Chapter 3
Evaluating Trade-Offs: Benefit–Cost Analysis and Other Decision-Making Metrics

Chapter 3 presents three decision-making metrics that can be used to evaluate policy options. The bulk of the chapter covers benefit-cost analysis, and explores the connection between static efficiency and maximizing net benefits. The first equimarginal principle and pareto optimality are introduced. Present value is reviewed and there is a discussion of which discount rate is best. Some difficulties associated with measuring benefits are raised, and there is a discussion of how to estimate costs. Cost effectiveness analysis and impact analysis are discussed as options to benefit-cost analysis. Since resources are limited it is not possible to undertake all ventures that might be desirable. The government for example has limited resources and cannot possibly address and solve every single environmental problem. Students need to understand how to wisely use scarce resources and this chapter provides a framework for allocating scarce resources.

■ Teaching Objectives

1. Understand that all actions have benefits and costs, and all benefits and costs are valued in terms of their effect on humanity.

2. Understand that (total) benefit is measured as the area under the demand curve, and total cost is measured as the area under the supply (or marginal cost) curve.

3. Define net benefit graphically as the difference between total benefit and total cost.

4. Explain that all costs should be measured as opportunity costs.

5. Define present value and the discount rate. Illustrate the basic discounting equations.

6. Calculate the present value of net benefits and show how benefit-cost analysis can be used to evaluate specific options.

7. Define optimality and economic efficiency.

8. Distinguish between static efficiency and dynamic efficiency. Use the equimarginal principle to illustrate both efficiency and inefficiency.

9. Define the concept of Pareto optimality.

10. Apply these concepts to real world examples.

11. Discuss several issues in estimating benefits such as the difference between primary and secondary effects.

12. Explain the different approaches to cost estimation.

13. Understand how to quantify risk and how to decide how much risk is acceptable.

14. Discuss how to choose the discount rate, and explain the difference between the social and private discount rate.

15. Discuss cost effectiveness analysis and impact analysis as alternatives to benefit cost analysis when benefit data is lacking.

■ Outline

I. Normative Criteria for Decision-Making

A. **Benefit-cost analysis** provides a method for determining whether or not an action should be supported. Most simply, if the benefits exceed the costs, then the action should be supported.
   1. **Benefits** can be derived from the demand curve for the good or service.
   2. **Total willingness to pay** or **total benefit** is the area under the demand curve from the origin to the chosen quantity.
   3. **Costs** are measured by the **marginal cost curve.**
   4. All costs should be measured as **opportunity costs.** Opportunity cost is the net benefit foregone when an environmental service is lost to a different use.
   5. **Marginal opportunity cost** is the cost of producing the last unit.
   6. **Total cost** is the sum of the marginal costs or the area under the marginal opportunity cost curve up to the chosen quantity. This will also be the area under the supply curve in purely competitive markets.
   7. **Net benefit** is the excess of benefits over costs or the area under the demand curve that lies above the supply curve. This is also **consumer plus producer surplus.**

B. **Benefit-cost analysis** requires comparing benefits and costs that usually occur at different points in time. The concept of **present value** allows us to incorporate the time value of money and to compare dollars today to dollars in some future period by translating everything back to its current worth.
   1. The present value of benefits, $\$B$, received n years from now is $\$B_n/(1 + r)^n$, where r is the discount rate.
   2. The present value of a stream of benefits $\{B_0,\ldots,B_n\}$ received over a period of n years is the sum from time $i = 0$ until year n of $\$B_i/(1 + r)^i$.
   3. **Discounting** is the process of calculating present value.

C. Finding the Optimal Outcome
   1. An allocation is **efficient** or has achieved **static efficiency** if the net benefit from the use of those resources is maximized by that allocation. If at an allocation marginal cost is greater than marginal benefit, then net benefits are less than the maximum possible, and the allocation is **inefficient** (too much has been produced). Likewise, if marginal benefit is greater than marginal cost, net benefits can be increased by increasing the allocation. Thus, an efficient allocation will be achieved when marginal benefit and marginal cost are equal. Inefficient allocations do not maximize net benefit.
   2. The **first equimarginal principle** says that net benefits are maximized when the marginal benefits from the allocation equal the marginal costs.

3. An allocation is **Pareto optimal** if no other feasible allocation could benefit some people without any negative effects on at least one other person.
4. Allocations that do not satisfy Pareto optimality are **suboptimal.**
5. An allocation has achieved **dynamic efficiency** if it maximizes the *present value* of net benefits.

II. Applying the Concepts

A. This section presents some examples of actual studies in which benefit-cost analysis has been used. The benefits and costs of U.S. air pollution control policy are discussed as are preservation versus development conflicts. The boxed Examples 3.2 and 3.3 in this chapter are useful case studies to discuss in class.

B. Issues in Benefits Estimation

Benefit-cost analysis involves judgments on:

- Which effects should be included (e.g., should secondary effects be included)?
- How many people incur benefits and costs and are the benefits and costs the same for each person?
- How to handle intangible values or those that cannot be reliably assigned a monetary value.

What should be counted might vary depending on the nature of the local economy. Thus it will vary by place and time. How these variables are measured is also important. Students may have trouble, for example, with the idea that the additional labor hired for a project will not be counted in an analysis if it is simply a transfer of labor that would already be employed elsewhere. A natural reaction is to include this on the benefit side when it is actually simply a rearrangement of productively employed resources. The quantification of intangible benefits will also likely be a stumbling block. The importance of sensitivity analysis should be stressed.

C. Approaches to Cost Estimation

Estimating cost is typically more straightforward than estimating some types of benefits. Difficulties involve estimating expected future costs and getting reliable cost information from firms. Some common approaches include the following:

1. The survey approach involves asking polluters about their control costs.
2. The engineering approach uses engineering information to estimate the technologies available and the costs of purchasing and using those technologies.
3. The combined approach uses both 1 and 2.

D. Treatment of Risk

For many environmental issues, scientific uncertainty complicates benefit-cost analysis. Thus, identifying and quantifying risks and then deciding how much risk is acceptable is important. Since it is very tedious and sometimes unfeasible to do a benefit-cost analysis for every possible outcome, we usually must utilize *expected* values.

1. A dominant policy is one that confers the highest net benefits in every outcome.
2. The **expected value of net benefits** is the sum over the possible outcomes of the present value of net benefits of that outcome weighted by its probability of occurrence. The policy selected should be the one with the highest expected present value of net benefits.

3. The above approach assumes **risk neutrality.** Whether or not it makes sense for the government to assume that society on the whole is risk neutral (versus risk loving or risk averse) should be discussed.
4. The evaluation of irreversible decisions requires extra caution.

E. Choosing the Discount Rate

The **discount rate** is defined as the social opportunity cost of capital. The discount rate will have two components: the riskless cost of capital and the risk premium. The rate on long-term government bonds is a common choice as a measure of the cost of capital. This can then be adjusted by a risk premium to reflect the level of riskiness of the particular project being considered.

The appropriate rate to use will depend on the nature and expected lifetime of the project, who is doing the financing, and the level of risk. The power of the discount rate to sway a decision one way or another should not be overlooked (Example 3.4). Sensitivity analysis to the choice of the discount rate should be performed. Numerical examples will facilitate the explanation of these concepts. A simple homework assignment will also help illustrate discounting. For example, an assignment could be designed such that the present value of net benefits flips from being greater than zero to less than zero with a change in discount rates. A 10-year project with equal expected annual benefits and differing annual costs, for example, could be put into a spreadsheet. Students can be asked to evaluate the project using both rates and to make a decision. Variations on this type of exercise can include changes in estimated benefits or costs or a change in the expected lifetime of the project.

III. Divergence of Social and Private Discount Rates

A. Private market decisions or outcomes may differ from society's decisions. This will be the case if individual rates of time preference differ and if private risk premiums differ from social risk premiums. The **risk premium** is the amount required to compensate capital owners for potential differences between expected and actual returns. Different discount rates will result in market outcomes that are not efficient. Asking your students about their rates of time preference in relation to an expected sum of money or student loans should result in a variety of responses. Topics such as gambling or speeding on the highway can spark discussion (and interesting stories) and help to illustrate rates of time preference and variations in risk perceptions.

B. A Critical Appraisal

Concern over the reliability of benefit and cost estimates is commonplace and should not be ignored. Unreliable estimates limit the value of a benefit-cost analysis. Ex-post benefit-cost analysis can be useful for fine-tuning the methodology of future benefit-cost analyses. Some examples from *ex-post* analysis are presented.

Accounting stance, or the geography of who benefits and who pays, should also receive attention. Whether the costs and benefits are measured at the local, national or international level will affect the results. (See, for example, Howe, C.W. "Project Benefits and Costs from National and Regional Viewpoints: Methodological Issues and Case Study of the Colorado-Big Thompson Project," *Natural Resources Journal* 261 (Winter 1987): 5–20.)

The pros and cons of benefit-cost analysis should be overviewed and outlined at this point. Teaching students to think critically about these issues is important.

IV. Cost-Effectiveness Analysis

Cost-effectiveness analysis is a useful alternative to benefit-cost analysis when the measurement of benefits is impossible, or estimates are unavailable. This alternative involves the minimization of the costs of achieving a policy target, such as an emission standard. A

minimum-cost solution requires the equalization of the marginal costs of all possible alternatives (Second Equimarginal Principle). Various proposed standards can thus be compared for their cost effectiveness.

A numerical example of this concept will be extremely helpful.

V. Impact Analysis

Environmental impact statements attempt to quantify consequences of an action. Impact analysis is useful when the data needed for either a benefit-cost analysis or a cost-effectiveness analysis is unavailable. These present the analyst with as much raw information as is available without any optimization or benefit-cost analysis. More sophisticated environmental impact statements sometimes include benefit-cost analysis or a cost-effectiveness analysis.

■ Common Student Difficulties

Students with a limited background in economics will have trouble with the **equimarginal principle** and will frequently confuse total and marginal cost. Simple numerical examples that illustrate the maximization of net benefits in terms of equalizing marginal cost and marginal benefit should help. They may also have difficulty with the concept of optimization and Pareto optimal allocations. This might be a good place to also start talking about the role of government intervention.

The concept of **discounting** might also be problematic for some students. Examples they can relate to (all students will likely have a high rate of time preference for money) will illustrate present value and the role of the discount rate. Asking them if they would like $100 today or $100 on the day they graduate should nicely illustrate the time value of money. If they are skeptical, this type of question should help prove to them that most people have positive rates of time preference (prefer benefits sooner and costs later).

■ Suggested Classroom Exercises

Total Benefit and Total Cost: an example that illustrates the difference between total benefit and cost and marginal benefit and cost will be very useful. Use the equations given below and have the students calculate total benefit, total cost, marginal benefit, and marginal cost for values of X ranging from 35 to 45. Next have the students graph total benefit and total cost on one graph, and marginal benefit and marginal cost on the other graph. Have them find the optimal value of X.

$TB = 314X - 1.6X^2$ $MB = 314 - 3.2X$
$TC = 50X + 1.7X^2$ $MC = 50 + 3.4X$

The Discount Rate: An in-class example or problem set related to discounting will not only let the students learn with a hands-on example, but will likely ease their minds about the difficulty of the concept. Alternatively this problem can be done at home using a spreadsheet program. The spreadsheet problem set below is a hypothetical example of two proposed uses for a coastal area. Obviously, you can think of many different scenarios and sets of numbers. You can tell the students, for example, that a coral reef area will either be protected or mined. A set of costs and benefits is given for a 10-year period. As you can see in the answers, I have set this problem up so that the net present value changes from positive to negative with a change in the discount rate. This is a nice illustration of the effect of the discount rate. The example is also set up so that a different project would be pursued at a different rate. Additionally, the answers can be calculated using a continuous discount rate if you are teaching your students both discrete and continuous discounting. A discussion on the choice of the discount rate could be started here or saved for a later chapter.

Problem Set 1. Discount rates

Project 1. Gringoland Marine Park

	Years										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Costs (thousands of $)											
Construction	1250										
Recurring costs		130	130	130	130	130	130	130	130	130	130
Foregone recreation	20	20	20	20	20	20	20	20	20	20	20
Benefits											
Increased tourist revenue	300	300	300	300	300	300	300	300	300	300	300
Net											
NPV @ 5%											
NPV @ 10%											

Project 2. Gringoland Coral Mining

Costs (thousands of $)											
Extraction costs	3000										
Costs of coastal erosion	200	200	200	200	200	200	200	200	200	200	200
Benefits											
Revenues from limestone	4500										
Net											
NPV @ 5%											
NPV @ 10%											

Answers:

Project 1. Gringoland Marine Park

	Years										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Costs (thousands of $)											
Construction	1250										
Recurring costs		130	130	130	130	130	130	130	130	130	130
Foregone recreation	20	20	20	20	20	20	20	20	20	20	20
Benefits											
Increased tourist revenue	300	300	300	300	300	300	300	300	300	300	300
Net	–970	150	150	150	150	150	150	150	150	150	150
NPV @ 5 188.26	–970	142.86	136.05	129.58	123.41	117.53	111.93	106.6	101.53	96.691	92.087
NPV @ 10 –48.31	–970	136.36	123.97	112.7	102.45	93.138	84.671	76.974	69.976	63.615	57.831
Continuous *r*											
NPV @ 5 181.14	–970	142.68	135.73	129.11	122.81	116.82	111.12	105.7	100.55	95.644	90.98
NPV @ 10 –68.44	–970	135.73	122.81	111.12	100.55	90.98	82.322	74.488	67.399	60.985	55.182

Continued

Project 2. Gringoland Coral Mining

		Years										
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Costs (thousands of $)												
Extraction costs		3000										
Costs of coastal erosion		200	200	200	200	200	200	200	200	200	200	200
Benefits												
Revenues from limestone		4500										
Net		1300	–200	–200	–200	–200	–200	–200	–200	–200	–200	–200
NPV @ 5	–244.35	1300	–190.5	–181.4	–172.8	–164.5	–156.7	–149.2	–142.1	–135.4	–128.9	–122.8
NPV @ 10	71.09	1300	–181.8	–165.3	–150.3	–136.6	–124.2	–112.9	–102.6	–93.3	–84.82	–77.11
Continuous *r*												
NPV @ 5	–234.86	1300	–190.2	–181	–172.1	–163.7	–155.8	–148.2	–140.9	–134.1	–127.5	–121.3
NPV @ 10	97.92	1300	–181	–163.7	–148.2	–134.1	–121.3	–109.8	–99.32	–89.87	–81.31	–73.58

■ Essay Question

Consider a project that will require a sizeable expenditure today in order to realize a stream of net benefits over the next 20 years. What happens to the present value of net benefits as the discount rate rises? Is it likely that different people evaluating the same project would end up choosing different discount rates? Discuss.