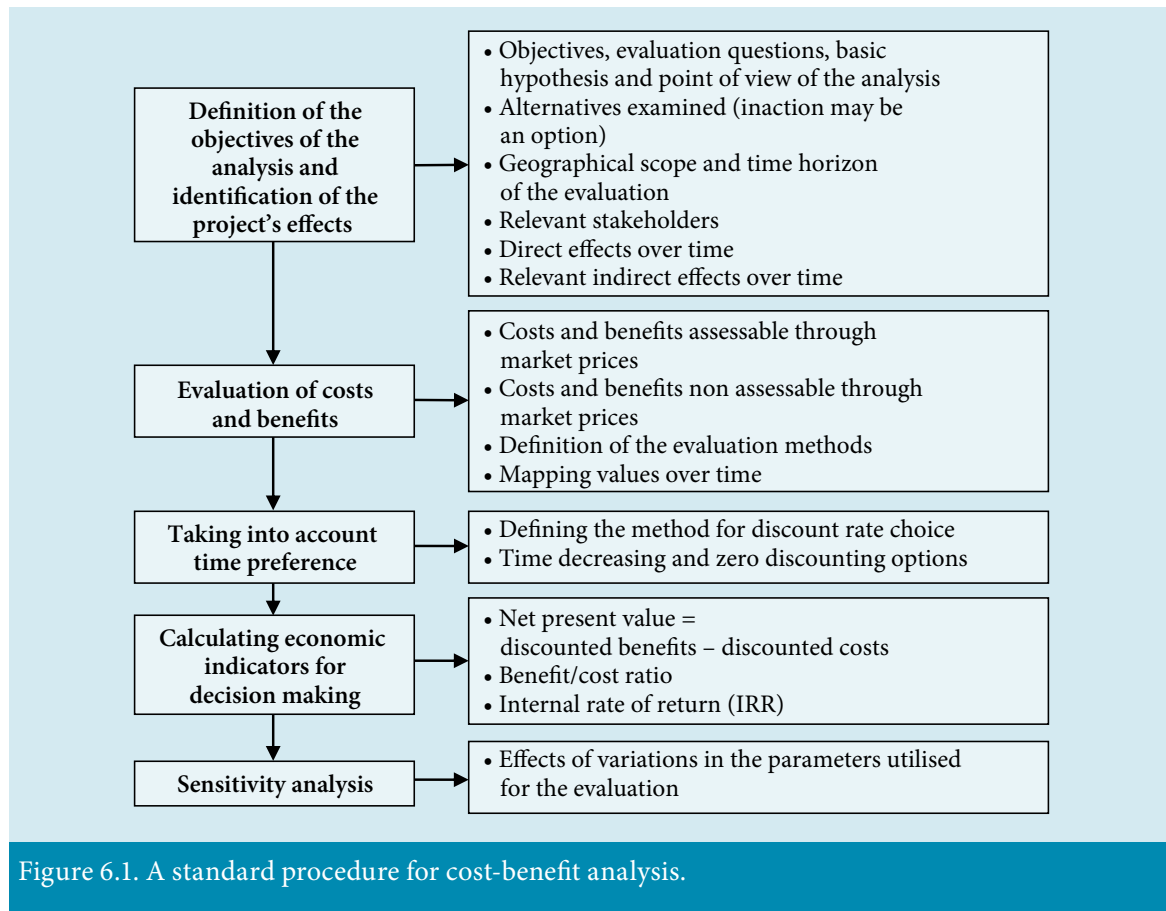
While CBA seems the most appropriate tool for the economic evaluation of the wide cross-sectoral outcomes targeted by the One Health approach, the monetisation of intangible goods and the notions of efficiency that underpins economic evaluations may be questionable or hard to interpret from a One Health perspective. For example, Garnett *et al.* (2015) offer an analysis on the relativeness and contradictions which may result from the application of the concept of efficiency in livestock production.

6.2.2 The cost-benefit analysis

6.2.2.1 The procedure of the cost-benefit analysis and its basic elements

Any economic evaluation requires a coherent procedure consisting in a logical progression of subsequent steps, which identify the objectives of the analysis, the examined alternatives, the effects or impacts in terms of resource use and outcomes obtained over time, the methods for the economic evaluation of the effects, and the indicators addressing the final choice.

Figure 6.1 summarises a CBA procedure. The first step of the process defines the essential hypothesis needed for the evaluation: the goals of the initiatives, the operational alternatives taken into consideration and the point of view of the analysis are necessary to formulate the economic evaluation questions, which detail the specific objectives of the assessment as well



as its scale and boundaries. An *ex-ante* evaluation aims to establish the best choice from a set of different alternatives for an initiative under consideration, while an *ex-post* evaluation investigates the results of an already implemented initiative to verify the hypothesis that justified the choice. In the case of an interim analysis, the *ex-post* evaluation of the part of the initiative that has been already implemented may help to correct the original hypotheses in the light of new data and objectives. CBA can be used in all these contexts: *ex-ante*, *ex-post*, and interim analyses.

The definition of the point of view, or perspective, of the evaluation is crucial, since a cost for one stakeholder may represent a benefit for another and this affects the classification of costs and benefits (Box 6.2A). In CBA, the evaluation perspective is, by definition, societal-welfarist (Section 6.2.1.2). As already seen (Section 6.2.1.1), the comparison between two or more alternatives for an intervention, or counterfactual (Box 6.2B) is a pre-requisite of economic evaluations, considering that also doing nothing may be one of the alternatives to be considered. In this case, the effects of inaction should be compared with the effect of a planned intervention.

Box 6.2. 'Perspectives' and 'counterfactual' in economic analyses.

A. Perspectives, multi-sector and multi-stakeholder analysis

The perspective of an economic evaluation determines whose costs and whose outcomes are included in the assessment. A societal perspective implies that all costs and outcomes should be included regardless of who sustains them. Another option is to adopt the perspective of the provider or funder of the intervention. In the context of health interventions, for example, evaluations often take the perspective of the health care system. Health care costs paid privately by patients, however, are usually considered, although a stricter funder perspective might not include them. A third approach acknowledges that a decision maker will have to deal with several concerns, apart from efficiency. It attempts to provide information that can reflect this variety of concerns which can be interpreted, prioritized, and given different weights reflecting context. This approach, known as decision maker perspective (Coast, 2004) is not rooted in welfare economics, although it can incorporate elements and methods of welfarist analysis (Drummond *et al.*, 2005). In the case of One Health initiatives, usually there will be several providers and/or funders involved, with different and often competing priorities. In addition, substantial costs or economic impacts of the intervention might fall on stakeholders in different economic sectors. In these cases, the allocation of costs and benefits across providers, funders, sectors, or subpopulations can be an important aspect of the economic evaluation. The 'separable costs-remaining benefits' method (Gittinger, 1985), for example, is a technique to allocate joint cost often used in the assessment of development projects that found application for the evaluation of One Health initiatives (Roth *et al.*, 2003). Such challenges are also encountered in the public health context (Claxton and Culyer, 2006). Although research in the area of multi-sector and multi-stakeholder economic evaluation remains scarce, this is a topic that attracts increasing attention (Remme *et al.*, 2014; Weatherly *et al.*, 2009). There is no one-size-fits-all recommendation on this issue. However, in the table below we provide some examples of how different authors have dealt with the issue of multiple perspectives.

Study	Topic	Perspectives adopted	Method proposed for allocation of costs and benefits
Roth <i>et al.</i> , 2003	Animal and human brucellosis	Private agricultural and public health sectors of animal and human brucellosis.	Application of the 'separable costs-remaining benefits' method: costs allocated in proportion to the savings for each sector derived from reduced incidence.
Schelling <i>et al.</i> , 2007	Joint human and animal vaccination	Health or agricultural ministries	In proportion to the number of personnel sent and rounds carried out respectively for human and animal vaccination. Outcomes of interest are hypothesized.
Remme <i>et al.</i> , 2014	Nutrition interventions	Public organisms in charge or addressing HIV and nutrition	Based on sector-specific assumed outcomes of interest, valued based on willingness to pay thresholds for interventions
Tiwari <i>et al.</i> , 1999	Irrigation intervention	Government officials, local communities	Use of participatory methodologies and multi-criteria decision analysis to determine outcomes of interest and costs

>>>

Box 6.2. Continued.

B. Counterfactual

The full economic evaluation of an initiative implies the comparison of its costs and outcomes with an alternative course of action. In the context of One Health, this alternative could be a non-integrated approach to the initiative or a situation with no intervention. In the example of Box 6.1A, the authors compare the integrated vaccination programme with the non-integrated approach because they have data on vaccination associated to both. In the example of Box 6.1D the cumulative costs of investment in public health through mass dog vaccination and PEP (the integrated approach) is compared with the non-integrated approach (only the PEP treatment). Both cases show the cost-effectiveness of the integrated approaches. Given the call for integration of disciplines and sectors in One Health, economic evaluations of One Health initiatives are generally likely to include a comparison with a non- or less integrated approach and thereby provide information on the economic efficiency of an integrative approach to health.

6.2.2.2 Identification of effects

The geographical scope and the time horizon of the evaluation are connected to the identification of the relevant effects or impacts of the initiative. The increasing awareness of the complexity of interactions between animal, human, and environmental health tends to expand the need to account for the spatial and time extent of One Health economic evaluations. In CBA, the definition of the geographical scope of the evaluation has also consequences on the point of view of the analysis, since an intervention may impact differently on the territories inhabited by different communities, for example when transboundary effects of pollution or disease spreading are concerned (Bond *et al.*, 2016; Otte *et al.*, 2004), while the time factor affects values and the evaluation of health and environmental effects through the operation of discounting.

For direct effects, we consider the consumption of resources directly related to the implementation of the intervention and the gains of the direct beneficiaries. Figure 6.2 describes the sectors potentially affected by an intervention in livestock farms to prevent the outbreak and spreading of zoonoses. In this case, the direct effects are represented by the costs for the intervention and the gains obtained by farms due to a reduction in livestock losses, improvements in animal welfare and productivity, savings on animal health expenditure and diminished health risks for farm workers. Indirect relevant effects are the benefits (and the possible costs) associated to population health, environmental health and biodiversity, food supply chain and related outcomes on national economy and the State budget, and the implications for the cultural values that the society may attribute to elements like: the environment, biodiversity, human and animal welfare, food traditions, etc. For each of the alternatives taken into consideration, it is necessary to identify the occurrence of the effects of the initiative and quantify their intensity.

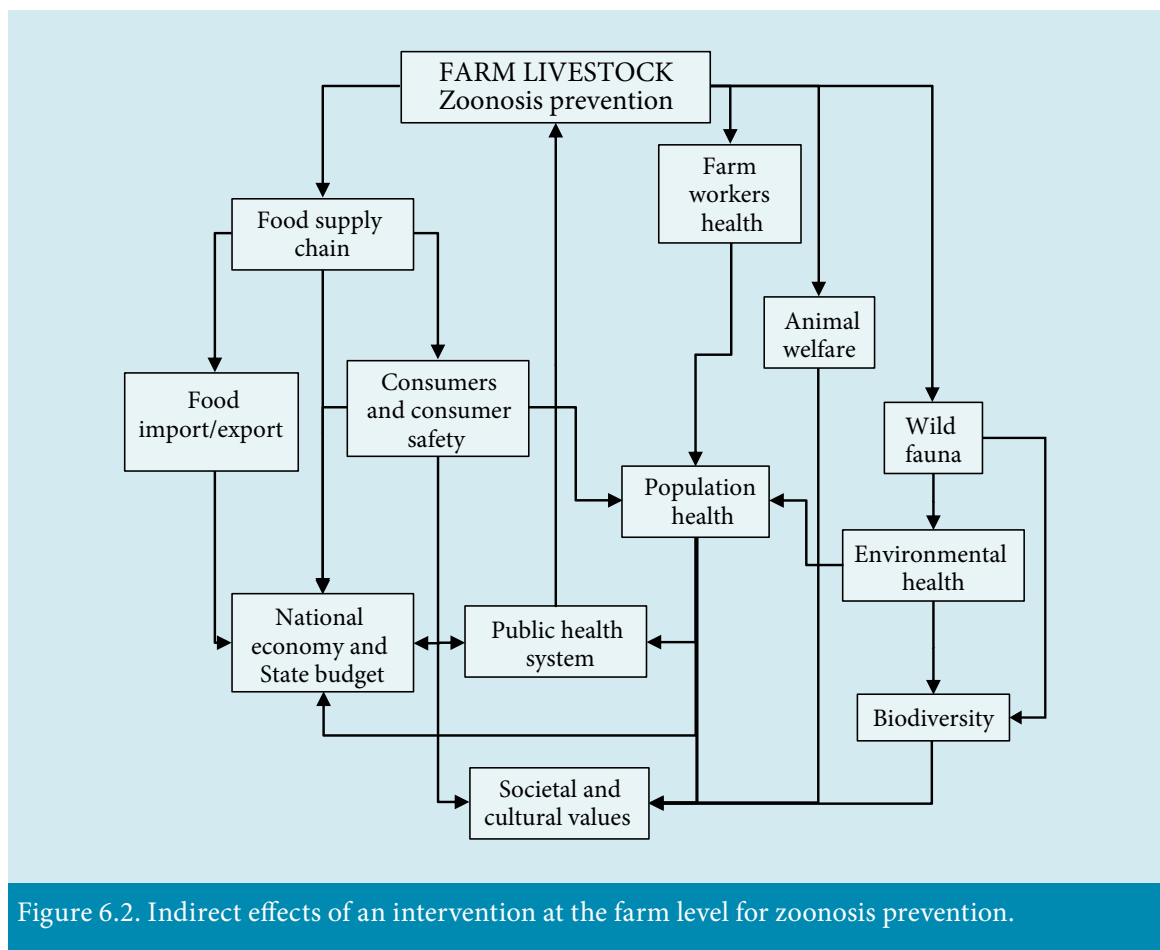


Figure 6.2. Indirect effects of an intervention at the farm level for zoonosis prevention.

The identification of effects is a crucial step of the evaluation of an intervention and often technical competences are more deeply involved in this process than economic expertise since the economic assessment is a subsequent step. Box 6.3 provides a brief picture of some problems to be faced in the identification and quantification of effects for economic evaluations.

Box 6.3. Identification and quantification of effects in economic evaluations.

A crucial issue when performing an economic evaluation is the identification and quantification of the effects resulting from the initiative analysed. In the comparative evaluation of health treatments, the highest standard in measuring the efficacy of the therapies is obtained by randomised controlled trials, but for the analysis of socio-economic impacts, as it may be needed in the evaluation of One Health initiatives, the design of this type of study is often impracticable. The methods that make use of non-experimental data are an alternative (Blundell and Costa Dias, 2005; Weatherly *et al.*, 2009). The propensity scores matching (PSM), for example, is a statistical technique which makes it possible to obtain unbiased estimates of the magnitude of the disease impacts (Heckman *et al.*, 1997; Ichimura and Taber, 2000). In PSM a treatment group is matched after propensity scores are estimated based on observable baseline characteristics to a control group with as similar as possible propensity score.

Applications of this technique in animal health economics can be found in Birol *et al.* (2010), who investigated the effect of market shocks caused by highly pathogenic avian influenza outbreaks on the livelihood of small producers of poultry in 4 African countries. To this end a PSM in which the treatment group (households suffering from a market shock) were matched with a control group (households which have not been affected by the market shock) based on the following matching variables: household demographics, assets, regional characteristics such as location, poverty status, number of income sources. The size effect was measured in terms of the average treatment effect of the treated group. An example of PSM application for socio-economic issues related to animal health in developed countries is in Rojo-Gimeno *et al.* (2016), who analysed the economic impact of reducing the use of antimicrobials through improved management practices in pig farms of Flanders.

6.2.2.3 Individual preferences, values, and willingness to pay

In CBA, the preferences of individuals are considered the only judgement of value. If one individual prefers the situation A to the situation B, it can be assumed that:

- his or her utility or welfare is higher in the situation A than in B;
- he or she values A more than B.

Any decrease in human welfare related to an initiative (e.g. the passage from the situation A to the situation B) implies a decrease of value or a cost, while any increase in human welfare represents a benefit. The preferences of one individual are measurable in terms of his willingness to pay (WTP) to obtain a benefit or to avoid a cost¹.

A further assumption relates to the fact that individual preferences can be aggregated: hence, the sum of all the individual benefits of an initiative corresponds to its social benefit and the sum of all the individual costs to the social cost. As seen in Section 6.2.1.2, an initiative is a

¹ For a reduction in welfare it is more appropriate to speak of willingness to accept (WTA) a given compensation for the cost suffered. Here we avoid the distinction between WTP and WTA since in most cases such a distinction is not relevant for the evaluation (Pearce *et al.*, 2006).

Pareto-efficient solution if, with respect to other possible solutions and to the status quo, it provides an increase of net social benefit and the gainers may compensate the losers.

The economic assessment of an initiative consists in a monetary evaluation of the WTP of all the concerned individuals to obtain the welfare increase and to avoid the welfare losses related to the effects of such initiative (Figure 6.3).

For the effects that correspond to the creation or consumption of goods and services traded in the market, also indicated as tangible effects in literature, the respective market prices are taken as indicators to appraise the WTP. For intangible effects, i.e. those related to the creation of non-tradable goods and services (e.g. a given health condition, a certain level of environmental quality, the beauty of a landscape, a cultural value, etc.), the WTP of individuals must be assessed through the analysis of the prices of other marketed goods and services that incorporate some aspects of the intangible goods examined or, alternatively, through surveys conducted on the population involved (Section 6.2.2.4). The use of the WTP concept in the economic evaluation of health interventions implies the attribution of

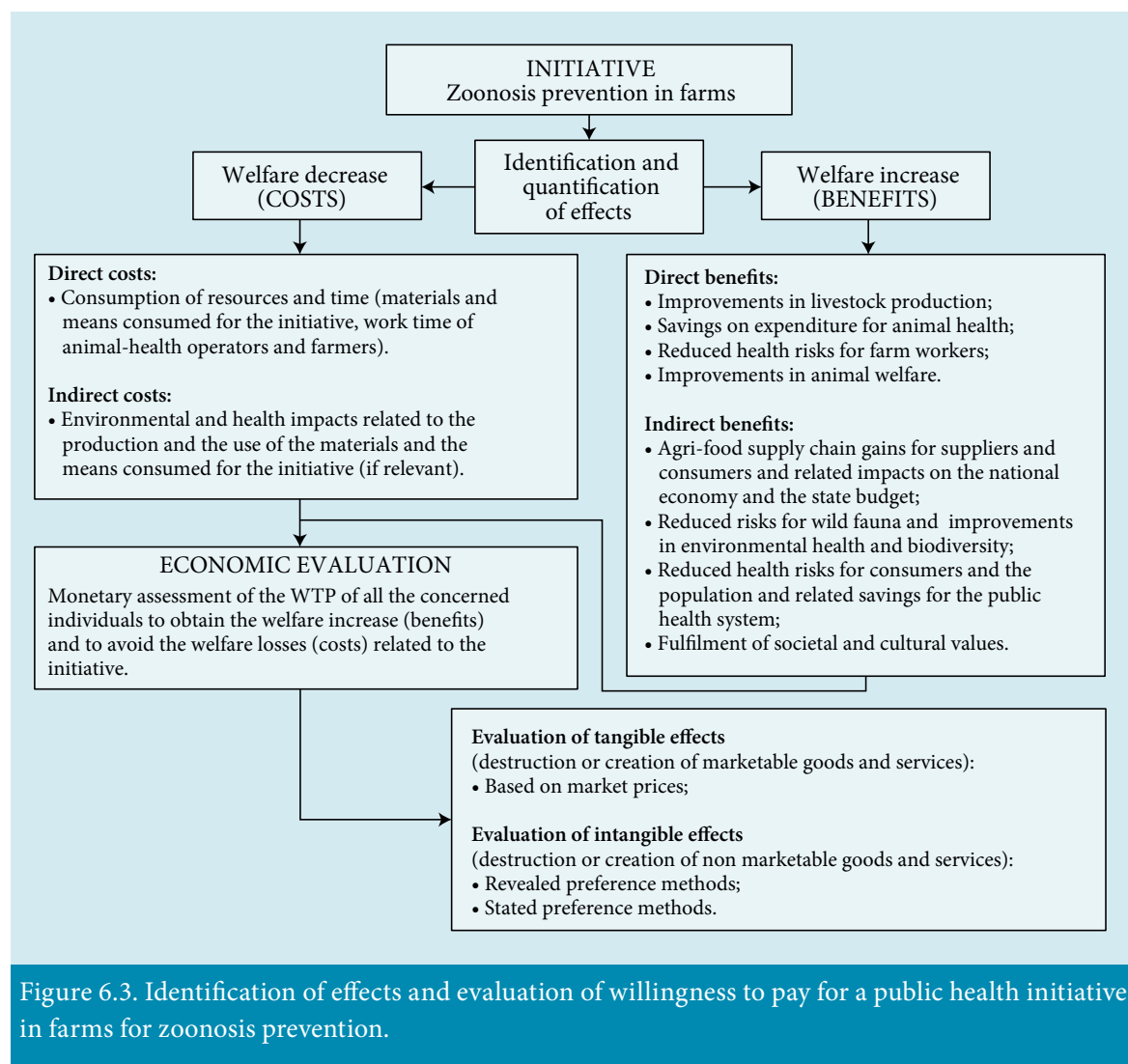


Figure 6.3. Identification of effects and evaluation of willingness to pay for a public health initiative in farms for zoonosis prevention.

monetary values to health states and lives of people, which rises important ethical concerns (Box 6.4).

The WTP is used to estimate the total economic value of environmental goods and services and this notion is also relevant in the One Health context, for example in evaluations related to environmental health, biodiversity, and animal welfare evaluations (Hansson and Lagerkvist, 2015, 2016; Laurila-Pant *et al.*, 2015; McInerney, 2004; Schreiner and Hess, 2017). The literature identifies the total economic value of a given environmental asset as formed by two types of values: use values and non-use values.

Use values are values related to the WTP of consumers for actual or possible uses of an environmental good or service. This includes option values, i.e. the possibility to avoid the actual consumption of an environmental good, to maintain the option of using it in the future.

Non-use values are related to the consumers' WTP to maintain the simple presence of an environmental good, independently on any possible use of it, actual or in the future. Existence values represent a common type of non-use values. Examples of existence values are those related to the consumers' WTP for maintenance of biodiversity, landscape beauties, wildlife, endangered species, ecosystems, animal welfare, etc., without any relation of a possible personal use of such goods. Other types of non-use values have been identified in the consumers' WTP to preserve environmental resources to the benefit (and use) of other

Box 6.4. Willingness to pay, prices, incomes, and monetization of health.

The use of the willingness to pay (WTP) concept to assign a monetary value to outcomes is consistent with the theoretical framework of welfare economics, which considers that every individual is the best judge of his own preferences and well-being. The amount of money that an individual is willing to pay to obtain something is then used to approximate how he or she values it. This would, in theory, be reflected by market prices in a perfectly competitive market. In practice, however, the outcomes of a One Health initiative are also non-marketed goods, so we do not have a market price to approximate their value. For example, we do not have market prices for quality of air or for health improvements of a collectively funded vaccination programme. In this case, we use other methods to estimate the hypothetical willingness to pay of individuals for these outcomes.

WTP of single individuals, however, depends on their income. In economic evaluations, theoretically, this implies acceptance of the status quo and of income inequalities among individuals (Jan, 1998; Johannesson, 1995), with the consequence of skewing allocation of resources towards the interventions that are most valued by the wealthiest part of the population. Other inconveniences of WTP monetization are related to the moral objections to the notion itself that life and health could be valued in monetary terms. Also for these reasons, cost-benefit analysis (CBA) evaluations are less commonly used in the context of human health than cost-effectiveness analysis and cost-utility analysis (Coast, 2004; Drummond *et al.*, 2005). Although similar concerns could be raised about placing a monetary value on the environment or on animal welfare (Ackerman and Heinzerling, 2005; Hansson, 2007; Heinzerling *et al.*, 2005), CBAs are far more widespread and accepted in this context (Pearce *et al.*, 2006).

people (altruistic values) or of future generations (bequest values) (McClelland *et al.*, 1992; Vázquez Rodríguez and León, 2004). There are authors who assume that the environment and other types of goods may have value by themselves, independently on consumers' WTP. In these cases, they speak of intrinsic values (e.g. Attfield, 1998; O'Neil, 1993).

6.2.2.4 Methods to estimate willingness to pay

According to mainstream economics, the value of a good corresponds to its equilibrium price in a perfectly competitive market, but such a condition is defined by a number of unrealistic assumptions (the supply or the demand of one single supplier or consumer is irrelevant with respect to the whole market demand and supply; the choices of one market operator do not influence market price and the choices of any other operator; all the operators are perfectly informed and act rationally and selfishly, with the only aim to maximize personal utility; products proposed by one supplier can be perfectly substituted by products proposed by any other supplier; etc.) that cannot be found in the real-world markets. Nonetheless, lacking perfect markets and better theoretical alternatives, in the current practice of economic evaluations, market prices are considered the main indicators to approximate the value of goods and services.

Further evaluation problems arise for the goods and the services that create utility to individuals without being the object of market transactions, the so-called 'externalities' (Section 6.3.2). To attribute monetary values to non-marketed goods, economists have developed specific methodologies, which are grouped under two main categories: the revealed preference methods and the stated preference methods.

Revealed preference methods

In the absence of market prices, the WTP can be approximated indirectly by analysing the consumer behaviour on surrogate markets. The basic principle is to make use of information from marketed goods and services to infer information on related non-marketed goods and services. These methods are commonly employed for the assessment of use values (Pearce *et al.*, 2006). The hedonic price method, for example, estimates the value of the environmental quality of residential areas by comparing the prices of buildings, under the hypothesis that consumers are willing to pay more for the properties located in the best areas (Brid Gleeson, 2007; Currie *et al.*, 2015; Portney, 1981). The travel cost method establishes the value of locations used for recreational purposes (parks, beaches, lakes, forests, wildlife, etc.) on the basis of the travel costs sustained by visitors to visit them, but it has also been used in the health sector to evaluate, for example, the benefits for impacted population of mobile health care units (Clarke, 1998) and of free distribution of vaccines (Jeuland *et al.*, 2010). Defensive expenditure and averting behaviour methods evaluate the environmental quality of an asset on the basis of the cost to be sustained to avoid the damage suffered from a diminution of such quality (Bresnahan and Dickie, 1995; Cullino, 1996; Nirmala, 2014): e.g. the value of an unpolluted lake is at least equal to the expenditure to be sustained to clean the lake from some type of pollution. Similarly, cost of illness and lost output methods evaluate the loss of environmental quality on the basis of the medical expenditure derived from related illness in humans (Freeman III *et al.*, 2014), or reduction in the output of livestock and crop production (Pearce *et al.*, 2006).

Stated preference methods

Stated preference methods identify the consumers' WTP for non-market goods and services by setting hypothetical markets for such goods. These methods can estimate both use and non-use values. Thanks to its wide adaptability, contingent valuation is the most used stated preference method: it consists of investigating the consumers' WTP for changes in the availability of non-market goods and services through a questionnaire-based survey (Carson, 2000; Halasa *et al.*, 2012; Klose, 1999; Venkatachalam, 2004). The conditions of the hypothetical market under analysis are described in the questionnaire submitted to the interviewees and should be realistically obtainable. The consumers' preferences should be expressed in monetary terms. Choice modelling is a group of stated preference methods based on surveys that allow to value multidimensional changes in environmental goods and services (Hanley *et al.*, 2002; Pearce *et al.*, 2006). They are particularly useful when the measure under analysis implies changes in different elements of an environmental asset and each variation needs a distinct valuation. Choice modelling can estimate marginal or unit changes in the elements affected by variations. Types of choice modelling are: choice experiments, in which respondents are asked to choose between two or more alternatives, including a status quo situation, under the assumption that the total utility provided by the environmental asset results from the utility of its constitutive elements subject to variations; contingent ranking, in which respondents indicate priorities among different alternatives characterised by a number of attributes at different levels; contingent rating, in which respondents rate the proposed alternatives on a numeric or semantic scale without making direct comparisons among them; paired comparison exercises, in which respondents indicate a priority between two alternatives by rating the level of their preference on a numeric or semantic scale (Hanley *et al.*, 2002).

The economic evaluations based on the assessment of revealed and stated preferences have their own pros and cons. A study of Dürr *et al.* (2008) compares results obtained from both types of techniques to estimate the WTP of the citizens of N'Djaména (Chad) for the antirabies vaccination of their dogs and the probability to have one dog vaccinated in function of the vaccination price charged to the owner. The aim is to set the price allowing the maintenance of dog vaccination rates at the WHO-recommended rate of 70%, which represents a public good whose cost of production has to be shared between the dog owners and the public health service.

6.2.2.5 Time preference and discounting

The evaluation of the effects allows mapping (for each alternative examined) of the values consumed and generated by the intervention over time, but a direct comparison among values occurring in different times is not possible. Individuals prefer to receive benefits immediately rather than delayed: for example, a gain of 1000 euros now is better than a gain of 1000 euros tomorrow or in one year. On the other hand, a delayed cost is preferred to a cost to be supported immediately. The comparison among values occurring in different times can be made only after the conversion of the identified costs and benefits to present values through the operation of discounting. Discounted costs and benefits make it possible to calculate the net present value (NPV) of each examined alternative, which is the first indicator provided by CBA to decision makers (Section 6.2.2.6).

The discounting of a future value is obtained as follows:

$$\frac{\text{Future value}}{(1 + r)^t} = \text{Present value}$$

Where, r is the discount rate applied and t is the time span between the present and the creation of value in the future: it can be observed that it corresponds to the reverse process of adding interest at the discount rate. As shown in Figure 6.4, such factors substantially influence the present value attributed to the costs and the benefits of an intervention. Thus, the choice of the discount rate is critical since it can significantly affect the amount of the NPV and the final decision on the feasibility of an intervention.

There are different approaches that may be adopted in CBA for the choice of the discount rate, also called 'social discount rate' (Kula, 2006; Zhuang *et al.*, 2007), for example:

- The social rate of time preference (SRTTP) assumes to compensate the diversion of resources from consumption caused by an investment in the public sector. The SRTTP is calculated by estimating a coefficient indicating the social time preference summed up to the expected growth rate of domestic consumption during the life cycle of the intervention.

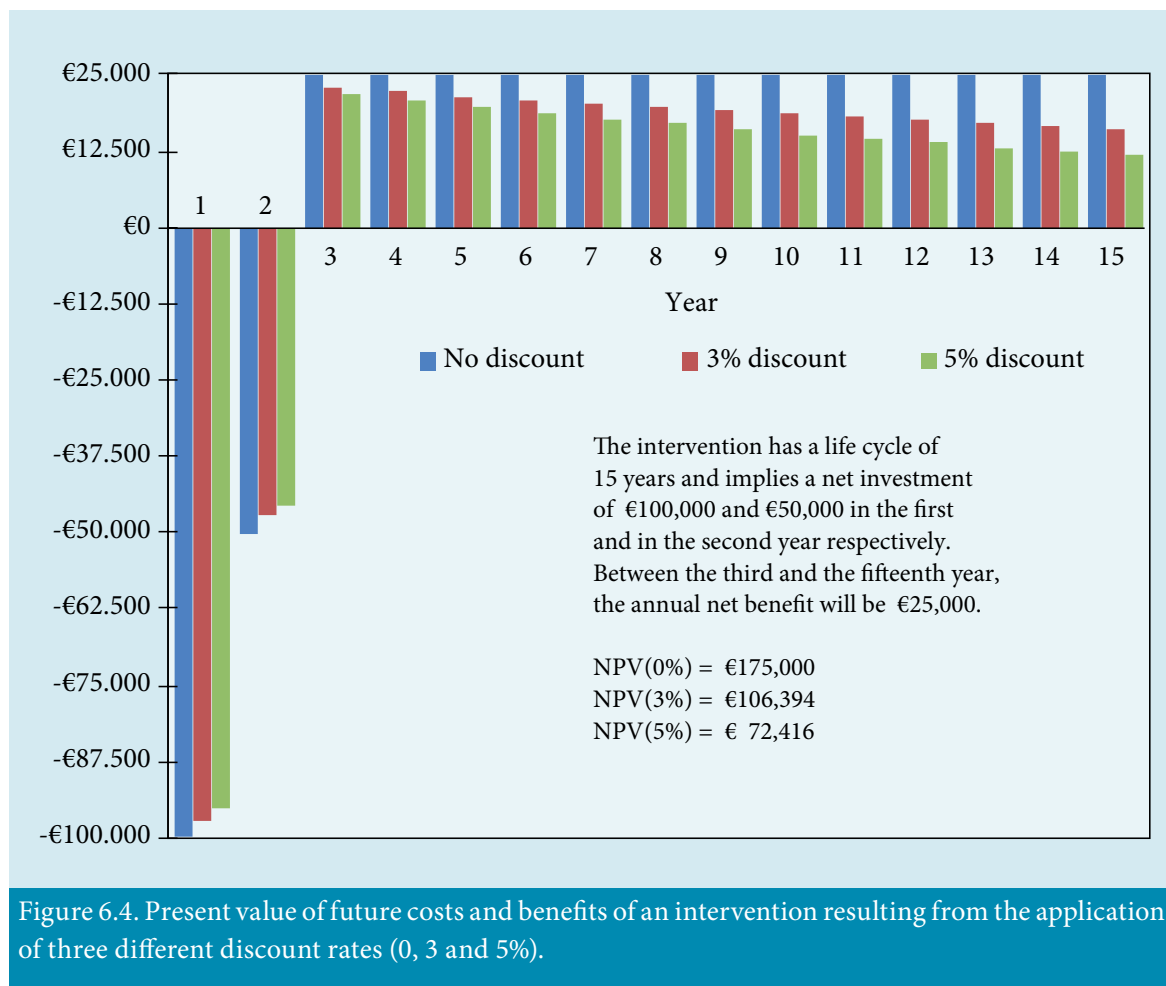


Figure 6.4. Present value of future costs and benefits of an intervention resulting from the application of three different discount rates (0, 3 and 5%).

- The social opportunity cost approach (SOC) assumes that an investment in the public sector implies reduction of resources available for private investments. Therefore, the social discount rate to be adopted should correspond, at least, to the return rate of private-sector projects that have an economic risk of the same order of the public-sector intervention under examination.
- The weighted average approach focuses on the possibility that investments for interventions of public interest may come from various sources including public, private, and foreign capitals. Thus, a weighted average between SRTP, SOC and the rate of the foreign borrowing is proposed, by considering the proportion of funding provided by the different sources.
- The shadow price of capital (SPC) approach assumes that resources for public investments are in part dislocated from direct consumption and in part from private investments. The latter are expected to generate an increased value of consumption in the future, which determines the SPC. This approach implies that one euro diverted from private investments reduces the discounted present value of a public intervention more than one euro diverted from direct consumption. Likewise, the gains from the intervention benefits flowing into private investments are valued more than the intervention benefits flowing into direct consumption (Boardman and Greenberg, 1998; Lyon, 1990).

Many government agencies indicate or suggest the social discount rate to be utilised in the economic evaluation of the initiatives of public interest. These rates vary significantly among countries and, for the same country, in the different years (Table 6.1). It can be observed that, in the recent years, there has been a general trend to decrease the social discount rates applicable for the economic evaluation of public interest projects and this has followed a progressive lowering of inflation and interest rates at the global level (Ferrero and Neri 2017; Holston *et al.*, 2017).

Discounting is a financial operation that raises ethical concerns when is introduced in the evaluation of interventions with effects on human health and the environment. Discounting social costs related to health or environmental damages occurring in the future implies that most of the burden due to their impact would be left to future generations. This phenomenon is called ‘tyranny of discounting’ (Figure 6.5) and does not comply with principles of sustainability and intergenerational equity. In order to avoid or reduce these inconveniences, many authors propose the use of time-declining rates or undiscounted values in the economic assessment of health and environmental impacts (Kula, 2006; Pearce *et al.*, 2006; Stern, 2008).

6.2.2.6 Indicators for decision making and sensitivity analysis

A positive NPV is the condition of feasibility for an intervention, according to Equation 1:

$$NPV = \sum Present\ value\ of\ benefits - \sum Present\ value\ of\ costs > 0 \quad (1)$$

The examined alternatives should be ranked by the respective NPV.

Another indicator for decision making is the benefit/cost ratio (BCR), which is subject to Equation 2:

Table 6.1. Social discount rates indicated by government agencies of selected countries (Zhuang *et al.*, 2007).

Country	Social discount rates	Approach for estimation ¹
Australia	1991: 8%; current: SOC rate annually reviewed	SOC
Canada	10%	SOC
China	8% for short and medium-term projects; lower than 8% rate for long-term projects	Weighted average
France	Real discount rate set since 1960; set at 8% in 1985 and 4% in 2005	1985: To keep a balance between public and private sector investment. 2005: SRTP approach
Germany	1999: 4% 2004: 3%	Based on federal refinancing rate, which over the late 1990s was 6% nominal; average gross domestic product deflator (2%) was subtracted giving 4% real
India	12%	SOC
Italy	5%	SRTP
New Zealand – Treasury	10% as a standard rate whenever there is no other agreed sector discount rate	SOC
Norway	1978: 7% 1998: 3.5%	Government borrowing rate in real terms
Pakistan	12%	SOC
Philippines	15%	SOC
Spain	6% for transport; 4% for water	SRTP
United Kingdom	1967: 8% 1969: 10% 1978: 5% 1989: 6% 2003: 3.5% Different rates lower than 3.5% for long-term projects over 30 years	SOC approach until early 1980s; thereafter SRTP

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Table 6.1. Continued.

Country	Social discount rates	Approach for estimation ¹
US – Office of Management and Budget	Before 1992: 10% after 1992: 7%	Mainly SOC approach with the rate being derived from pre-tax return to private sector investment. Other approaches (SPC, treasury borrowing rates) are also mentioned
US – Congressional Budget Office and General Accounting Office	Rate of marketable treasury debt with maturity comparable to project span	S RTP
US – Environmental Protection Agency	Intra-generational discounting: 2-3% subject to sensitivity analysis in the range of 2-3% and at 7%, as well as presentation of undiscounted cost and benefit streams. Intergenerational discounting: presentation of undiscounted cost and benefit streams subject to sensitivity analysis in the range of 0.5-3% and at 7%	S RTP

¹ SOC = social opportunity cost approach; SPC = shadow price of capital; S RTP = social rate of time preference.

$$B/C \text{ ratio} = \frac{\sum \text{Present value of benefits}}{\sum \text{Present value of costs}} > 1 \tag{2}$$

If two or more alternatives have the same NPV, the one with the highest BCR is the best choice since it implies the least investment.

The internal rate of return (IRR) corresponds to the discount rate that reduces to zero the NPV of an intervention. Then the IRR is the discount rate that resolves Equation 3:

$$\sum \text{Present value of benefits} - \sum \text{Present value of costs} = 0 \tag{3}$$

The examined alternatives should be ranked according to the higher IRR. With respect to the NPV and the BCR, the IRR has the advantage to avoid the choice of the discount rate, but other shortcomings strongly limit its utilisation, especially for ranking mutually exclusive interventions (HM Treasury, 2003; Kelleher and MacCormack, 2004; Pearce *et al.*, 2006; The World Bank, 2007): for example, the distribution of costs and benefits over time may result in multiple IRR or in illogical or misleading results (Kelleher and MacCormack, 2004; The World Bank, 2007). Figure 6.6 shows how the highest IRR may not result in the highest NPV. In general, the most accepted approach to the use of decision making indicators refers

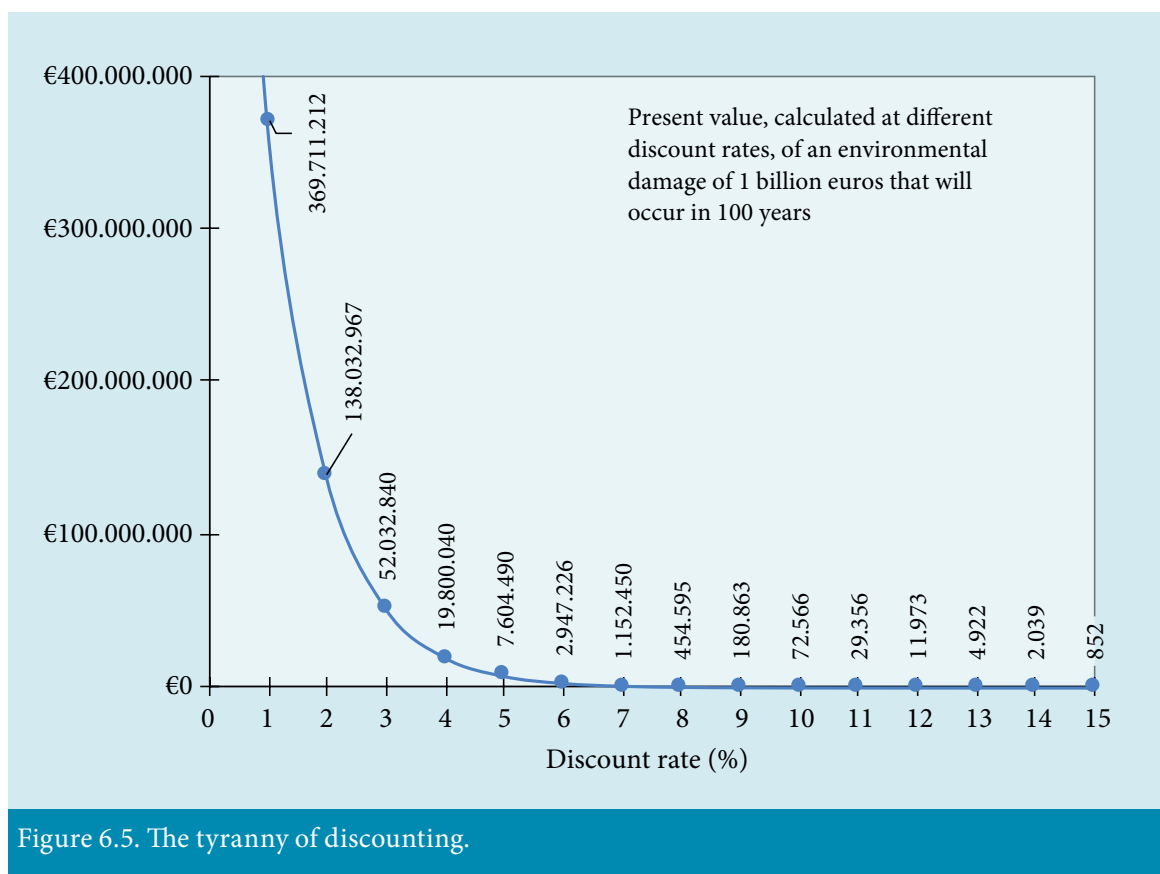


Figure 6.5. The tyranny of discounting.

to a positive NPV for the feasibility of an initiative and to the higher NPV for ranking the alternatives (Pearce *et al.*, 2006).

After the calculation of the NPV, the sensitivity analysis represents a test of reliability on the profitability of the intervention. It consists in changing the parameters previously used in the CBA (prices, currency exchange rates, materials used, production techniques, discount rate, etc.). The aim is to examine how these changes have an impact on the estimated values and therefore on the final indicators of the economic evaluation (Section 6.2.4).

6.2.3 Other economic evaluation methods in the health sector: cost-effectiveness and cost-utility analyses

6.2.3.1 Cost-effectiveness analysis

CEA evaluates the cost of the outcomes of an initiative expressed in natural units, along a one-dimensional scale, e.g. number of individuals treated, cases prevented or detected, deaths avoided, years of life gained, etc. Like in CBA, in CEA evaluations costs and outcomes should be compared to counterfactuals, which may correspond to alternative initiatives and/or a status-quo situation (no initiative). CEA is most used in health economics, but it finds also relevant application in studies that investigate environmental impacts and environmental policies (Görlach *et al.*, 2006) and in animal health evaluations (Babo Martins and Rushton, 2014).

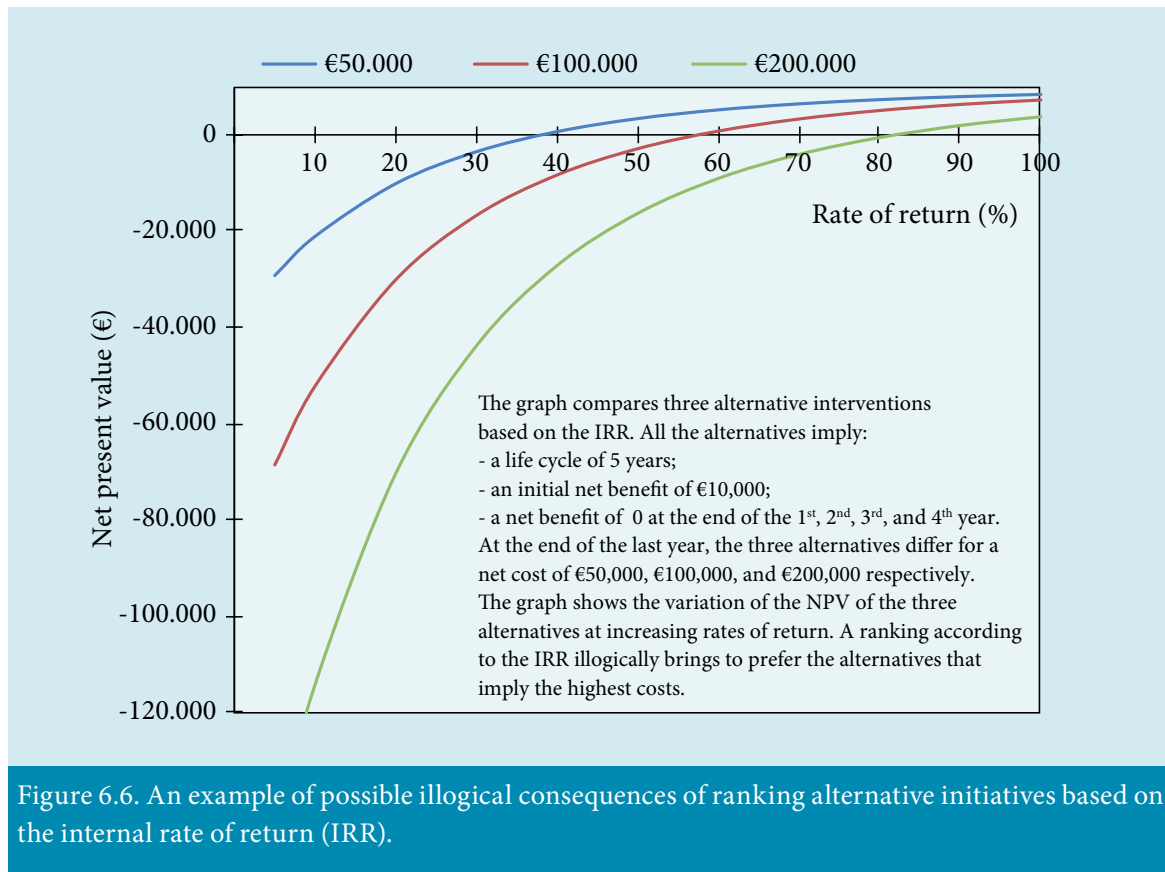


Figure 6.6. An example of possible illogical consequences of ranking alternative initiatives based on the internal rate of return (IRR).

CEA results are commonly presented in the form of incremental cost effectiveness ratio (ICER), which is the incremental cost per additional unit of outcome of the analysed initiative and indicates the efficiency with respect to the counterfactual. For example, if the outcome of an initiative is measured in terms of the number of immunized individuals, the corresponding ICER indicates the extra cost per additional individual immunized vis-à-vis the counterfactual scenario.

In CEAs of initiatives impacting on environment a variety of effectiveness indicators can be found: e.g. Berbel *et al.* (2011) made use of Mm³/year of underground water extracted as an outcome variable, and compared the cost per avoided Mm³/year of extraction, across a set of water management initiatives; Harrington *et al.* (1999) calculated the cost-effectiveness of Arizona's vehicle inspection and maintenance regulations based on the cost of vehicle control per reduced ton of pollutants (HC, CO, and NO_x); Wynn (2002) evaluated cost-effectiveness of biodiversity management in Scottish heather, wetlands, and herb-rich grasslands through indicators of habitat suitability of species and other indicators of biodiversity based on the portion of the total area covered by the different species. A wide review of CEA studies with the respective indicators of effectiveness utilized is presented in Babo Martins and Rushton (2014).

Table 6.2 shows the CEA of a hypothetical integrated *Escherichia coli* surveillance programme. The example is inspired by one of the studies mentioned in Box 6.1 (Elbasha *et al.*, 2000).

Table 6.2. Cost-effectiveness analysis of a hypothetical integrated *Escherichia coli* surveillance programme, figures are hypothetical.¹

Items	I_1	I_0	Incremental ($I_1 - I_0$)
Direct costs	€ 2,500,000	€ 2,000,000	€ 500,000
Indirect costs	€ 5,900,000	€ 6,000,000	-€ 100,000
Total costs (TC)	€ 8,400,000	€ 8,000,000	€ 400,000
Health effects (HE) = cases prevented	400	300	100
Incremental cost effectiveness ratio (ICER) = $(TC_1 - TC_0) / (HE_1 - HE_0)$			€ 4,000

¹ I_1 = integrated surveillance programme; I_0 = tracking reported cases, no integrated surveillance (counterfactual).

All the figures of the table are hypothetical. The introduction of an integrated surveillance system increases direct costs, which include personnel, set-up, and coordination among others. However, it reduces indirect costs, including health care costs associated to treating infected patients. The ICER represents the incremental cost per additional case of *E. coli* infection prevented.

The results of ICER calculation can be represented in a cartesian diagram called 'cost-effectiveness plan' (Figure 6.7), where the examined alternatives are identified as points of the plan and are confronted with the counterfactual, which is positioned at the origin of the axes. The horizontal axis indicates the increase (or decrease) in efficiency of the examined alternatives with respect to the counterfactual, whereas the vertical axis refers to the incremental cost of the alternatives per additional unit of the efficiency indicator.

The initiatives positioned in the fourth quadrant are more efficient and cheaper than the counterfactual, therefore they are Pareto superior: i.e. there is an absolute dominance of the alternative initiative with respect to the counterfactual. On the contrary, the initiatives positioned in the second quadrant are less efficient and costlier than the counterfactual, which is dominant in this case.

The alternatives positioned in the first quadrant (as in the case described by Table 6.2 and reported in Figure 6.7) are more efficient but also costlier. In this case, the initiative can be compared with one or more economic thresholds (e.g. budget constraints, opportunity cost for other projects, societal WTP for the initiative, etc.), which act as benchmarks to orient the decision-making process. In Figure 6.7, the hypothetical integrated surveillance programme (I_1) results more efficient and costlier than the counterfactual tracking of reported cases without integrated surveillance (I_0); but its position below the economic threshold indicates that it could be adopted. Finally, the third quadrant collects the initiatives that result less

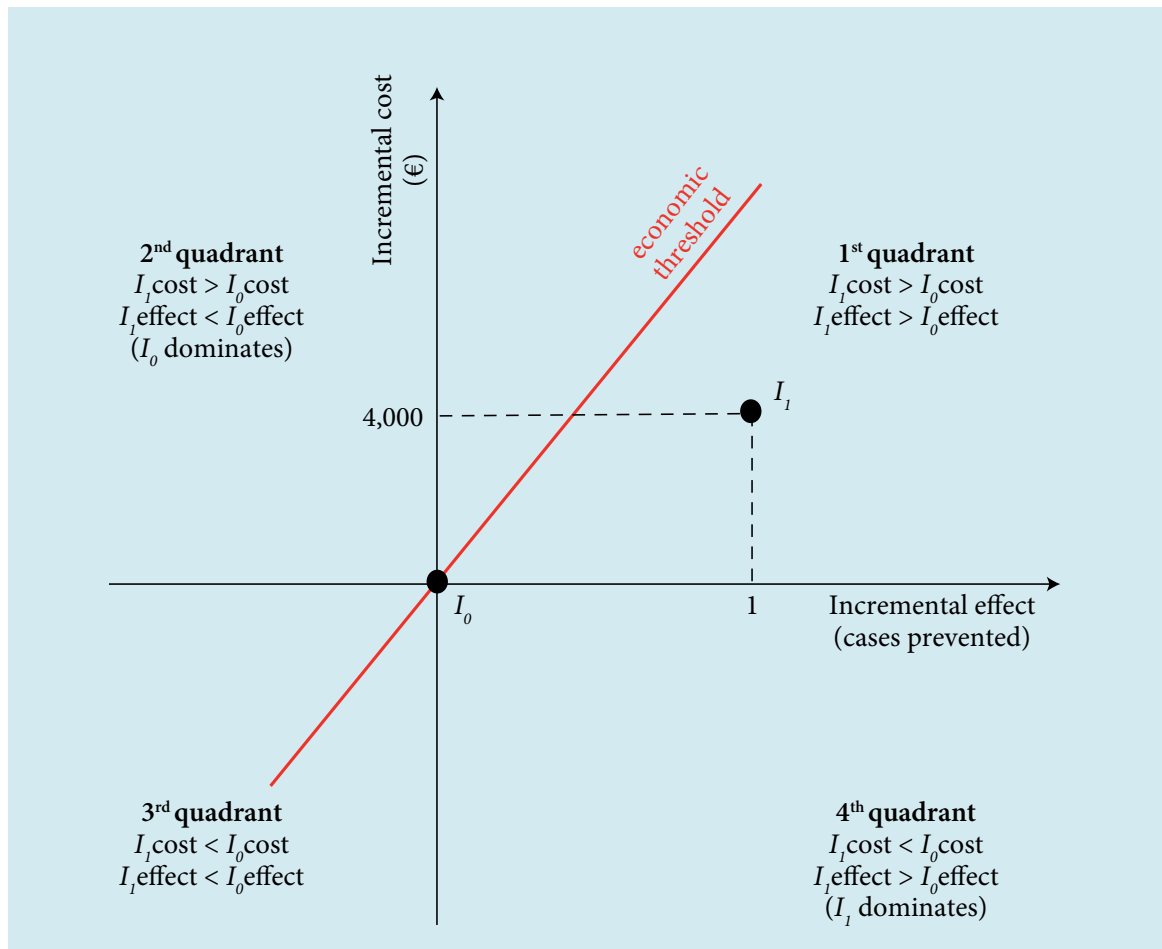


Figure 6.7. Cost-effectiveness plan of a hypothetical integrated *Escherichia coli* surveillance programme, figures are hypothetical.

I_1 = integrated surveillance programme; I_0 = tracking reported cases, no integrated surveillance (counterfactual).

efficient and less costly than the counterfactual. Also in this case, the setting of economic threshold can help decision making.

One of the advantages of CEA is that it is a relatively simple method. Outcome variables in natural units can be measured more accurately and involve fewer assumptions than the more complex approaches used in CBA (Section 6.2.2) or in CUA (Section 6.2.3.2). For this reason, results can be appreciated by a wider audience beyond health economists and managers. Terms such as ‘additional cost per case prevented’ or ‘additional cost per person treated’ can be easily understood by people not familiar with economic evaluations. However, this simplicity can be misleading and thus hinder the usefulness of CEA in informing decision-making.

An important limitation of CEA is the one-dimensional nature of the effectiveness indicator, which prevents a direct comparison of resource allocation among alternatives that cannot be referred to the same physical parameter of efficiency: e.g. to evaluate the opportunity of

financing a given health programme with respect to another programme that operates in a completely different field of health cares. Furthermore, it may occur that the indicator of efficiency chosen is imperfectly correlated with the real objective of the initiative (Diamond and Kaul, 2009; Garber and Phelps, 1997; Raftery, 1999; Weintraub and Cohen, 2009). For example, an intervention might be the most efficient at increasing the number of persons treated, but if the treatment is less targeted, it might not be efficient at reducing the incidence of the disease. It can also be difficult to compare across settings or populations: for example, we can find that a vaccination campaign costs £20 per case prevented in one region and £40 per case prevented in another more remote region. However, the population affected in the second area might have lower access to the health care services in general, so that the mortality and morbidity associated to each case might be higher. In that case, it could be preferable to fund the second intervention, which in a simplistic CEA would seem less efficient.

These limitations apply to CEA in general. In the context of One Health there are often several outcomes of interest, including environmental and health interventions. Unlike CBA, CEA cannot be used to integrate different types of outcomes into the analysis, since it does not provide a common metric. Multi-criteria approaches, however, can be used in combination with economic analysis tools to integrate multiple outcomes and take into account the preferences and trade-offs across these. For example, CEA can be used to inform multi-criteria decision analysis (Section 6.3.7).

6.2.3.2 Cost-utility analysis

Several health-related utility measures have been developed by economists to overcome the limitations of CEA. This approach describes the outcomes of a health initiative through generic indicators that map the multi-dimensional concept of health onto a one-dimensional cardinal index, which integrates both life expectancy and quality of life (Figure 6.8). Such indicators, which permit a higher comparability of outcome variables, have brought CEA to a relevant evolution by allowing, for example, the comparison of resource allocation between initiatives impacting on distinct areas of the health sector on the basis the cost of additional utility provided to patients or the whole society in terms of quality of life and lifetime gained.

The evaluations that make use of these generic metrics can be considered a specific type of CEA and are commonly indicated in the scientific literature as cost-utility analyses (CUAs) (Birch and Gafni, 1992; Drummond *et al.*, 2015; Garber and Phelps, 1997; Leung, 2016; Tengs, 2004): where the term 'utility' is derived from the von Neumann-Morgenstern's utility theorem (von Neumann and Morgenstern, 1953) and refers to the preference of single individuals or society for a given health state (Drummond *et al.*, 2015). The most commonly used CUA indicators, taken as measures of efficiency for the examined initiatives, include QALYs, DALYs and Healthy Year Equivalent (HYE), while the designation of Health Adjusted Life Years represents a general umbrella definition for such indices (Gold *et al.*, 2002). Evaluation results are presented in the form of the incremental cost per additional DALY, QALY, or HYE (as shown in Figure 6.8), also defined by some authors as incremental cost-utility ratio (Jakubiak-Lasocka and Jakubczyk, 2014).

The various indicators differ for methodology used to set the metrics and the underlying assumptions. Therefore, the most suitable index depends on the context and aims of the

evaluation. QALYs, for example, are based on large population surveys. DALYs, on the other hand, are based on expert judgement on the morbidity and loss in quality of life associated to different diseases. DALYs are therefore not appropriate for measuring relatively small changes in the health status of individuals but are easier and cheaper to obtain. These and other differences explain why global studies of burden of disease and evaluations in low and middle-income countries normally make use of DALYs. On the other hand, QALYs are more frequently used to assess health-care interventions in high income countries, although data availability and resources allocated to evaluation of health in low-and-middle income countries are improving (Bleichrodt, 1995; Devleeschauwer *et al.*, 2014a; Gold *et al.*, 2002; Murray and Acharya, 1997; Weinstein *et al.*, 2009).

The construction of these metrics involves many assumptions that may raise ethical and technical concerns, and theoretical and practical limitations can make the results harder to be interpreted than in CEA, and limit comparability across population groups and regions (Barker and Green, 1996; Devleeschauwer *et al.*, 2014a; Weyler and Gandjour, 2011). Furthermore, the use of health-related quality of life indicators does not avoid CUA being affected by some key shortcomings of the CEA approach. One relevant limitation, for instance, has been identified in the use of the ICER (also called incremental cost-utility ratio – in CUA) and of economic thresholds as parameters for decision making, since they do not assure the achievement of a

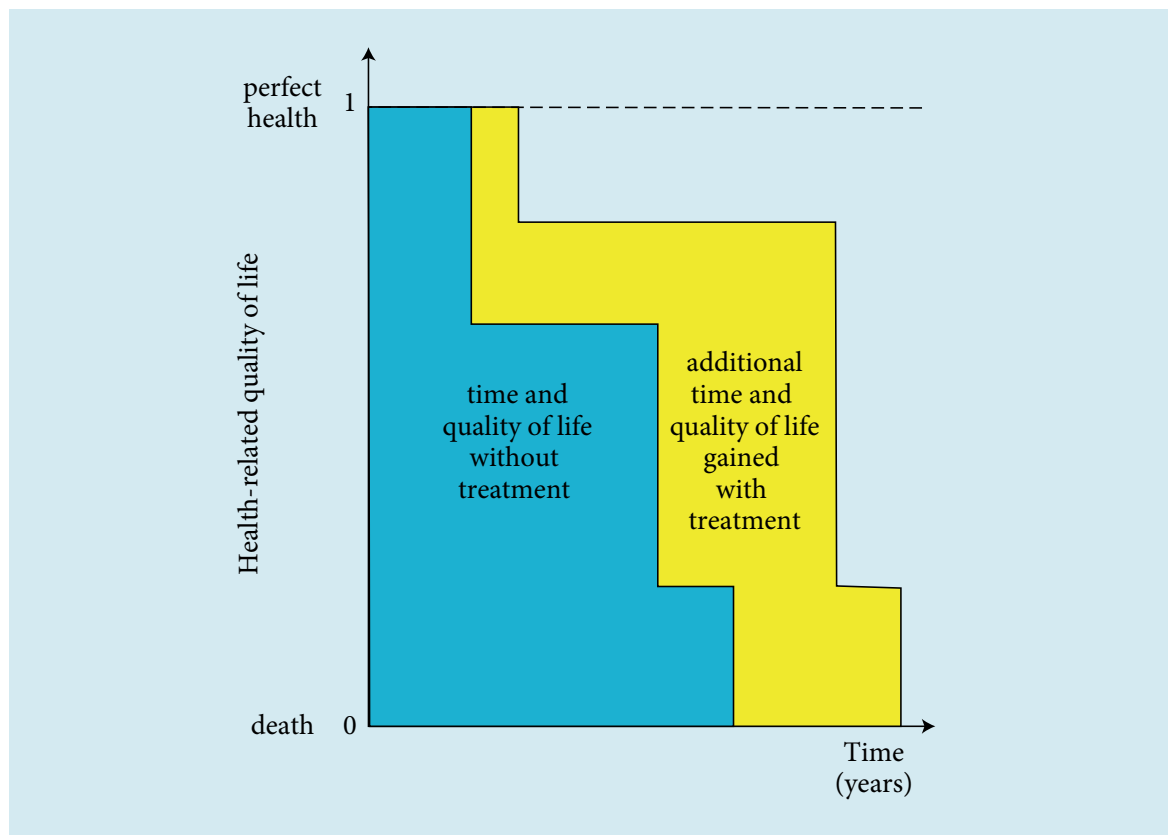


Figure 6.8. Perspectives of time and quality in the lives of patients receiving and not receiving treatment: the yellow area represents the incremental life quality and expectancy (QALYs) provided by the treatment.

societal optimum (Garber and Phelps 1997; Diamond and Kaul 2009; Weintraub and Cohen 2009). In the example of Figure 6.7, the solution I_1 results more effective, but also costlier than I_0 and is chosen because its incremental cost does not exceed the economic threshold. However, in the practice of health economic evaluations, the justifications for setting this kind of thresholds are in general weak and do not incorporate all the societal preferences needed to guarantee that the decision-making process issue an optimal solution (Nuijten and Dubois, 2011). For a discussions on the different CUA indices, see also: Bleichrodt (1995), Morrow and Bryant (1995), Anand and Hanson (1997), Murray and Acharya (1997), Dolan (2000), Gold *et al.* (2002), Mathers *et al.* (2003), and Devleeschauwer *et al.* (2014b).

DALYs, QALYs, and HYE are generic indicators of health-state preference adaptable to assess interventions in almost all areas of health-care, which has made of CUA the most utilized economic evaluation tool in this sector (Drummond *et al.*, 2015). Beyond the described health adjusted life years-type measures, also disease-specific indicators have been elaborated to evaluate the particular state preference settings in many pathologies (Bowling, 1995; Fayers *et al.*, 2002; Guyatt *et al.*, 1986; Kirkley and Griffin, 2003), but their application is limited to the comparison between interventions targeting the disease concerned.

CUA indicators of generic health-state preference are already widely used to capture the effects on human health of initiatives addressed to improve animal and/or environmental health, as in Roth *et al.* (2003), Hutton (2008), Zinsstag *et al.* (2009) and Babo Martins and Rushton (2014). Therefore, they may result very useful also for One Health evaluations, where they could also be integrated in broader frameworks with other decision-making tools, e.g. multicriteria analysis, and weighed against other relevant outcomes (Hitziger *et al.*, 2018).

On this perspective, animal loss equivalents have been also proposed (Shaw *et al.*, 2017). They are calculated as a ratio between the sum of the monetary values of animal losses (mortality, fertility, production, weight, etc.), plus the animal health expenditure incurred by livestock owners and public veterinary services, on the one side, divided by the gross domestic income per capita, on the other side. This procedure intends to give account of the livestock contribution to economy and of the timework needed by an average worker to create the value that could replace the animal loss. According to the authors, in a zoonosis assessments animal loss equivalents could be added to the DALYs derived from human health impacts to issue a combined metric indicated as zoonotic DALY.

6.2.3.3 Cost-consequence analysis

Cost-consequence analysis (CCA) consists of a systematic presentation of the outcomes considered relevant for the decision-making process of a given initiative. These studies do not indicate the most efficient solutions, but just show the significant information and leave independent choice to decision makers (Coast 2004; Jacklin *et al.*, 2003; Kaufman and Watkins, 1996; Kaufman *et al.*, 1997). Although less popular than CEA, CUA, and CBA in disciplinary assessments, the flexibility of this approach can offer some advantages in the complex and multidisciplinary framework of the evaluation of One Health initiatives. Costs and outcomes can be calculated with respect to a counterfactual or can be merely a description of the current situation, resulting in partial evaluations (Section 6.2.1.1). CCA

does not necessarily imply an efficiency assessment, and can incorporate different types of information, including qualitative.

This method is not rooted in the welfarist theory, which is seen as a strong limitation by some authors (Birch and Gafni, 2004; Claxton, 2005; Wilkinson, 1999), who point out that there is a risk of producing ad hoc analyses lacking theoretical background. Other authors argue that this methodology has the advantage of relative simplicity and transparency and recognizes the decision maker's role in weighting and prioritizing different outcomes (Coast, 2004). Table 6.3 provides a hypothetical example of a CCA of an *E. coli* integrated surveillance system. This integrates a range of costs and outcomes deemed relevant, highlighting who incurs specific costs. The decision maker then has an explicit role in establishing preferences across these outcomes and weighing them against each other, relying on either formal or informal decision-making processes (including multicriteria decision analysis; MCDA). Another example is in Mindekem *et al.* (2017), who compare cumulative costs of conventional and One Health approaches in initiatives against rabies in N'Djamena, Chad.

6.2.4 Uncertainty, sensitivity analysis and reporting results

Economic evaluations always imply many assumptions regarding correctness and relevance of both the data and methodologies utilised, which is cause of uncertainty about the results. The main types of uncertainty relate to the data requirements of the study, the extrapolation to outcomes beyond the primary data sources (e.g. it is assumed that CO₂ emission reduction has effects on global warming), generalisability of outcomes from a specific context to other contexts, and soundness of methodologies used (e.g. is it correct to discount future values related to human health or environmental states?) (Briggs, 1995, 2001). A common practice

Table 6.3. Cost-consequence analysis of a hypothetical integrated surveillance programme for *Escherichia coli*. All figures are hypothetical. For a published example of an *E. coli* integrated surveillance programme evaluation see Elbasha *et al.* (2000).

Outcomes	Current practice	Integrated surveillance
Human morbidity	200 cases/year	100 cases/year
Costs to small farmers	20 €/head of cattle; total € 500,000	40 €/head of cattle; total € 1,000,000
Other costs of surveillance	€ 1,000,000	€ 2,500,000
Costs to health-care sector	€ 6,000,000	€ 5,900,000
Involvement of farmers in surveillance mechanism	Farmer report low trust and engagement with surveillance mechanisms	Increased trust on health regulators and institutions. Increased engagement with surveillance

in economic evaluation is to analyse the impact of these uncertainties on the outcomes of the initiative by using sensitivity analysis. There are two main approaches to sensitivity analysis: deterministic and probabilistic.

In a deterministic sensitivity analysis, the examined parameters are changed by a certain value (e.g. assume intervention is effective in 75% of cases instead of 80%). These can be done for one parameter at a time (univariate) or for multiple parameters combined (multivariate). One-way deterministic analysis is easy to perform and to understand but has the limitation that it cannot provide information on the level of uncertainty and on which parameters the uncertainty depends for the most. Multivariate deterministic analysis brings only partial solutions to these problems since just two-ways analyses can be easily conducted and represented (although they are difficult to be interpreted when the two parameters examined are interdependent). With more than two variables this exercise becomes cumbersome to be executed and increasingly difficult to be illustrated and interpreted (Drummond *et al.*, 2015; Taylor, 2009; Walker and Fox-Rushby, 2001).

Scenario analysis is a type of multivariate analysis where multiple parameters are simultaneously set at values that are considered relevant for the investigation: e.g. in the best/worst case analysis the examined parameters are set at the levels respectively considered the most advantageous and the most disadvantageous with the aim of observing the sensitivity of the outcome under extreme circumstances. However, in general, the probability that the best or the worst combination of variables take place is very scarce, therefore even if the outcome results sensitive to the extreme combinations, this does not provide a useful information about the level of uncertainty of the evaluation (Drummond *et al.*, 2015; Walker and Fox-Rushby, 2001).

Probabilistic sensitivity analysis may overcome some of these shortcomings. In this type of exercise, a computer software attributes a probabilistic distribution to the examined parameters and estimates the model outcome a great number of times (e.g. between 1000 and 10,000) by picking sample values at random from the distribution of each parameter. The results of such iterations are graphically visualised to assess the impact of the parameter variability on the outcome (Baio and Dawid, 2008; Briggs, 2001; Drummond *et al.*, 2015; Edlin *et al.*, 2015; Taylor, 2009).

For example, if two alternative solutions are compared in a CEA or CUA, the findings can be presented as points of a scatter plot in a cost-effectiveness plane (Section 6.2.3.1), which allows to observe the possible variability of the outcome with respect to the positions of the plane's cartesian quadrants and the economic threshold. Figure 6.9 shows an example where the probability that the examined alternative results cost-effective (I_0 is the counterfactual) is represented by the points of the scatter located below the economic threshold (the yellow point represents the ICER). With more than two alternatives to be examined, a comparison with a scatter plot is not practicable. In these cases, evaluators make use of cost-effectiveness acceptability curves, which show the probability that each alternative is cost-effective by varying the economic threshold (Baio and Dawid, 2008; Drummond *et al.*, 2015; Edlin *et al.*, 2015).

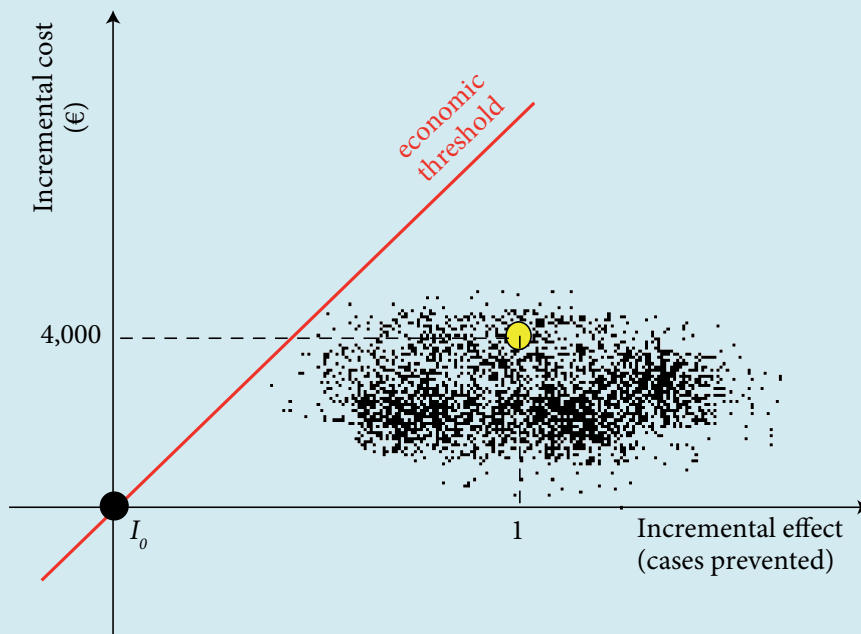


Figure 6.9. Results of a probabilistic sensitivity analysis of a hypothetical integrated surveillance programme for *Escherichia coli*. All figures are hypothetical. For a published example of an *E. coli* integrated surveillance programme evaluation see Elbasha *et al.* (2000).

6.2.5 Limitations and challenges for the use of economic evaluation techniques in the context of One Health

CEA, CUA and CBA offer a structured yet relatively flexible framework for economic evaluations. Additionally, there is a large body of theoretical and applied research on within these methodologies, in the fields of human, animal, and environmental health economics, which provides a solid base for their use to evaluate One Health initiatives. Nevertheless, many of the core assumptions of mainstream economic evaluation methods can be problematic in the context of One Health.

The framework for economic evaluation is mathematically formalised, designed to deal with quantitative information, and ill-equipped to incorporate qualitative information. Relevant outcomes of One Health evaluations include environmental attributes or elements of process, such as community engagement and trust, or knowledge, which are difficult to quantify. In addition, according to the *ceteris paribus* assumption, central to economic evaluations, all factors other than those directly considered as the variables for efficiency assessment (i.e. effects, costs, and benefits) are taken as fixed. In particular, the institutional framework is assumed to be unchanged by the initiative or during the course of it, as are the societal and individual preferences and cultural norms.

This type of assumption can be a reasonable simplification of reality in many cases. One Health initiatives, however, often consist precisely of institutional changes, encouraging cooperation,

for example, between health systems and institutions concerned about biodiversity, animal health or land use, or with actors along the food supply chain. In Box 6.1B, for example, the setup of an integrated surveillance system for *E. coli* involves the collaboration between meat producers and health care providers. Increased collaboration between local institutions, communities and national government actors is also often a fundamental aspect of the initiative, leading to important changes in preferences, knowledge, and attitudes. In the case of vaccination of nomadic communities (Box 6.1A), researchers acknowledge the relevance of increased trust of nomad communities on the health care system as an outcome of the initiative, and comment on it, but do not include these process measures explicitly in the evaluation framework, which is restricted to quantitative information. Narrod *et al.* (2012) propose addressing the issue in a more formalised way, carrying out a KAP (knowledge, attitudes, and perceptions) assessment after the economic evaluation, to determine the factors that can affect the uptake of desirable, efficient One Health initiatives. This is one alternative, but we might also consider the possibility that these factors should determine what we consider to be a desirable initiative and should be incorporated into the evaluation itself. A cost-consequence framework could be appropriate for this type of analysis.

The question of how to interpret efficiency in One Health is a cross cutting issue which emerges from considering the previous limitations concerning multi-dimensional outcomes, the relevance of processes, the centrality of changes in population needs and institutional framework, the possibility of inter-generational and irreversible impacts, and the existence of various stakeholders representing potentially conflicting interests. Although efficiency is certainly an important criterion for evaluation, it should also be considered that this term has been trapped in the sustainability debate and is currently used with different and often contrasting meanings by scientists depending on their disciplinary and ideological backgrounds and aims (Garnett *et al.*, 2015). Hence, the use of efficiency as a general guiding principle in One Health evaluations should be carefully appraised. This does not mean to reduce the relevance of economic evaluation for this type of initiatives. Rather, it calls for a broader interpretation of the concepts and practices of economic evaluations and for conscious methodological choices to be undertaken case by case. Rather than considering different tools mutually exclusive, evaluations can gain explicative potential by using different methods complementarily, while being aware of the differing assumptions that might be implicit.

6.3 Dealing with complexity

6.3.1 Introduction

The aim of this section is to provide an overview on the main analytical tools that may allow economists to deal with complexity to investigate the relationships and interactions working among the economic, the environmental and social dimensions of One Health initiatives in the perspective of their evaluation.

Qualitative and multidimensional evaluation methods can provide a powerful tool for dealing with complexity, complementing quantitative information to provide a holistic assessment. Several authors (Jan, 1998; Ostrom, 2008) have argued for an increased use of

mixed quantitative and qualitative methods for the evaluation of health and environmental interventions from an institutionalist perspective. In economics, the institutionalist school of thought places a strong emphasis on complexity, context, and non-linear causation (Menard and Shirley, 2005; Rutherford, 2001). Nevertheless, qualitative approaches remain infrequent in the economic evaluation literature and even when mixed (quantitative and qualitative) methods for evaluation are used, these are often not explicitly identified as such. The study indicated in Box 6.1A (Schelling *et al.*, 2007) could be considered an example of mixed evaluation, combining quantitative information of certain aspects of the evaluation (cost per women or child immunized in the nomadic communities), while relying on qualitative information for other aspects of the assessment, structured in a narrative form: e.g. improved reliance of local populations towards livestock and human vaccination programmes and public health services; contribution of population surveys to identify health services organisational failures causing disease outbreaks; enhanced collaboration between public health services and private veterinary services, etc.

Such considerations imply that economic evaluations understand the effects of One Health initiatives in their whole complexity. Some characteristics of One Health complexity that are relevant for economic evaluation have been already outlined (the non-linearity of the relationships occurring in health systems and the existence of feedbacks and loops, the large array of outcomes across sectors and their critical time-value profile, and the emerging properties of the context where the One Health initiatives are implemented), as well as the aspects that economics, and especially the mainstream marginalist approach, may disregard, mainly because of conceptual and methodological limits. In few words, the traditional economic approach, often resulting in formally impeccable models of the real world, may fail to grasp exactly what we need to know about the effects of One Health initiatives. On the other side, economics has however undergone a conceptual and methodological evolution, also allowing for a better consideration of complex situations.

Before entering the core of this section, we retrace the ways economists look at the complexity of the real world and how economics has evolved to overcome, in part, its own limits. This is an unusual exercise: complexity as such has been rarely a main concern of the economic thinking, which prefers simplifications and reduces the reality to basic patterns to focus on specific analytical issues. In the following pages we provide a brief insight about some aspects of such evolution that may help to understand the limits and the possibilities of the economics to capture the complexity of One Health.

6.3.2 Economists and the complexity of the real world

Few milestones of economic reasoning and methodologies may well represent the way economists, and especially the neoclassic school, look at the understanding of economic phenomena: according to some postulates (e.g. scarcity of resources, and hedonism, rationality, and perfect information of economic agents) the analysis on consumers' and producers' behaviour is based on the so-called methodological individualism (Box 6.5). The relevant economic interaction between economic agents (i.e. producers and consumers) is the market, where the value of goods, identified with their price, is established by trading.

Box 6.5. Economic analysis and methodological individualism.

Economic analysis is mainly based on methodological individualism, an approach that explains social phenomena as the result of individual actions (Arrow, 1994). In economics, the methodology consists in setting elementary units such as the consumer or the producer and considering each of them as isolated from any other individual. This method is at the core of the analysis of producers' and consumers' choices and market dynamics. One of most known representation of this approach is the 'homo economicus', a virtual individual who reflects and conforms to all the fundamental hypothesis determining the behaviour of economic agents and is assumed to act perfectly rationally in order maximize an individual function of hedonistic benefit.

The equilibria of the economic agents are mathematically identified through the marginal analysis, which allows an optimal allocation of scarce resources to maximize an individual index (i.e. profit maximization for a producer or utility for consumer) according to specific functions representing the state of the nature (e.g. a production function or a cost function for the producer; a utility function for the consumer). Optimization is identified by the confrontation of incremental ratios: for a producer, for example, the equality between incremental (say marginal) cost and incremental (marginal) revenues.

The individual choices of economic agents about the use of resources are supposed to aim, hedonistically, at the maximization of individual benefits.

A consumer maximizes his benefit when he or she obtains with the available resources the maximum of utility, or satisfaction, from the consumption of goods and services. Thus, his/her purchases are driven by the ratio between the satisfaction attainable from the consumption of goods and services and the respective prices, under the income constraints. A producer, on the other side, aims to maximize profit as difference between the revenues from selling products and the cost of production. His/her choices are driven by the ratio between the productivity of inputs, their prices, and the selling price of products.

In a perfect market, where all consumers and producers are perfectly informed, and act rationally as described, and without influencing each other, the competitive behaviour of agents brings the price of the traded good to an equilibrium. At the equilibrium price all the supply of the good is sold, all the demand is satisfied, and all the agents obtain the maximum of benefit achievable. This corresponds to a Paretian optimum, i.e. the best possible solution that grants the optimal use of available resources, through individual choices of all the economic agents acting freely and selfishly. This marginalist interpretation of the Adam Smith's Invisible Hand concept is mainly due to Alfred Marshall (1890) and the so-called neoclassical school of economics, whose methods and approaches to economics have become largely prevailing in the academia worldwide.

Before Marshall, the marginalist economist Léon Walras (1874) had tried a mathematical formalisation of a general equilibrium theory. Since all sectors of the economy are interrelated and all goods and services can be somewhat subrogated by other goods and services, a price adjustment taking place for any reason (e.g. a bad harvest, a plant or animal disease outbreak,

etc.) in the market of a given good also affects the market prices of all the other traded goods. This means that the condition of equilibrium may be defined only simultaneously in all the markets of all the traded goods and makes a practical application of the Walras' theory unlikely. To overcome this problem, Marshall introduced the *ceteris paribus* assumption allowing the analysis of one market by considering only its relevant variables under the hypothesis that all the other possible variables remain unchanged.

Few considerations about the way the marginalist-neoclassical approach looks at complexity emerge from the picture above:

- The mutual relationships among individuals are reduced to the market mechanisms that also regulate, through simple adjustments in the demand and supply functions, the transmission of economic effects across the different markets and industries.
- The concept of market equilibrium and the optimisation goals limit the analysis to a deterministic approach, which eliminates the possibility to consider evolutionary adaptation.
- The *ceteris paribus* assumption, largely adopted at any level of the theoretical and empirical analysis, results in the elimination of a series of variables determining the complexity, namely: the context (thrown out from the field of economic analysis by definition), the institutional framework and its evolution and the existence of feedbacks among actors.
- The social dimension of the analysis is reduced to a linear aggregation of individual behaviours (microeconomic equilibria) generating a macroeconomic equilibrium that involves the whole economy.

Such simplifications stem from the definition of the scientific field of economics and the analytical methods developed by marginalism. Reasoning in term of complexity, this approach could be considered a step back from the former political economy of the classical economists (Screpanti and Zamagni, 2005), but further conceptual developments occurred during the 20th century that improved the degree of complexity of the economic analysis.

A few pillars of this evolution should be mentioned because of their relevance in relation to the objective of this section, namely:

- The theories of welfare economics admitted the possibility that the market may not succeed in the optimal allocation of resources and opened to the idea that a greater social and economic welfare can be reached by correcting market failures through adequate incentives provided by the state (Pigou, 1920).
- The concept of externality, a particular case of market failure (Arrow, 1970; Pigou, 1920) showed that other mechanisms beside market can transmit the value of tangible and intangible goods across sectors, economic system and the whole society (e.g. environmental models, epidemiological models, social behaviour models are exemplification of alternative ways of transmitting values -usually not coinciding with market prices- which fit with the need to analyse complexity of effects occurring in the One Health context).

- The institutionalism and related schools of thought (Hodgson, 2000; Menard and Shirley, 2005; Rutherford, 2001) focused their attention on the economic nature and role of the institutions (i.e. any kind of rule governing the behaviour of the economic agents in a mutual evolving relationship), enlarging the traditional analysis to understand the effects of the *context* on the behaviour of the economic agents.
- The application of the game theory to economic analysis has revealed the dynamic nature of the economic equilibrium as the result of mutual strategic behaviours of economic agents (Nash, 1951), while the role of information in economic relationships and the removal of the rationality assumption funded the evolutionary approach in economics (Krugman, 1996).
- As in many other disciplines, several essays were made to re-build the economic analysis according to the fundamentals of the system thinking. This means to investigate the intrinsic complexity of economic phenomena through a system approach, which has been applied in different areas, from the level of the business units (Thompson and Valentinov, 2017), to the meso- and macroeconomic levels (Dopfer *et al.*, 2004), as well as in the teaching of economics (Colander, 2000; Moscardini *et al.*, 1999; Wheat, 2007). Thanks to this trend, rooted economic models have been reshaped according to system analysis, and new models created according to a system vision (Foster, 2005; Radzicki, 1990, 2009).

Many other developments would deserve attention to understand the conceptual complexity of the current economic analysis. In general, the strict assumptions of the marginalist-neoclassical approach have been revised and criticised along the last century, adding shades, or weakening the traditional foundations of economists' reasoning.

Though simplified and incomplete, the picture outlined above shows that economics evolved to deal with complexity. Reductionism of original economic models have different reasons and undeniable empirical convenience and the neoclassical approach remains at the core of the current economic evaluation tools, with its set of concepts, methods, and criteria (e.g. individual utility, social utility, efficiency; the conceptual background of optimisation criteria; the partial equilibrium approach applied in many evaluation; the CBA). But models are just tools to understand the reality, not the reality itself: 'In short, I believe that economics would be a more productive field if we learned something important from evolutionists: that models are metaphors, and that we should use them, not the other way around' (Krugman, 1996).

As problems evolve, economic concepts and theories should also evolve to face new situations. One Health initiatives create indeed new situations and problems that do require a methodological innovation to adequate the existing tools (or create new ones) to perform evaluations in complex frameworks. In the next sections we will see how economic evaluation can take advantage of new concepts and tools to comply with the needs of One Health evaluations. We will comply with this task going through a limited number of models that we deem relevant for the purpose, namely: the socio-ecological system framework, the agrarian system and the food supply chain analyses, the bio-economic models, the dynamic transmission models, and the multi-criteria analysis. A common trait shared by almost all these models is the reference to systems approach and systems thinking.

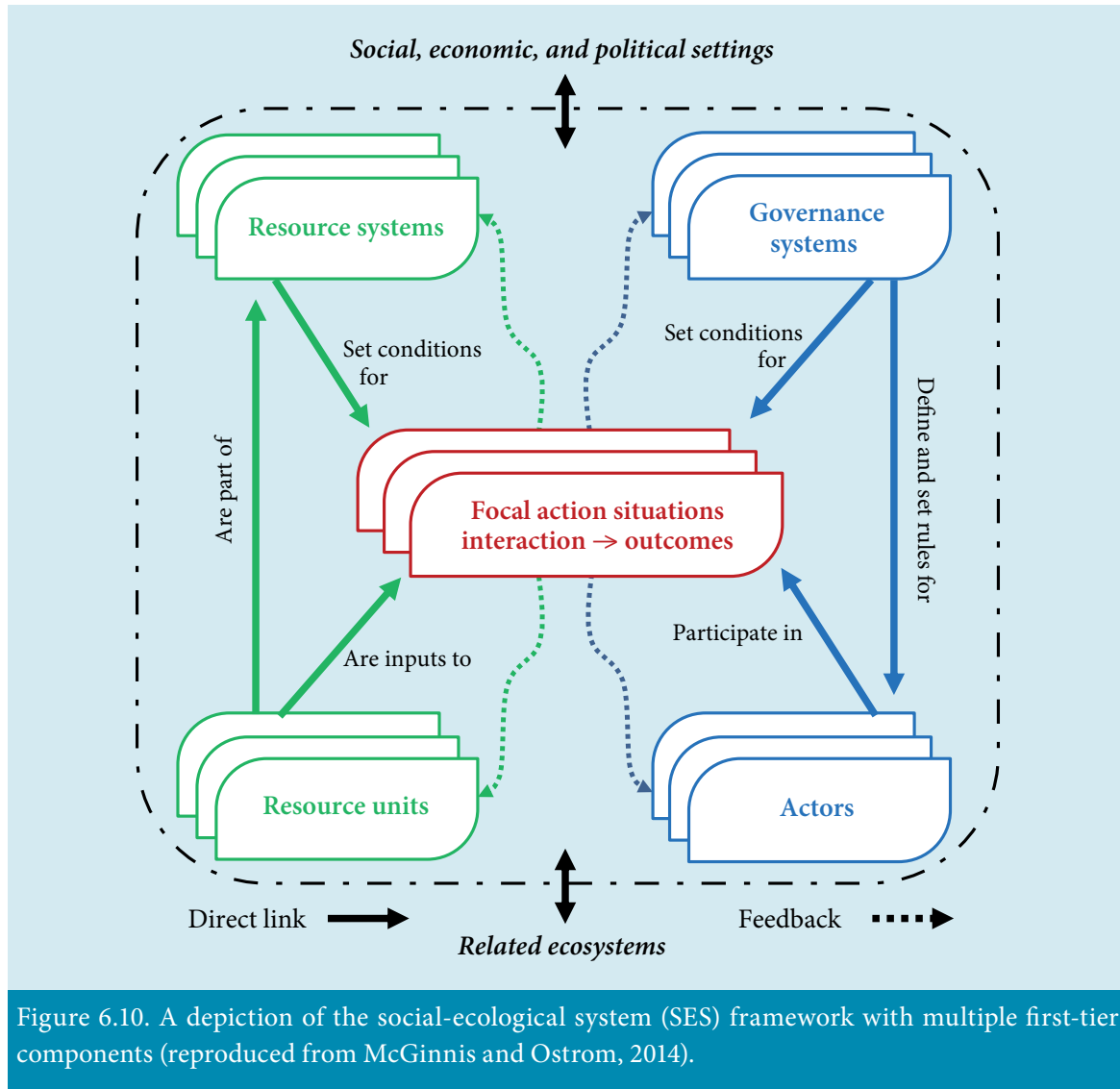
6.3.3 Social-ecological system framework

The premise of systems theory is the recognition that the structure of any system, the many interconnected relationships among its components, is as important in determining its behaviour as the individual components themselves (Pinstrip-Andersen and Watson, 2011). A systems approach to One Health places emphasis on the different types of structures that shape human, animal, plant and environmental health, including the geophysical and biological systems, the organisational systems in which people work and the political systems that govern public policies (Leischow and Milstein, 2006). Social-ecological systems (SESs) incorporate individuals and their environment by relating outcomes, such as health and wellbeing, to systemic interactions, which are influenced by a person's own behaviour, as well as the institutions and resources available within a given social, economic and political setting (Ostrom, 2007).

SESs are dynamic systems that are continuously changing (Schlüter *et al.*, 2014). They co-evolve through interactions between people, institutions, and resources constrained and shaped by a given social-ecological context (Holling and Gunderson, 2002). A SES can be defined as a comparatively bounded structure consisting of interacting, interrelated, or interdependent elements that form a whole and generally consists of a community that is situated within an environment, such as health systems and food systems. The term 'social-ecological' explicitly incorporates the social, institutional and cultural contexts of people-environment relations (Stokols, 1996). This perspective emphasises the multiple dimensions (physical, biological, and social) and multiple levels (individuals, groups, organisations) that interact within a complex system, which are inherent properties of One Health.

One of the major constraints of systems thinking in the context of One Health is the inherent interdisciplinary nature of One Health problems. Different disciplines use entirely different frameworks, theories, and models to analyse various parts of the complex multilevel whole. Ostrom (2009) posited that: 'Without a common framework to organize findings, isolated knowledge does not cumulate.' To address this constraint, this author and colleagues developed the now well-established multi-tier SES framework, which aims to allow knowledge accumulation (McGinnis and Ostrom 2014).

The framework, presented in Figure 6.10, conceptualises SESs into four highest-tier variables: (1) resource systems (e.g. a designated protected park with a distinct human-animal-wildlife interface); (2) resource units (e.g. trees, wildlife, amount and flow of water); (3) governance systems (e.g. organisations that manage the park, the specific rules related to how the park is used, and how these rules are made); and (4) actors (e.g. individuals that use the park for subsistence, recreation, or commercial purposes). All highest tiers affect and are affected by action situations, which denote, on the one side, the transformation of inputs, by actions of multiple actors, into outcomes. On the other side, feedback occurs from action situations to the tier categories. Each of these core subsystems contain multiple second-level variables, which are then further composed of lower-tier variables. The SES framework provides a common set of variables for organising research, so that isolated knowledge acquired from studies of diverse resource systems in different countries by bio-physical and social scientists can cumulate. Intuitively, by sharing data and information, synergy in the organisation of research should be more effective and the use of resources allocated to research more efficient.



Zinsstag *et al.* (2011) have introduced human and animal health as quantitative and qualitative interaction and outcome of SESs in what they call ‘health in social-ecological systems’:

Analogous to ‘systems biology’ which focuses mostly on the interplay of proteins and molecules at a sub-cellular level, a systemic approach to health in social-ecological systems (HSES) is an inter- and trans- disciplinary study of complex interactions in all health-related fields. HSES moves beyond ‘one health’ and ‘eco-health’, expecting to identify emerging properties and determinants of health that may arise from a systemic view ranging across scales from molecules to the ecological and socio-cultural context, as well from the comparison with different disease endemicities and health systems (Zinsstag *et al.*, 2011).

Challenges to using the SES framework include the difficulty in evaluating all components empirically, the integration of knowledge and theories from different disciplines, the variety

of possible explanations and competing priorities of actors within the system (including those involved in developing the framework to represent the system), the uncertainties of social and ecological processes (Baumgärtner *et al.*, 2008). Some of these challenges may be overcome by the adoption of common methodology, terminology and frameworks (McGinnis and Ostrom, 2014), whilst others may be inherent characteristics of complex system and require acknowledgement but can be incorporated into the system (Ford, 2010). Empirical methods that can be applied to SES frameworks are discussed in Section 6.3.5.

6.3.4 Agrarian system and food supply chain analyses

6.3.4.1 Agrarian system analysis

Issued from the French tradition of comparative agricultural studies (Cochet, 2012, 2015; Cochet *et al.*, 2007; Dufumier, 2007), the agrarian system analysis can be considered a heterodox approach characterized by an inherent rejection of some fundamental neoclassical paradigms, such as the rational choice scheme, and by an empirical-holistic method focused on the actual causes of the behaviours of the economic agents and institutions, rather than on the application of deductive theories (Colin and Crawford, 2000). The concept of agrarian system is the main operational tool for this type of analysis, applicable at the regional (or meso-economic; Section 6.3.4.2) level at different scales (village, municipality, district, etc.). Following a structuralist approach, an agrarian system is defined as the theoretical representation of a type of agriculture historically constituted and geographically localized, composed of a distinctive cultivated ecosystem (or agro-ecosystem) and a specific social productive system (Mazoyer and Roudart, 2006).

The agro-ecosystem (which includes the natural characteristics of the examined areas as modified by human activities) and the social productive system (which provides all the means and organization necessary to the agricultural production and to the agro-ecosystem fertility regeneration) are both analysed through sub-systems. The social productive system, for example, includes the agricultural holdings, the farming systems (i.e. the organization of production at the level of the agricultural holdings, including cropping systems, animal production systems, means of production, human work, farm management, etc.), the system of interrelations and exchanges taking place within the agricultural holdings and with the external agents, up to embrace all the relevant elements of the social and economic structure of which the agrarian system is part (i.e. institutions, social organization, markets, agro-food supply chains, etc.) (Mazoyer and Roudart, 2006). The identification of sub-systems and all their components implies the setting of the agrarian system boundaries that are functional to the specific aims of each study. The analysis consists in studying the organization and the functioning of all the system components and the complex of their feedbacks.

Productivity and sustainability of agrarian systems depend on the maintenance of fertility in the exploited agro-ecosystems and on the technical and organizational capacities of society. The historical and spatial contextualization and the concurrence of environmental resource exploitation, technology, and social organization to the definition of productivity levels in a given society match the Marxist concept of 'mode of production' and allowed a similar application of the agrarian system concept to historical and geographical studies on

agriculture (e.g. Devienne, 2011; Ducourtieux, 2015; Dufumier, 2006a,b; Le Coq *et al.*, 2001; Mazoyer and Roudart, 2006).

As an analytical tool of comparative agriculture, the agrarian system concept followed the application of this discipline to agricultural development studies (Dufumier, 2007), by elaborating specific methods of economic analysis and using techniques of rural participative appraisal for the evaluation of projects and policies. A distinctive feature of this approach is the regional diagnostic of farming systems (Cochet, 2015; Cochet and Devienne, 2006; Dufumier, 1996), where the historical and functional analysis of the various components of a regional agrarian system is completed by a survey operated through interviews to farmers and local experts that bring to define a typology of the agricultural holdings. This is a basis for a characterization of the farming systems, which are represented through mathematical models showing their technical and economic performances and allowing evaluations about the perspectives of the different types of holdings under different scenarios.

6.3.4.2 Food supply chain analysis

Supply chain, also often referred as 'value chain', is a concept widely used in the economic analysis of the agri-food industry that, despite some important conceptual differences (Aragrande and Argenti, 2001; Lebailly, 1990; Temple *et al.*, 2011; Terpend, 1997), can be intended as the most common English translation of the French *filière*. In such terms, the supply chain can be defined as a set of business activities involved in the production, processing and distribution of a given product or a given type of products (e.g. dairy products, meat products, fish, etc.). The supply chain business units are connected directly or indirectly through technical and economic links (Labonne, 1987; Raikes *et al.*, 2000; Shaffer, 1973; Terpend, 1997).

The technical links refer to the operations performed by the different units along the supply chain necessary to bring the product (e.g. an agricultural commodity) to the final consumption stage: provisions of raw materials and technical means, transportation, processing, quality and health control, packaging, labelling, conservation, stocking, marketing, wholesale, retail, delivering, etc. Economic links denote the commercial and contractual relations between supply chain operators (e.g. supplier-customer, farmer cooperatives and other producer organizations for product processing or marketing, marketing boards, supply chain agreements, etc.) that define the integration among the different operational units and the different industries involved.

The supply chain horizontal relationships qualify the links among the business units belonging to the same economic sector (e.g. among agricultural producers, or among industrial processors). The vertical relationships indicate the links occurring between firms classified in different sectors (e.g. between farmers and industrial processors and between the latter and the retailers). The complementary or side activities surround the basic vertical structure of the supply chain by supplying technical inputs and services (e.g. financial services, energy, communication, informatics, transportation, packaging, advertising, etc.) to the main sectors. Vertical and horizontal links define the basic structure and organization of the supply chain, schematically represented in Figure 6.11.

Despite the lack of a rigid theoretical formalization (Labonne, 1987) and the methodological eclecticism which characterize the studies in this field (Temple *et al.*, 2011), supply chain analysis is a very flexible and intuitive method to study complex economic phenomena related to the production of good and services. Differently from many economic studies, mainly based on isolated firms or on specific industries, the supply chain concept focuses on a system of relationships that, within the context of specific products and spatial dimensions, cross-cuts the traditional sectoral classifications of economic activities (primary production, manufactures, services) without falling in the generalization of the whole (macro) economic system. The supply chain actually identifies a meso-economic level (or meso-system), where multiple aspects (technical, economic, social) and complex relationships can be understood.

The supply chain analysis can be applied to complex phenomena such as social contexts, habits, regulatory frameworks, and relationships among operators. This may occur on the demand side, with the inclusion of social and cultural factors in modelling demand behaviour in different types of society (Malassis, 1979), as well as on the supply side from the perspective of one single enterprise, up to a global perspective, with the concepts of value chain (Porter,

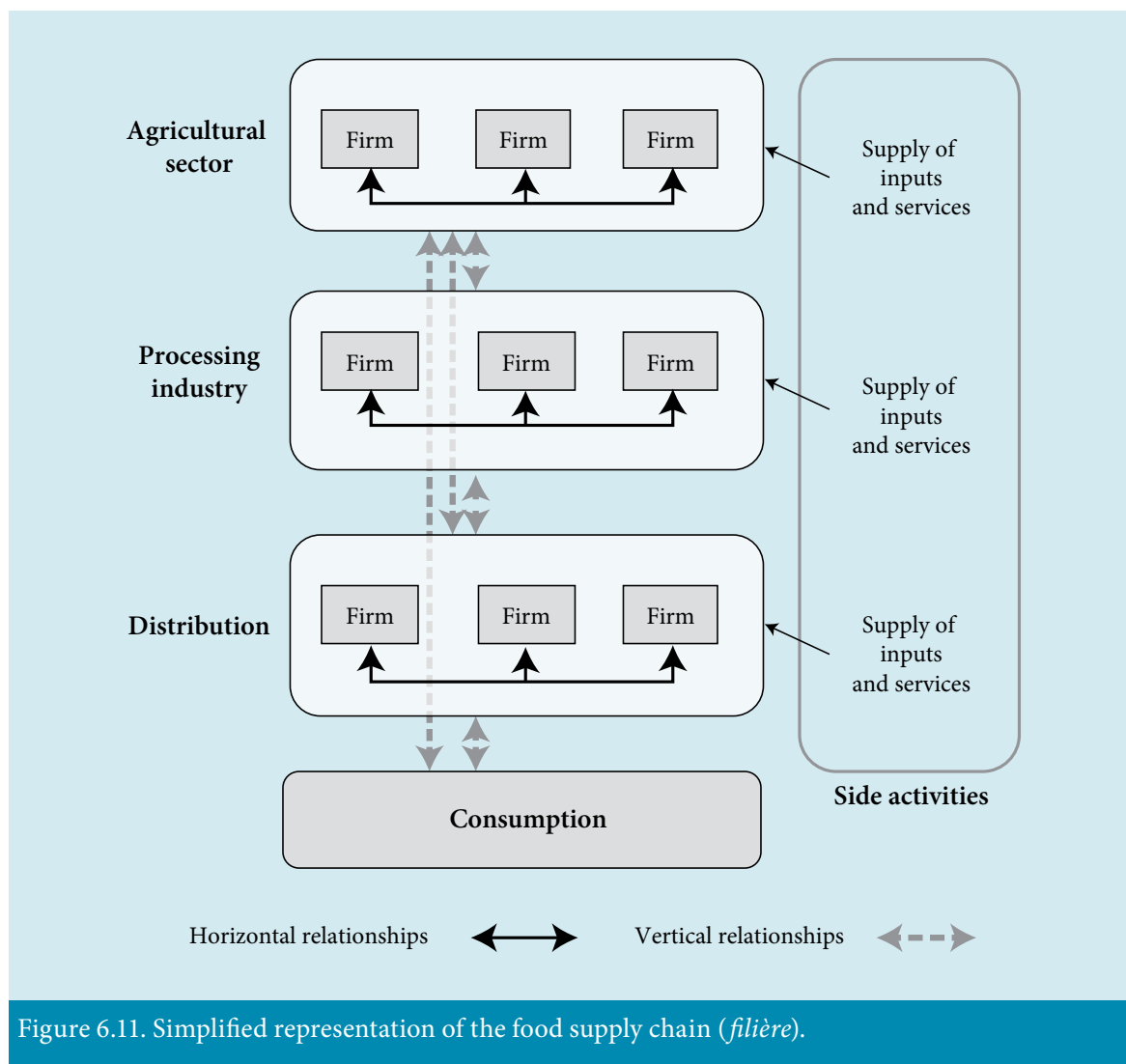


Figure 6.11. Simplified representation of the food supply chain (*filière*).

1985), global commodity chain (Raikes *et al.*, 2000), and global value chain (Gereffi *et al.*, 2005) revealing the means of worldwide governance of production in modern post-industrial economies by huge industrial groups. All these methods share a common inspiration to the basic concept of supply chain.

Supply chain management is a key issue for food safety and environmental protection (Canali *et al.*, 2017; Hammoudi *et al.*, 2015; Lang *et al.*, 2009; Nesheim *et al.*, 2015), which deeply involves One Health and related economic evaluations. On this perspective, the food supply chain analysis is a necessary tool to map the flows of materials and values in all the different activities connected to farming. This is crucial in the present-day context, when most of the income derived from food consumption in both developed and developing economies is not created by the farm sector, but in the upstream and downstream industries. In the United States, for example, out of \$100 spent by consumers for food in 2012, only about \$17 were destined to the farm sector, which contributed for less than 10% to the total added value generated along the food supply chain (Nesheim *et al.*, 2015). These figures explain the economic relevance of the activities siding animal and crop production and how health concerns in the food sector may have huge impacts on economy and society. Food scares have provided clear examples of the consequences of human, animal, and environmental health issues affecting the food supply chain, by showing that the collateral effects on economic activities may be costlier than the direct burden of the diseases (Adinolfi *et al.*, 2016; Aragrande and Canali, 2017; Buzby *et al.*, 1998; Hassouneh *et al.*, 2010, 2012; Hussain and Dawson, 2013; Livanis and Moss, 2005; Lloyd *et al.*, 2006).

6.3.4.3 Strength and weaknesses for One Health evaluations

A major limitation of supply chain analysis is seen in its prevailing qualitative and descriptive nature, as well as in the lack of adequate quantitative tools to fully account and hierarchize, for example, the impacts of specific animal health initiatives on the great variety of stakeholders involved (Rich and Perry, 2011; Rich *et al.*, 2011). Similar observations could be also advanced for the agrarian system analysis. However, such aspects can be considered inherent to these analytical approaches, which were not specifically conceived for health-related economic evaluations, but actually bring researchers to understand the wider context of animal and environmental health issues and identify, for each specific problem, the interactions that need to be deeply examined and the quantitative methods that are necessary to integrate the analysis (Jarvis and Valdes-Donoso, 2015; Rich *et al.*, 2011).

6.3.5 Dynamic transmission modelling

Dynamic models are mathematical models that account for time-dependent changes in the state of a system. Schlüter *et al.* (2014) defined dynamic model as a ‘formal, theory- or empirically-based simplified mechanistic representation of the structure and processes of a real-world entity considered relevant to answer a specific question about the development of the system over time.’ Based on this definition they are useful tools to study the change in SESs over time, particularly in situations for which time-series data are not available and experimentation is difficult.

Dynamic models have two distinct roles, prediction and understanding, which are related to the model properties of accuracy and transparency (Keeling and Danon, 2009). Predictive models usually require a high degree of accuracy, whereas transparency is a more important quality of models used to improve our understanding. Predictive models can be powerful tools in specific situations, guiding difficult policy decisions, where a trade-off between two or more alternative strategies or policies exist. Models can also be used to understand how dynamic systems behave in the real world, and how various complexities affect the dynamics. They provide an ideal world in which research can be conducted under ‘experimental’ conditions; individual factors can be examined in isolation and where every facet of the problem is recorded in perfect detail.

Using mathematical analysis to simulate interactions between the social and ecological components of the system, dynamic models facilitate the exploration of the consequences of salient relationships in the system. In turn, they can determine the system’s sustainability and inform effective management strategies to improve the system being analysed. As such, models of SES are thought experiments for hypothesis generation and testing, particularly for exploring potential future development paths of a system under a given set of assumptions and potential pressures. Their usefulness for understanding the dynamics of SES is highest when they are part of a larger process of empirical and theoretical SES research (Baumgärtner *et al.*, 2008).

Dynamic modelling approaches commonly used for systems analysis include compartmental, network, agent-based models and system dynamics. In compartmental models, individuals in the population are divided into subgroups and the changes in the number of individuals in each subgroup are tracked over time based on different states. For example, mathematical analysis and modelling is central to infectious disease epidemiology and are used both in the generation and testing of hypotheses and the design of practical strategies for disease control (Grassly and Fraser, 2008; Keeling and Danon, 2009). The dynamics of infectious diseases among people, animals and plants result from the transmission of a pathogen either directly between hosts or indirectly through the environment, vectors, or intermediate hosts. The efficiency of transmission depends on the infectiousness of the infected host or hosts and the susceptibility of uninfected individuals who are exposed to infection. Infectiousness is a function of the biological, behavioural, and environmental context within which the pathogen is circulating.

Dynamic transmission studies constitute the backbone for dynamic economic modelling of One Health initiatives (Zinsstag *et al.*, 2005, 2009, 2017). The criteria that define an appropriate mathematical model with which to address a One Health question should be based on the principle of parsimony (chose the simplest model that explains the data), and the ability of the model to answer the question of interest (Grassly and Fraser, 2008). Therefore, the decision of which modelling approach to use and what level of detail to incorporate in the model should be based on the model’s purpose. The usefulness of the model relies precisely on its ability to represent the key components of the system and their interactions, while ignoring the less important ones. There are many criticisms on the use and misuse of dynamic modelling and their limitations must be made explicit. Dynamic models of SESs are often based on assumptions about human behaviour or ecological dynamics that are uncertain

but potentially have a substantial effect on model outcomes. Sources of uncertainty include: (1) lack of knowledge about people's decision-making processes; (2) how people value future benefits; and (3) the various processes that form a considerable component of natural resource dynamics, such as climatic variation (Schlüter *et al.*, 2014). Nevertheless, they provide useful tools in exploration of One Health scenarios, helping to improve our understanding and help to predict possible outcomes of One Health actions.

6.3.6 Bio-economic modelling

Bio-economic models define interrelations between economic and bio-physical variables with the aim to support decision-making in the management of biological resources. Typically, such models focus on how to maximize gains from economic exploitation of one or more species or ecosystems while maintaining the exploitation sustainable: e.g. the populations of the exploited organisms grow at given rates, depending on the carrying capacity of the ecosystems, and the exploitation should allow the maximum of profit compatible with those rates (Van der Ploeg *et al.*, 1987). Sectors like fishery, aquaculture, forestry, hunting, wild fauna, crop and animal farming, food security, agro-ecosystems, biodiversity, and environmental services have experienced the development of these tools (Brown, 2000; Brown and Hammack, 1972; Eggert, 1998; Janssen and Van Ittersum, 2007; Knowler, 2002; Kragt, 2012; Llorente and Luna, 2016; Mouysset *et al.*, 2011; Rewe and Kahi, 2012).

Bio-economic models are developed to respond to specific situations and problems, therefore the criteria for classifications may end up being extremely varied. Brown (2000) analyses the bio-physical or socio-economic components found in such models and identifies a first type of bio-economic models in biological process models enhanced with some economic components, e.g. accounting equations allowing cost-benefit assessments related to scenarios or management strategies simulated by the model. A second and opposite type is represented by economic optimization models that incorporate bio-physical features. In this case, the prevailing component of the model is socio-economic: examples are the models that account the multiple objectives of one decision-making unit (e.g. an agricultural holding) under different resource endowments and constraints. Integrated bio-economic models represent a convergence between the two previous types. They try to embody both to a large extent: the complex rationale of the economic optimisation models and the process simulation capacity of the biological process models (Brown, 2000).

Despite dating back several decades, integrating the two main components of bio-economic models remains extremely challenging, because of the inherent complexity. Table 6.4, reproduced from a literature review (Kragt, 2012), summarizes the main characteristics of bio-economic models from different sectors. The author of this study reported the scarcity of integrated studies and the lack of scientific foundation in many ecosystem evaluations. Economic optimization models are blamed for providing too simplistic representations of the underlying of natural processes at the origin of environmental transformations. On the other side, bio-economic integrated models represent complex systems, and the attempts to reduce complexity to make them more understandable and usable for stakeholders and decision makers, leading to the emergence of trade-offs that researchers are not always willing to resolve (Nielsen *et al.*, 2017). In this case, bio-scientists and ecologists often oppose the

Table 6.4. Identification of main characteristics of bio-economic models from different sectors based on a literature review (reproduced from Kragt, 2012).

	Forestry	Fisheries	Agriculture	Non-market values
Type of resource assessed	Single- or multi-species forest strands	Single- or multi-species fisheries	Representative farm systems	Variable
Modelling techniques	Linear/dynamic programming	Linear/dynamic programming, accounting	Accounting, regression, linear/dynamic programming	Environmental valuation techniques
Spatial scales and dynamics	Timber production per ha	Vary with habitat of study species	Paddock, whole-farm	Vary with resource under valuation
Temporal scales and dynamics	Steady state harvest models based on annual or seasonal changes in harvest activities			Typically, 15-30 year impacts
Bio-physical analysis	Mechanistic biological growth functions. Environmental conditions exogenous. Limited accounting for externalities or multiple ecosystem benefits			Environmental scenarios based on econometric considerations or expert opinion
Socio-economic analysis	Maximise net present value of profits from forestry, fish harvesting, crop and livestock production			Maximize net present value of allocating environmental resources across users and non-users

‘irreducible complexity of ecosystem functioning’, the idea of ‘whole’ as different from the sum of components, and holistic viewpoints to the reductionist approaches of economists (Kragt, 2012; Wam, 2010).

Herd models simulate livestock population dynamics under different parameters (e.g. mortality and fertility rates) to reproduce the effects of diseases or the outcome of disease control measures (Shaw, 2003). They can be classified as stochastic, when the parameters follow probability distributions, or deterministic, when the variables are taken as average values. Static models describe a heard steady state (e.g. James, 1995), while dynamic models track output changes over time resulting from animal health interventions (e.g. Doran, 2000). They are also distinguished for the prevailing targets, e.g. to assess the output value (economic models) or manage feed resources by considering a variety of biological parameters (bioeconomic models, e.g. Von Kaufmann *Et Al.*, 1990).

Progress in integrated bio-economic modelling requires improvements in the capacity of managing complexity by scientists and the interdisciplinary collaboration between bio-physical and socio-economic research (Kragt *et al.*, 2016), which is also the main challenges of One Health. The convergence between the One Health vision and the developments needed to the evolution of bio-economic modelling potentially makes it one of the most promising fields for economic research within the One Health context. On this perspective, a number of studies already gives relevant examples of models integrating environmental, epidemiological and socioeconomic variables in animal disease or welfare management (e.g. Collins and Part, 2013; Fenichel *et al.*, 2010, 2012; Getaneh *et al.*, 2017; Grace *et al.*, 2017; Horan *et al.*, 2008; Kingwell, 2002; Rich, 2007; Shwiff *et al.*, 2013; Sikhweni, 2014; Tschopp *et al.*, 2012).

6.3.7 Multicriteria decision analysis

Traditional tools for economic evaluation tend to focus on a single outcome measure or criterion. Different outcomes can then be assigned a monetary value to make them comparable and facilitate a synthetic judgement. As discussed in Section 6.2, this approach has limitations and may not be feasible or appropriate in all cases. MCDA offers an alternative approach, which can be particularly well-suited for the evaluation of One Health interventions. With reference to a set of alternative interventions examined, an MCDA can express, through a single synthetic judgement, a complex set of assessments related to all the criteria chosen for the evaluation by taking into account the priorities established among them. Criteria can include environmental sustainability, wildlife preservation, inequality of health impacts, or economic costs among others. Furthermore, MCDA allows for the consideration of both quantitative and qualitative information. This framework is consistent in principle with a decision maker perspective but can integrate several perspectives.

MCDA can be used as an additional step, where the results of the economic evaluation are considered alongside other criteria, such as ethical or political concerns. Alternatively, MCDA can constitute an integral part of the economic evaluation. Tiwari *et al.* (1999) apply an MCDA framework for environmental-economic decision making in irrigated agricultural lowlands. This study incorporates measures of monetized NPV from several perspectives (government, farmers, societal), alongside a range of non-monetized environmental sustainability criteria. In the area of health economics this MCDA is still not widely used, although some authors have advocated for a move towards this methodology, which can better reflect the range of concerns that decision makers face. Baltussen and Niessen (2006) propose a multi-criteria framework for economic evaluation integrating efficiency measures as well as other criteria such as potential to reduce health inequalities of vulnerable populations, or to respond to life-threatening situations. To improve knowledge integration in the governance of One health initiatives, Hitziger *et al.* (2018) indicate MCDA as a main tool to create a participative convergence among interests, preferences and values of the multiple actors involved and identify shared priorities for collective action.

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