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1 Introduction

1.1 Scope of the study

Most real-world policy changes create conflicts of interest. For example, if a forest which is used as a recreation area is cleared, those owning the forest will gain, while those visiting the area or those concerned about an endangered species living there will lose. Nevertheless, a decision must be taken whether or not to cut down the forest. The decision-maker must implicitly or explicitly transform all values to a single 'dimension' to compare them. Only then can he decide whether or not the value of the timber exceeds the value of the preserved forest. The economist's way of performing this transformation is to try to express all utility changes in monetary terms. This is the essence of *social cost-benefit analysis*. Once all benefits and costs have been expressed in monetary units, the social profitability of the considered project can be assessed.

The beginnings of cost-benefit analysis date back over a century to the work of Jules Dupuit, who was concerned with the benefits and costs of constructing a bridge; Dupuit's famous paper 'On the utility of public works' was published in 1844. In particular, Dupuit introduced the concept of the consumer surplus, i.e. the fact that benefits are measured by an area under a demand curve, not by what is actually paid. The next major contribution to cost-benefit analysis seems to have appeared almost one hundred years later.

In a well-known paper, 'The general welfare in relation to problems of taxation and of railway and utility rates', published in 1938, Harold Hotelling, among other things, formulated the case for marginal cost pricing: 'The efficient way to operate a bridge is to make it free to the public, so long at least as the use of it does not increase to a state of overcrowding' (Hotelling, 1938, p. 158).

The first attempts to apply cost-benefit analysis to empirical decision-making also date back to the thirties. The United States Flood Control Act

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of 1936 introduced the principle that a project is desirable if 'the benefits, to whomsoever they may accrue, are in excess of the estimated costs'. However, the precise meaning of a 'benefit' remained unclear, and individual agencies often approached similar projects from different standpoints. This stimulated academic interest in the subject. Beginning in the late fifties, an extensive literature on the foundations of cost-benefit analysis emerged: see Eckstein (1958), Krutilla and Eckstein (1958), McKean (1958), Maass (1966), Marglin (1967), Harberger (1969, 1971), Musgrave (1969), Little and Mirrlees (1968), Dasgupta *et al.* (1972), Boadway (1975), Lesourne (1975), Srinivasan and Bhagwati (1978), Diewert (1983), Drèze and Stern (1987), and Starrett (1988), just to mention a few. Tinbergen (1952), Meade (1955), and Arrow and Kurz (1970) are examples of related works which have influenced the development of cost-benefit analysis.

The basic idea of a (social) cost-benefit analysis can be illustrated by means of a simple example. Suppose that the air quality in a particular area can be improved. Since this improvement is associated with a cost, perhaps for filters and other equipment, the question arises whether the investment is worth its cost. In other words, are people really willing to make the sacrifice the investment represents? By examining the total sum people are willing to pay we get a monetary benefits measure that can be compared with the investment cost, so that the profitability of the investment can be assessed. An individual's *willingness to pay* is simply the maximum sum of money he is willing to give up to ensure that the suggested project is undertaken. Alternatively, we may want to find the minimum *monetary compensation* the individual needs in order voluntarily to accept that the proposed project is not undertaken. This amount of money makes him as well off as if the project had actually been undertaken, i.e. compensates him for the 'loss' of the project. Summing over all affected individuals yields the overall or aggregate compensation requirement, just as summing each individual's willingness to pay produces the aggregate or overall willingness to pay. These aggregate sums of money can then be compared to the project's total costs, and the project's social profitability assessed. (This aggregation procedure is a common, though highly questionable one, as is shown in chapter 7.)

For a long time, it was widely believed that it was difficult, if not impossible, to value empirically public goods or 'bads' such as pollution of the air and the water. They were often classified as intangibles. There has, however, been a progressive development during the past two decades, with the result that many goods and services that were earlier classified as intangibles are now classified as measurable. In turn, this means that the possibility of undertaking cost-benefit assessments of activities that affect the environment has increased dramatically.

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This study is an attempt to introduce PhD students to the theory of cost-benefit analysis of projects or changes that positively or negatively affect the environment. The focus of interest is therefore on the evaluation of activities that either provide public goods or create external effects. This means that some issues which are highlighted in many earlier contributions, such as the treatment of taxes and market imbalances, although in no way ignored, play a secondary role in this book. Instead, issues that are focused upon include the following: valuing public goods and externalities in a general equilibrium context, the treatment of flows and stocks of both natural resources and pollutants, intragenerational and intergenerational aggregation, evaluation of risky projects, the treatment of irreversibilities and health effects, and assessing projects which affect other countries, e.g. transboundary pollution. Throughout, reference is made to various empirical methods and approaches that can be used in applied project evaluations. For example, a separate chapter is devoted to different methods that can be used to measure the willingness to pay for public goods, and in other chapters the methods used in empirical studies to assess various kinds of benefits and/or costs are reported.

Although there has been a great deal of development in the theory as well as the measurement of environmental benefits and costs, much remains to be done. Cost-benefit analysis can capture and express in a single dimension (monetary units) many, but never all, of the effects of environmental projects. Such analyses enlarge as well as improve the information set available to policy-makers. Nevertheless, given all the unresolved issues in cost-benefit analysis, some of which will be hinted at in this book, such analysis can seldom constitute the one and only factor in decision-making. Usually, the decision-maker also wants to consider a proposed project's private profitability, its impact on the governmental budget, its political consequences, and so on; see, for example, Mueller (1989) for details. Still, if cost-benefit analysis is to be used in decision-making, it is essential that it is based on solid theoretical foundations and the best available practical empirical methods. Hopefully, this book constitutes a step, however small, in this direction.

1.2 Plan of the study

Cost-benefit analysis is applied welfare economics. As a service to the reader, an initial chapter on basic tools in welfare economics has been included. The chapter starts by defining indirect utility functions and profit functions, and presents some of their properties. These tools will play a central role in later chapters. The chapter then turns to a brief presentation of the properties of the perfect market economy. A perfect market economy

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attains a general equilibrium characterized by equality between supply of and demand for each and every commodity provided, such that it is impossible to improve the situation of some individual(s) without making at least one other household worse off. In the present context, the importance of this Pareto superiority result lies in the fact that it is the point of departure in welfare economics for analysis of real-world economies as opposed to the perfect model economy. The chapter then introduces public goods, and derives conditions for the Pareto-optimal provision of such goods. It is important to stress, however, that if one changes the distribution of endowments across households, a new equilibrium is reached. Unfortunately, the Pareto criterion is unable to rank changes which produce both winners and losers. What is needed is some further ethical criterion for choosing among allocations. Such a concept, namely that of a social welfare function, is introduced. The function is used to characterize the properties of a social welfare optimum. After this digression into general welfare economics, the rest of the book is devoted to applied welfare economics.

The benefit side is extremely important in assessing environmental projects. There is a large and growing literature on both the economic theory and the measurement of such benefits. This is hardly surprising given that many of the services provided by the environment are unpriced. There is therefore a need for money measures of utility change caused by 'commodities' that can be viewed as public goods or externalities, and for methods for the practical evaluation of such money measures. Chapter 3 introduces consumer surplus measures, concentrating on the concepts of compensating and equivalent variation. Measures of a *ceteris paribus* change in the provision of a public good as well as of complex changes involving many prices, wages and public goods are presented.

Several different practical methods of measuring the willingness to pay for public goods and unpriced private goods have been suggested in the literature. Chapter 4 is devoted to a brief review of the most frequently used methods: the contingent valuation method, travel cost methods and hedonic price approaches.

Private firms are often considered as causing a considerable proportion of our environmental problems. However, in many cases firms are also affected by pollution. Therefore, in order to assess projects which affect the environment, producer surplus (change) measures are needed. The first section of chapter 5 is devoted to a presentation of such measures. These are a necessary input in any evaluation of a project's social profitability, since firms are ultimately owned by households. This is true even if a firm is directly owned by a pension fund or the government, for example. These institutions are ultimately owned by households. The different pieces, i.e.

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consumer surplus measures and producer surplus measures, are put together in section 5.2 and a general equilibrium type of evaluation of a small environmental project is undertaken. The rest of the chapter considers the evaluation of large projects as well as the treatment of distortionary taxes and unemployment in project assessments.

A typical feature of many environmental projects is that their consequences last for many years. Intertemporal evaluations are the topic of chapter 6. Natural resources, renewable as well as non-renewable, are introduced and the treatment of such resources in a social cost-benefit analysis is explored. An optimal-growth theory model is used to derive cost-benefit rules for flows as well as stock pollutants. This model is also used to discuss the concept of sustainable development and the shortcomings of traditional national income accounts as regards flows of environmental services and changes in stocks of natural resources and pollutants.

As mentioned above, a typical approach in cost-benefit analysis is simply to add gains and losses across households. This approach is examined in chapter 7. Using a social welfare function, the relationship between a project's impact on social welfare and its monetary profitability is examined. A positive aggregate consumer surplus is often interpreted as implying that gainers can, at least hypothetically, compensate losers from a proposed project. The circumstances under which this claim holds, and the ethical judgements underlying it, are clarified. The second part of the chapter turns to the intergenerational aggregation problem. The choice of social discount rate in projects affecting several generations is discussed using both conventional growth models and overlapping-generations models. The concepts of transfers in kind and impure altruism are also explored. The final section of the chapter discusses how to deal with altruism in a cost-benefit analysis. It turns out that some types of altruism can be ignored while other types must be accounted for in a cost-benefit analysis.

The effects of a proposed environmental project are often difficult to predict. There is thus a need for cost-benefit rules for a risky world. Chapter 8, which is the first of two chapters on the treatment of risk, derives project evaluation rules which can be used when an environmental investment has uncertain consequences. The chapter also considers the appropriate choice of money measure in cases where risk can be diversified away (is insurable), or is collective.

In some cases, a project affects the probability that a certain event will occur; it shifts the probability distribution. This is typically the case for complex projects aiming at the preservation of endangered species or the reduction of the greenhouse effect. Similarly, projects may affect the probability that human beings will experience one or another health status,

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including the probability of death. These issues, including results from empirical studies, are dealt with in chapter 9. The chapter also includes a discussion of the value of information. There are both benefits and costs of postponing a project until more is learned about its possibly irreversible consequences, for example. The chapter also contains a discussion of the problems faced – in particular, time inconsistency and credibility – when designing policies in an intertemporal context.

Unfortunately, there seem to be few, if any, cost-benefit analyses of environmental changes that strictly follow the project evaluation rules derived in this book. Alternatively, they are presented in such a sketchy way that it is impossible to infer what rules have been used. Nevertheless, in chapter 10 a few empirical studies are summarized. The first two studies presented are both based on the contingent valuation method, one using continuous responses, the other using both continuous and binary responses. A study explicitly introducing risk is then presented. Next, the possibility of using computable general equilibrium models in cost-benefit analysis is highlighted by summarizing a CGE-based evaluation of environmental regulations. The study by Hammack and Brown (1974) illustrates how optimal control theory and simulation models can be employed in evaluations. Finally, attempts to account for natural resource depletion in national accounts are discussed.

The final chapter of the book is devoted to a presentation of policy instruments that can be used to achieve a socially efficient allocation of environmental resources. These instruments include regulations, emissions charges, and transferable emission permits. The chapter also discusses the evaluation of international environmental problems, i.e. how to assess activities which affect not only the domestic environment but also environmental quality abroad (globally). Policy instruments that can be used to handle such 'international games' are discussed with reference to a recent empirical study.

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2 Some basic concepts

This chapter can be viewed as a quick refresher course in microeconomics and welfare economics. The chapter presents some of the tools, such as indirect utility functions, profit functions, definitions of a general equilibrium, Pareto optimality and the social welfare function, that will be used throughout this book. Of necessity, the presentation must be only an outline. The reader interested in detailed investigations is referred to some standard book in microeconomics, such as Kreps (1990) or Varian (1992).

The chapter is structured as follows. Section 2.1 is devoted to the utility maximization problem for a household, while section 2.2 takes a look at the profit maximization problem for a firm. Equilibrium in markets and the meaning of the Pareto-efficiency of a competitive equilibrium are considered in section 2.3. Public goods are introduced in section 2.4, where we derive the condition for the optimal provision of a public good. Sections 2.5 and 2.6 introduce the concept of a social welfare function. The chapter ends with a few comments on the relationship between the social welfare function and social cost-benefit analysis.

2.1 Households

Let us consider a household consuming n different private commodities x_i, where $i=1, \ldots, n$. These can be bought in non-negative quantities at given, fixed, strictly positive prices p_i. The household supplies k different kinds of labour denoted L_j for $j=1, \ldots, k$, treating wage rates, denoted w_j, as fixed. The household is viewed as being equipped with an ordinal utility function $U=U(x, L)$, where x is a goods vector of order $1 \cdot n$, and L is a labour supply vector of order $1 \cdot k$. The utility function is assumed to be continuous, increasing in its first argument and decreasing in its second argument, twice continuously differentiable, and 'well-behaved' so as to generate an interior solution to the household's utility maximization problem as well as demand functions having the usual properties.

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The economy is assumed to consist of H different households. The problem of utility maximization for household h ($h = 1, \ldots, H$) can now be written as follows:

$$\left.\begin{array}{ll} \max \; U^h(x^h, L^h) & \\ \text{s.t.} \quad y^h + wL^h - px^h = 0 & \forall h \end{array}\right\} \quad (2.1)$$

where a superscript h refers to household h, $\forall$ means 'for all', $y^h = Y^h + \Pi^h - \tau^h$ is a lump-sum income, treated as fixed by the household, Y denotes a transfer to the household, τ denotes a tax paid by the household, Π denotes profit income, if any, received by the household, p is a price vector of order $1 \cdot n$, w is a wage vector of order $1 \cdot k$, and any sign referring to transposed vectors is ignored here and throughout. There is also a time constraint saying that working time plus leisure time sum up to 24 hours a day, but this constraint is suppressed in order to avoid unnecessary clutter.

According to (2.1), the household is assumed to act as if it maximizes a well-behaved ordinal utility function subject to a budget constraint. It chooses a bundle of consumption goods and supplies of labour so as to attain the highest possible level of utility subject to the constraint imposed by the budget. First-order conditions for an interior solution to this utility maximization problem are stated in the appendix to this chapter. Solving these conditions for x and L in terms of prices, wages and lump-sum income yields demand functions for goods and supply functions for labour:

$$\left.\begin{array}{ll} x^h = x^h(p, w, y^h) & \forall h \\ L^h = L^h(p, w, y^h) & \forall h \end{array}\right\} \quad (2.2)$$

where $x^h = [x_1^h(p,w,y^h), \ldots, x_n^h(p,w,y^h)]$ is a vector of goods demands, and $L^h = [L_1^h(p,w,y^h), \ldots, L_k^h(p,w,y^h)]$ is a vector of labour supplies. The quantity demanded of a commodity and supplied of a labour skill, respectively, are functions of prices, wages and lump-sum income.

Substitution of equations (2.2) into the direct utility function in (2.1) yields the indirect utility function:

$$V^h = V^h(p, w, y^h) = U^h[x^h(p,w,y^h), L^h(p,w,y^h)] \qquad \forall h \qquad (2.3)$$

The indirect utility function expresses utility as a function of prices, wages and lump-sum income. Taking the partial derivative of the indirect utility function with respect to the ith price and the jth wage rate, respectively, and invoking the envelope theorem yields:

$$\left.\begin{array}{ll} \partial V^h(\cdot)/\partial p_i = -\lambda^h(\cdot) \cdot x_i^h(\cdot) & \forall h, i \\ \partial V^h(\cdot)/\partial w_j = \lambda^h(\cdot) \cdot L_j^h(\cdot) & \forall h, j \end{array}\right\} \quad (2.4)$$

Thus the partial derivative of the indirect utility function with respect to a price is equal to minus the demand for that commodity multiplied by λ^h. Similarly, differentiating the function with respect to a wage yields the

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corresponding supply function multiplied by λ^h. In turn, it is easily demonstrated that λ^h, the Lagrange multiplier associated with the budget constraint in (2.1), is the partial derivative of the indirect utility function with respect to lump-sum income:

$$\partial V^h(\cdot)/\partial y^h = \lambda^h(\cdot) = V^h_y(\cdot) \qquad \forall h \qquad (2.4')$$

In the light of this result, it is not surprising that λ^h (or V^h_y which is the symbol we will use henceforth) is frequently referred to as the marginal utility of income.

2.2 Firms

The economy is assumed to consist of F different private firms. These are ultimately owned by households, implying that changes in profits constitute an ingredient in a social cost-benefit analysis. For notational simplicity each firm is assumed to produce all the n commodities consumed by households, using k different labour skills as variable inputs. Profits of an arbitrary firm are defined as:

$$\Pi^f = pF^f(l^f) - wL^f \qquad \forall f \qquad (2.5)$$

where $F^f(\cdot) = [F^{1f}(L^{1f}), \ldots, F^{nf}(L^{nf})]$ is a vector containing the fth firm's production functions for the n different commodities, L^{if} for $i = 1, \ldots, n$ is a vector of labour demands of order $1 \cdot k$, and $\sum_i L^{if}_j = L^f_j$ for $j = 1, \ldots, k$. The production functions are assumed to be strictly concave, and twice continuously differentiable.

According to (2.5), profits are equal to the difference between sales revenue and wage costs, ignoring here any fixed costs due to a fixed capital stock. The assumed aim of the firm is to maximize its profits, treating all prices and wages as unaffected by the firm's actions. Solving the profit maximization problem (see the appendix) one arrives at the demand functions for labour. Substitution of these into (2.5) yields the profit function:

$$\Pi^f = \Pi^f(p,w) \qquad \forall f \qquad (2.6)$$

The profit function is increasing in its first argument and decreasing in its second argument. Taking the partial derivative of the function with respect to p_i and w_j respectively yields:

$$\left.\begin{aligned} &\partial \Pi^f(\cdot)/\partial p_i = x^f_i(p_i,w) && \forall f,i \\ &\partial \Pi^f(\cdot)/\partial w_j = L^f_j(p,w) = \textstyle\sum_i L^{if}_j(p_i,w) && \forall f,j \end{aligned}\right\} \qquad (2.7)$$

where $x^f_i = F^{if}(\cdot)$. The partial derivative of the profit function with respect to a price (factor price) is the supply function (demand function) for the corresponding commodity (input). Note that the jth labour skill is used by

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the firm to produce all n commodities, which explains why we sum across commodities in the second line of equation (2.7).

2.3 Markets, general equilibrium and Pareto optimality

Basically, a market characterized by perfect competition is one in which the individual buyer or seller treats the price as independent of his purchases or sales. This is the assumption we have employed in deriving demand and supply functions for households and firms. In this section we will take a look at competitive markets and their welfare properties. The point of reference is the Pareto criterion. By this criterion a policy change is socially desirable if everyone is made better off (the weak Pareto criterion) or at least some are made better off (the strong Pareto criterion) while no one is made worse off. When the possibilities of making such policy changes are exhausted, we are left with an allocation of commodities that cannot be altered without someone being made worse off. Such an allocation is called *Pareto-optimal* or efficient.

In order to relate our model economy to the Pareto criterion, let us start by defining a market equilibrium. The ith market will be in equilibrium if p_i is such that aggregate supply is equal to aggregate demand:

$$\textstyle\sum_f x_i^f(p_i,w) = \sum_h x_i^h(p_i,p^-,w,y^h) \qquad \forall i \qquad (2.8)$$

where the vector p^- contains all prices but the ith price, and p^-, w, and y^h, $\forall h$, are fixed at arbitrary positive values. If we fix p_i above the level implicitly given by (2.8), excess supply will result, while there will be an excess demand if the price is fixed below its market-clearing level. It is left to the reader to examine the market for an arbitrary labour skill. The reader should note that the kind of models considered here cannot determine absolute prices. Some particular price must be kept constant, and used as the numéraire. Prices are thus expressed in terms of this numéraire price, i.e. we can only determine relative prices. Alternatively, one defines a price index, but this approach too amounts to fixing one price at an arbitrary level.

We are now ready to define an equilibrium (relative) price and wage vector. This is a vector (p,w) such that all goods and factor markets *simultaneously* are in equilibrium. It is not necessarily true that an equilibrium price vector exists. Alternatively, there may be multiple equilibria in the sense that more than one price vector results in general equilibrium, given the initial distribution of endowments (property rights to firms, etc.). We will not analyse these difficult issues. In this book it is simply assumed that there is a unique equilibrium price vector. The reader interested in existence proofs is referred to Arrow and Hahn (1971) or Varian (1992), for example.

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