4.4 VALUING ENVIRONMENTAL GOODS AND PUBLIC HEALTH: PUTTING A PRICE ON A SUNSET

A first step in understanding how environmental or health attributes might be measured is to recognize the distinction between "private" and "public" goods. A private or **market good** is an item or service for which the amount of use by one person reduces the amount available for others, and access can be controlled by an owner. These goods include a new car, a restaurant meal, or a club membership. Private goods can be traded among individuals. Prices for private goods reflect the value that individuals place on consuming a commodity up to the point at which the cost equals the "**marginal**" or **incremental benefit**.

Public or nonmarket goods are those amenities for which excluding any individual from benefiting is difficult or impossible. In other words, these goods are generally "nonrival"—others' consumption does not reduce the amount available—"nonexcludable"—people cannot be prevented from enjoying the good—and "indivisible"—the good cannot be divided. Classic examples of public goods include sunsets, national defense, lighthouses and recreational fisheries. Public goods range from "pure," such as a sunset, to those where access can be controlled or congestion becomes a problem, such as Yosemite Park.

The benefits received from public goods vary across individuals, and, because these benefits are essentially open to everyone, they can not be traded directly. Thus, unlike private goods, no "market-clearing" price is available as a proxy for each individual's marginal benefit. Likewise, if consuming a resource involves purchasing a private good (e.g., a tree for its lumber), but also results in adverse impacts, the market price is unlikely to reflect the net value of the public good or bad — no market exists for wildlife, so no explicit value is created through the economic system. Economists call this inability to put a price on a public good a **market failure**, and the value not captured in the market price for the private good is called an **externality**.

Market failures result in a divergence between "optimal," or preferred, *individual* choices and optimal *social* outcomes. If the market price for a private good does not capture the value of a public good which is being damaged or otherwise impacted (i.e., the price is too low), then individuals will tend to over consume the private commodity and overuse the public good. For example, if gasoline prices do not include the value of damages associated with air pollution, then drivers will buy too much gasoline and travel too far from a societal perspective. By valuing public goods it can be determined how much the preferred social solution differs from the current market-driven outcome.

While economists agree that economic value should be attached to public goods, large differences in actual values can exist among people enjoying the same nonmarket attribute. This is both because people value the same public goods differently, and also because there is no easy way to determine nonmarket prices — as previously discussed, public goods are not traded so "market-clearing" prices do not emerge. Further, a sunset viewed from a mountaintop will have a different value than one seen at the beach, both for a single individual and between two individuals. As a result, use of a single value for an environmental amenity or a health attribute in all situations is inappropriate.

Natural resources have several dimensions of value which can be derived using different methods:

Market price, traded commodities: To the extent that the resource has a

PAYING TO PRESERVE A RESOURCE OR BEING COMPENSATED FOR ITS DEMISE?

A problem in determining the appropriate value for public goods stems from the difference between ***willingness to pay*** *(WTP) and* ***willingness to accept*** *(WTA) values. WTP represents what an individual would be willing to pay to protect a resource from being destroyed. WTA is the flip side, or what an individual will accept as payment in return for giving up the resource. Under traditional economic theory, WTP and WTA should be equivalent — as they are for private goods. However, the empirical evidence on public good valuation has found significant differences between the two approaches.*

In fact, a close examination of the underlying compensation principles in economic theory finds that if a "public" good has no substitutes, a consumer can not be fully compensated for its loss with "private" goods (i.e., money). In this vein, WTP reflects a tradeoff among a portfolio of goods and is constrained by available income; WTA is made in the context of a willingness to part with a single good unconstrained by income, and theoretically could be infinity. Thus, WTA typically will be higher than WTP for preserving natural resources. For example, a homeowner near a stream full of debris and junk may not be willing to pay much to clean up the stream, but if that same stream was pristine, the homeowner may demand a substantial price to allow dumping of the same material at the site.

The implication for policymakers is that a "wedge" exists between the value associated with the compensation necessary to pay for the damage imposed on a publicly-owned good versus the value of the private good if the polluting firms hold the ***property rights*** *and those wishing to preserve the environment have to purchase the land. The asking price in the former case will be higher than the bid price in the latter. In this situation, simply assigning property rights does not lead to a "socially optimal" outcome and the wedge cannot be eliminated through some form of government policy short of a subsidy. Instead, the government must choose whether it will act as the owner of a preserved locale or compensate developers for their lost ability to utilize the resources.*

value in an ongoing market — lumber, fish, minerals — it can be assigned a price based upon its traded value. In the case of a redwood forest, this price would reflect the future worth of the timber produced. Market-based valuation requires an assessment of the future value of money, as well as other variables that could affect the future price of a commodity, but in general is a fairly straightforward technique using common economic assumptions.

Nonmarket values, nontraded, direct-use resources (use values): Some natural resources are utilized by the public but not traded in an economic **marketplace**. For instance, people expend resources to visit national parks and forests but generally do not pay an admission fee that reflects a true market-set price. In these cases, the economic value of the natural resource — equivalent to a "market-clearing" price — can be derived by evaluating the public's "revealed preferences," or actual **willingness to pay** to enjoy the resource. Such an analysis may include an assessment of travel time and **opportunity costs**, as well as admission fees, if estimated with the so-called **travel-cost method**. The travel-cost method can work well for natural resources which are visited frequently but is less accurate for valuing remote wilderness with few "consumers."

Nonmarket values, nontraded, unused resources (nonuse values): Neither of the first two values capture the worth of the simple existence of some resources to society. A remotely located, old-growth redwood forest has intrinsic value, whether used or not. This value has been subdivided by economists into four different categories, depending on what motivates the value, as follows:

- **Existence value** reflects society's willingness to pay for the existence or preservation of a natural resource. Values for natural resources exist—and may be quite high—even in cases in which people may never visit, or even see, the resource.
- **Bequest value** reflects society's desire to ensure the existence of a resource for future generations. For example, the Nature Conservancy considers its land purchases "a legacy for future generations." This value is considered to be essentially concurrent with existence value for analytical purposes.
- **Option value** reflects society's willingness to pay to protect a resource from **irreversible** development or demise (e.g., not harvesting a stand of old-growth redwoods, thereby retaining the option to use the resource at a later date). Option value may be thought of as an insurance premium for uncertainty about future preferences, incomes and technologies that may make the present value of future alternative uses for the resource greater than the present value of its current or proposed use.
- **Quasi-option value** is related to option value but is a risk-free measure of the **expected value** to society of information gained from postponing an

irreversible development. Quasi-option value is based on the concept that a resource's value and appropriate uses are discovered through time, and that irreversible development that destroys the resource cuts short this discovery process. Quasi-option value is the amount society is willing to pay to guarantee that this learning process continues.

Nonmarket values for, say, a unique old-growth forest may by higher than the market value of cut board because the total worth to society to protect the forest may be higher than its product value. However, nonmarket resources are not traded in any marketplace for two predominate reasons. First, property rights for existence values are absent — the owner cannot simply charge people for the pleasure of knowing the forest exists. Similarly, people cannot be excluded from enjoying the existence of the resource. Second, the **transaction costs** — the costs of putting together buyers and sellers — are quite high due to the nonexclusivity and lack of clearly defined property rights for both use and nonuse values. Although the market does not recognize these values, numerous indications say that they are real, such as the regular passage of parks bonds.

The notion that natural resources have nonuse values has played a role in American political thought for over a century and has been a part of economic theory for over three decades. The loss of a species or the disfigurement of an unique scenic area can cause acute distress and a sense of genuine relative impoverishment to society. A large portion of the millions of dollars in fees and voluntary contributions paid by members of environmental groups, and the willingness of environmental activists to volunteer their time to lobby for such legislation such as the Endangered Species Act can be cited as evidence for the reality of nonuse values. Economists consider the existence of unique and fragile natural resources a significant part of the real income of many individuals.

Society's belief in nonuse values is also reflected in various natural resource laws and regulations (e.g., the federal Endangered Species Act of 1973, and state-specific programs to insure the continued existence of farmland). These programs have real costs to both private sector firms and society in general, costs which represent one measure of existence values. Moratoria on timber harvesting on private lands, though rarely reimbursed by the public, also represent the value society places on the risk of losing a unique resource.

Since no market data exists on the nonuse values attributed to natural resources other means must be employed to determine these values. **Contingent valuation methods** (CVM) offer one of the best means of quantifying existence and bequest values. Other possibilities include assessing revealed political choice through actual ballot measures (initiatives or referendums) to purchase natural resources, or the estimated cost society pays as a result of legislative and regulatory action to protect the environment.

Studies have shown that nonuse values can be twice to almost ten times as great as the recreational or use values of a resource. The magnitude of nonuse value tends to depend on the unique characteristics of the resource, and whether the perspective is to estimate a willingness to pay to preserve the resource or a **willingness to accept** its destruction. For abundant goods, such as a sea gull, the existence value is likely to be quite small. Some unique resources, such as the Grand Canyon, may be "priceless" (see "Paying to Preserve a Resource or Being Compensated for Its Demise?" textbox).

While valuing environmental assets with economic methods is attractive from a policy making perspective, critics have argued that current techniques are inadequate for the job. Reducing the value of a single element in a complex ecosystem to "price metric" can result in abandoning information that may be important to **stakeholders** in weighing the significance of the entire system. In addition, valuation techniques generally rely on exploring the value of an environmental asset to individual consumers. This approach has two problems. The first is that most of us have little experience with attaching values to natural resources. The ability to determine values for various commodities and assets is developed through participation in markets—not a common activity for "buying" environmental assets. The second problem is that values for these public goods are contextual and developed from social norms. That is, consumer preferences are not independent of the setting or the moral values attached to the asset. Environmental debates are as much about establishing new social norms as about ordering preferences within the existing order.

4.4.1 NONMARKET GOODS VALUATION METHODS

Methods to value public goods have been developed over the last thirty years, with significant progress made in the last decade. These methods can be divided into two broad categories: environmental resource valuation and pollution-based valuation.

Environmental resource valuation includes the following methods:

- **Revealed preference or market-good unbundling.** The premise of this approach is that while people do not directly purchase a public good, they do buy associated market goods, incorporating the value of the public good into their willingness to pay. For example, one might value a view of the mountains by looking at the difference in price between two otherwise identical houses, one with the view, the other without. Two primary revealed preference methods have been developed:

  1. **Hedonic valuation; and**

  2. **Travel cost method (TCM).**

- **Direct inquiry or contingent valuation method.** This approach relies on directly asking people in a survey to make trade-offs between goods, non-market and market, in such a way that it reveals their inherent preferences. A common technique is to formulate the question as a referendum and ask what is the willingness to pay different tax levels to carry out a policy option. The direct inquiry method which has become most widely used is the *contingent valuation survey method.* This approach uses carefully structured surveys to ask impacted individuals about the value that they put on an environmental amenity. This approach allows for valuation of nonuse aspects such as existence values.

Pollutant-based valuation includes the following methods:

- **Politically-revealed preference or control costs method.** This method assumes that the choices made by political decision makers reflect the values of the voting public, and therefore these values can be determined from the compliance costs associated with the relevant regulations and laws. Emission control costs, as listed in the California Energy Commission's *1992 Electricity Report*, or the prices paid for permits under a tradeable permits program (e.g., South Coast Air Quality Management District's RECLAIM program) represent indicators used in this approach.
- **Damage functions.** This approach assesses the economic losses or avoidance costs associated with pollution based on scientific relationships between the source and impacted resources. This technique can draw on information from both the revealed preference and direct inquiry methods for valuation measures.

Detailed descriptions of each of these methods is provided in the sections that follow.

4.4.2 HEDONIC PRICING

Hedonic pricing is based on a fundamental economic principle that an analyst should be able to "unbundle" the value inherent in a good by examining how individuals weigh the various characteristics of that good. To do this, the hedonic pricing method takes the difference in prices for two similar market-traded goods, identifies differences in characteristics of the goods — such as environmental quality — and attributes the variation in market price to the value associated with the characteristics of interest. For example, if two identical houses in two different locations differ only in the degree of visibility allowed by air quality, the value of improved visibility is assumed to be the difference in property values. This difference is the implicit market price for the characteristic.

Data Requirements: Most hedonic pricing studies of environmental amenities rely on differences in property values. Thus, the key piece of data is information on sales prices for comparable homes or buildings. Information on other factors which may influence house prices, such as location relative to the workplace, quality of government services, other neighborhood characteristics, as well as measures of environmental quality, is also necessary. Differences in the **socioeconomic** status of home buyers are frequently used in the analysis.

Common Applications: Hedonic pricing can be used to estimate "use" values associated with owning property in specified locations. Nonuse values, such as those for existence, obviously cannot be determined this way because the value being derived represents an implicit market price for a good being "consumed."

Hedonic pricing was first developed to determine how much consumers would be willing to pay for options on automobiles, such as an automatic transmission. Economists have since used it to value differences in government services such as education and public safety. Hedonic pricing has recently been used to value variations in air quality in Southern California and water quality in the San Francisco Bay.

Strengths and Weaknesses: The fundamental theory of hedonic pricing is well understood, in a large part because the basic approach is used in demand analysis of market-traded goods. Hedonic pricing analysis is done in a wide range of settings and applications so that the literature is rich with methodological discussions.

Hedonic pricing can be limited in its applications because of the difficulty of obtaining the data needed to conduct the analysis. For environmental valuation, it is difficult to find data to compare market-driven prices with comparable fixed assets. Housing sales are the typical comparable asset employed in the analysis, but due to market volatility, the time frame for these sales must be consistent for the data to be of use. Likewise, it may be difficult to find comparable houses sold to similarly situated buyers in locations with different environmental quality. For example, large opulent homes are more likely to be located in higher quality environments. Even getting accurate house sale prices can be difficult because of the recording processes in various localities. Due to property tax law changes (e.g., Proposition 13) and the tendency for downward bias in property assessments, county tax rolls are also frequently not an accurate measure of property value. Finally, other factors, such as neighborhood or local schools quality, can have a large influence on housing prices. Often the estimation error in these other factors overwhelm the environmental values imbedded in the property through **multicollinearity**. In addition, differences in assumptions about housing supplies and the income and preferences of those purchasing homes can influence the interpretation of the results of hedonic analysis. For example, differences in household socioeconomic traits may prevent comparison of values between individuals.

Hedonic analysis has recently been used to assess how much people value life's amenities, such as enjoying a sunset, a good meal, or a beautiful day. The hedonic method relies on **benefits transfer** from other studies on how people value different amenities. While this approach holds promise, it is fairly new and has not been fully developed yet.

4.4.3 TRAVEL-COST METHOD

Description: The concept behind the **travel-cost method** (TCM) is that recreators incur travel costs to reach a site, and that these costs can serve as a proxy for the market price of the site. Site use would be expected to decline as distance and travel costs rise —the classic economic assumption about prices and demand. By observing people's recreation choices — site visits — the TCM traces out the prices paid by recreators in terms of travel costs to reach their chosen recreation site. As recreators travel to a selected site from diverse origins, their different travel costs trace out the price/quantity relationship known as the **demand curve**. Through application of this data, the **"use" value** for a resource can be measured.

Travel costs are based on both direct out-of-pocket costs — fuel, hotels, entrance fees — and the **opportunity cost** from giving up work income to travel to the site. This latter component generally is the larger of the two but also is the most difficult to measure. Usually, the analyst assumes that the opportunity costs of travel time equals some portion of the average hourly **wage** (e.g., one-third to one-half). Unfortunately, however, these estimates are derived from commuter surveys and may be unreliable for use in weekend recreation. The travel costs from the survey are then statistically extrapolated to the target population to derive estimated "user" values.

The shape of the **demand curve** for any particular resource and the value of any changes to the resource's recreational or aesthetic quality are sensitive to the presence of **substitutes, alternatives** and **complements**. The incremental value for a change in quality will be larger for resources with fewer **substitutes** or alternatives, that are located near other complementary resources (e.g., two neighboring national parks) that are closer to large population centers and that serve higher income user groups.

Data Requirements: Three types of TCM studies are usually done. The first approach uses surveys of individuals at the recreation sites to determine visitors' characteristics, including place of residence. These results are then used to statistically infer demand for a larger population group, including those who have not travelled to the site. This type of study requires in-depth surveys of a large number of recreators and the application of rather sophisticated statistical techniques.

The second approach uses a "gravity" model. This model takes a population with an expressed or known demand for various recreational opportunities and distributes this demand among the various recreational options based on the relative costs and characteristics for each option. Demand can be estimated from a household survey (rather than a site survey). The exact characteristics of those actually visiting the sites need not be known, but the total number of visitors to all facilities must be equal to the number of individuals who indicated that they visited the sites in the household survey. Otherwise, demand becomes insensitive to changes in travel costs due to the need to force total demand to equal a particular visitation level.

A third approach relies on **time series** analysis of a particular site. In this case, site visits are statistically compared to factors which might affect demand, such as changes in income, out-of-pocket costs per mile, the size of relative population centers, and key characteristics of the site. The difficulty with this approach is gathering enough observations to be **statistically valid**.

Common Applications: TCM measures only the "use" values associated with a resource, because the method inquires only about the costs expended by those visiting a resource. Nonuse values cannot be evaluated with this approach. This acts to limit TCM's applicability to resources which are not altered substantially by a policy option — that is, will not be destroyed or irreparably harmed — but rather are being managed in concert with other goals (e.g., timber harvesting or water supplies).

TCM has been used mostly to estimate the value attached to recreational opportunities such as fishing or hunting. For example, the values attached to salmon fishing in the Pacific Ocean and on the Sacramento River have been assessed in several TCM studies.

Strengths and Weaknesses: The travel-cost method has been used extensively by several federal agencies to evaluate the recreational benefits under their management. The method is probably the most widely reviewed of the nonmarket valuation approaches. The analytic steps are well understood, including the statistical estimation techniques.

The main weakness in the analysis, other than its limited applicability, is its reliance on the opportunity cost associated with travel and time spent at the location as the major indicator of value. These estimates often are based on analyses of commuter preferences from transportation studies which may not have been designed for use in measuring recreational activity. Travellers may attach a value to the trip itself, or may visit multiple sites, thus diminishing the opportunity cost of visiting a single site. Finally, the reliability of extrapolating values from visitors to nonvisitors depends on determining why people do not visit a site, a difficult task to accomplish.

4.4.4 CONTINGENT VALUATION METHODS

Description: Although it can be used to estimate both use and nonuse values, the primary goal of the contingent valuation method (CVM) is to create a simulated market for natural resource nonuse values. Through a questionnaire format, the physical change to be produced by the proposed policy (e.g., public protection of an old-growth redwood forest), as well as how the policy would come about, and how payment would be extracted from each household if the policy is implemented, is described. In some cases, various protection levels based on different prices are also characterized. The questionnaire is administered to a sample of individuals who would be affected by the proposed public policy to determine what they would be either **willing to pay** or **willing to accept** in order to have the policy adopted. The survey instrument typically is implemented only after several focus group meetings and pretests have been conducted. In general, in-person interviews are preferred to telephone interviews, as they allow researchers to better educate respondents about the characteristics of the resource in question.

Data Requirements: CVM analysis is based on survey results. Thus, the analysis requires a well-designed survey instrument applied to a representative population that fully understands the implications of the questions being asked. The questions must be constructed so that the respondents give truthful answers, not ones based on "gaming" the questionnaire. The survey sample must be large enough to be **statistically valid** — typically in excess of 100 individual responses. The response rate itself should be high enough so that it adequately represents the target population. A response rate of 25 to 40 percent is common on these types of surveys.

Common Applications: CVM has been used in many of the most visible environmental policy issues. Perhaps the best-known application was to assess damages in the *Exxon Valdez* Alaskan oil-spill case. While the actual damage evaluation done for the State of Alaska was not revealed, the lower bound estimate was reported to be $3 billion. Exxon ultimately agreed to a settlement of $900 million paid out over a nine-year period in addition to the clean-up costs already expended. Other applications include evaluating visibility in the Grand Canyon to determine whether pollution controls on a coal plant were needed and estimating a value for preserving the Northern Spotted owl through timber-harvesting restrictions. Damages from numerous maritime oil spills also have been determined using CVM.

Strengths and Weaknesses: Since the mid-1980s, CVM has been increasingly adopted by economists, public agencies and the courts as a valid methodology for determining the **nonuse values** associated with environmental goods. For instance, the District of Columbia Circuit Court of Appeals affirmed both the importance of nonuse values in estimating the costs of damages to natural resources and the use of CVM as the "best available technique" to quantify these values. CVM is now a widely accepted method recommended by the U.S. Water Resources Council for use by federal agencies for benefit-cost analysis, and by the U.S. Bureau of Land Management, the U.S. Army Corps of Engineers, the U.S. Forest Service, and the U.S. Department of the Interior for valuing resource damages. Environmental groups also generally have been supportive of CVM (see "The Blue Ribbon Panel and Contingent Valuation" textbox).

THE BLUE RIBBON PANEL AND CONTINGENT VALUATION

Issues related to the reliability and quality of contingent valuation studies have recently been raised in the assessment of natural resources damages. Since 1989, two federal agencies — the Department of Interior (DOI) and the Commerce Department's National Oceanic and Atmospheric Administration (NOAA) — have been in the process of issuing guidelines for the evaluation of environmental damages associated with oil spills and releases of other hazardous substances, as provided for by CERCLA (DOI) and the 1990 Oil Pollution Act (NOAA). In response to questions about CV techniques raised by various industry groups, NOAA appointed a Blue Ribbon Panel to review the measurement of nonuse values and the role of CV in their measurement. The Panel was headed by Kenneth Arrow and Robert Solow, Nobel Prize winners in economics; the other members were economists Roy Radner, Paul Portney, and Edward Leamer, and sociologist and survey expert Howard Schuman.

The Panel held public hearings and received voluminous comments during the summer and fall of 1992. Its report, issued on January 12, 1993 and subsequently published in the Federal Register, concluded that "CV studies can produce estimates reliable enough to be the starting point for a judicial or administrative determination of natural resource damages" as long as they adhere to certain guidelines. The guidelines cover various aspects of sample design, survey construction and survey administration. Any studies done assessing environmental resources should be assessed in light of these guidelines.

Although widely accepted, CVM has its problems. As a result of the difficulty in conducting an accurate CV, a large number of flawed CVM studies have been published. Unless adequate numbers of focus groups and pretests are conducted to accurately determine people's perceptions of the resource under consideration, there is no assurance that the survey respondents will understand, or believe, the characteristics of the resource they are "buying" or "selling." It is also difficult to get people to think about unfamiliar nonmarket goods in the same way as they think about goods they actually buy in the marketplace. This is a particular problem since a CVM study occurs in a much shorter timeframe than a more typical experience with marketplace goods.

CVs must address the need to distinguish individuals' overall environmental concerns from their interest in a specific resource (i.e., "aggregation"). For example, some studies have found that values expressed by individuals for preservation of an entire **ecosystem** may be substantially less than the aggregated values for preserving certain species of plants and animals in that ecosystem. Whether this occurs because of a theoretical flaw or misdesigned surveys has not yet been determined.

Individuals also may engage in strategic behavior when answering a CV survey. If the respondent believes that they will not actually have to pay their reported "price," they may overvalue the resource, while if they believe a tax or fee may be assessed based upon what they say, they may strategically underprice the resource. However, research suggests that strategic bias in CVM studies is not a major problem.

Another consideration in estimating nonuse values is the size and scope of the paying population (i.e., what geographic scope of people should be charged the estimated payment to cover preservation of the resource). For example, an old-growth redwood forest in California also may have an **existence value** to the population of the Pacific Northwest, the entire United States, or even other nations. Many environmentalists believe that protecting old-growth forests is a global issue. Typically, this question has been dealt with by assessing the nearby population (i.e., California in this case) and the full cost, and by discounting the expected payment as the populations become more geographically distant. Alternatively, people in distant locations could be surveyed to determine their **willingness to pay** for protection of a resource far away from them. This was the basis of the analysis done for the State of Alaska in the *Exxon Valdez* case.

Recent analyses have uncovered various inconsistencies in CV results. For example, responses are frequently unrelated to the respondents' income—an implausible result under the willingness to pay formula, which suggests that, all other things equal, higher-income individuals are willing to pay more for desired goods and services (see discussion ***"Paying to Preserve a Resource or Being Compensated for Its Demise?"*** textbox). A more serious problem is the differences in values individuals place on resources versus how the household they represent values the resource. In some cases, the sum of individual values is greater than the sum of household values from two identical surveys.

Another problem with CV is that biases in responses may occur as the survey questions change. This phenomenon is called *starting-point bias,* and results in valuations by individuals that differ only because the initial values that the survey taker offers as a starting bid for the resource changes. So, for example, a higher initial bid value can cause a higher final valuation by the individual. Although a technique called the *double-bid* method has been developed to solve this problem, whether this method will work in all cases is still untested.

4.4.5 POLITICALLY-REVEALED PREFERENCES OR CONTROL COSTS

Description: The politically-revealed preference (PRP) method assumes that society reveals its priorities about how to use various resources through the political process. These priorities, in the case of reducing pollutants, are manifested through varying levels of pollution control costs. In other words, the political forum becomes the equivalent of the **marketplace** in setting values on environmental resources. Polluters must pay a price, through controls, for using environmental resources, such as air quality or stream flows. As in a marketplace, economists assume that the marginal benefits to society are equated to the **marginal costs** in setting pollution control levels. In an efficient society, the control costs would be equal to the benefits garnered from reducing **pollution** at the margin (see Figure 5-1 in Section 5.2 "Benefit-Cost Analysis").

Data Requirements: The control cost method relies on three types of data. First are the air quality regulations set through the political process. This determines the target level for pollutants. The second is the required amount of pollution reductions to achieve these standards, broken down by source of emissions or effluent. And third is the engineering, financial and economic costs for each control measure required to achieve the required reduction. These values can come from either a centralized planning process, such as the South Coast Air Quality Management District's (SCAQMD) Air Quality Management Plan or the market price for tradeable permits, such as those for sulfur dioxide (SO_X) under the 1990 U.S. Clean Air Act Amendments.

Common Applications: The politically-revealed preference method can be used in many settings where information about control costs is readily available. The California Energy Commission (CEC) used values derived from SCAQMD analyses in its *Electricity Reports* until the CEC decided to rely on a damage function approach.

Strengths and Weaknesses: The politically revealed preference method relies on readily available data that is relatively noncontroversial compared to other non-market good valuation methods. Virtually all jurisdictions have relevant environmental regulations, and control cost data usually is not difficult to find. This method also has the benefit of giving back to policy makers the answer that they have already derived themselves about what are the important priorities, thus making the results politically palatable.

Using the PRP method raises three serious issues. The first is in its inability to distinguish exercise of political power from societal values. Policy makers often will choose the most politically attractive option without seriously considering the associated **economic** consequences of their decision. Likewise, control costs reflect all of the various factors — many of them noneconomic — which influence policy making, including institutional relationships, cultural influences, and interest group organization. As a result, control costs may not accurately reflect the aggregated <u>economic</u> choices that individuals would make. Conversely, some advocacy groups that believe that economic estimates should include equity and other concerns favor the PRP method because these values <u>are</u> embodied in the estimate.

The second problem with PRP is that the world is far from ideal, and decision makers do not possess perfect information about the true marginal costs and benefits associated with controlling pollutants. This makes moving sequentially from low cost to high cost options and equating marginal costs and benefits difficult. It can also lead to inconsistency in decisions among and even within jurisdictions about the relative value of pollution control. What may appear to be a difference in control costs may simply reflect variations in information availability among locations or even time periods. Because of the financial and political commitments necessary for most controls, a regulator is unlikely to reverse a past decision if a measure is found to be too costly relative to other options in the future. As a result, control cost results may be distorted.

These two problems can create a situation where certain polluting sources are over controlled, while others are under controlled. The former sources may be more easily identified (e.g., a large industrial plant) or less politically influential. The latter sources are often less identifiable (e.g., nonpoint sources) or politically valuable. Control measures may be imposed in the absence of adequate information based on a short-term public perception of large risks associated with the pollutant. The use of the control cost approach tends to perpetuate values despite changing information and attitudes because the political process and societal infrastructure are slow to change.

The third problem with the politically-revealed preference method is that <u>by definition</u> it may not give policy makers any new information. The values are derived from the policy makers' own actions in balancing benefits and costs. However, decision makers may not be fully aware of the cost implications of their choices, and the PRP can make these costs explicit. And finally, control costs are frequently defined by geographically broad—federal or state—legislation and applied equally to all localities. However, differences in geography, population, and other characteristics may make the actual benefits differ by area, an effect that would not necessarily be captured by the PRP method.

4.4.6 DAMAGE FUNCTIONS OR AVERTING EXPENDITURES

Description: Damage **functions** measure the *marginal benefits* associated with the relationship between pollution reduction and improvement or deterioration in health, cleanliness, and aesthetics. Damage functions provide an overarching measurement technique that incorporates valuation of resources from both the revealed preference and direct inquiry methods, as well as market-based measurements of economic losses associated with degraded environmental quality. The damage function approach examines how a pollutant impacts a large environment rather than focusing on a single resource and assessing its value given all of the environmental "stressors."

To estimate the ultimate economic effect of a particular environmental hazard, a series of relationships must be specified that trace the pollutant from its source to the damaged location ("receptor") and, finally, its associated value **determined**. First, the amount, location and time of the pollutant are identified. Next, the impacts of the pollutant on environmental quality are assessed. This must be done with an understanding of how the pollutant interacts under various environmental conditions, such as weather, terrain, season, biological setting and other pollutants. Third, the physical responses by humans or other biological resources are measured based on changes in environmental quality. This is known as the dose-response relationship. These responses include health effects (morbidity and mortality); ecological damage to vegetation and animals; damages to economic resources such as agriculture, timber or minerals; material damages to buildings, fixtures or vehicles; and aesthetics (visibility or odors). Dose-response functions assess the increased **risk** to the exposed population and those among them that are most susceptible. Finally, the physical responses are converted into economic values to society, usually denominated in dollars.

Damage function values can be derived both from measured income losses (e.g., crop losses due to ozone exposure) and imputed individual valuations (e.g., differences in house values from variations in visibility). Various market valuation techniques can be used to estimate direct economic losses — the revealed preference and direct inquiry methods are used to derive imputed

CAN VALUES FROM ONE SETTING BE APPLIED TO ANOTHER?

Because of the paucity of studies on valuing environmental and health ***attributes****, a number of analysts have tried to generalize these values from a few reports. Several problems arise from such* ***benefits transfers*** *—the use of study results from one problem or geographic area applied to a similar situation that differs in context or location—not least of which is that the original studies are often context- and location-specific. Also, many studies, particularly those for* ***nonuse values****, evaluate large environmental changes, such as the demise of a species or an ecosystem. Applying these values to the small impacts created by a single project or regulation is generally inappropriate.*

The problems associated with benefit transfers depends on the amenity at issue. Generalizing health benefits may be appropriate in some cases, but the values are usually dependent on the characteristics of the affected population. As a result, a benefit transfer requires adjusting for demographic differences. Transferring recreational values is more problematic because the studies are almost always site specific.

In addition, two fundamental mathematical problems arise with regard to applying values from one situation to another:

- *The possibility of* ***nonlinearities*** *in the valuation of particular outcomes or attributes; and*
- *Nonadditivities in the valuation of multiple items resulting from these nonlinearities and the shape, or "curvature," of the estimated benefits* ***function****.*

Nonlinearity refers to the fact that the marginal value associated with an increment in some outcome variable may not be a constant. Nonlinearity can cause values to change dramatically for small incremental shifts in the variable. For example, a loss of 1,000 salmon out of a run of two million fish does not have the same value as the same salmon loss out of a run of 2,000 fish. This may reflect a "threshold" effect.

Nonadditivity refers to the fact that the value associated with a given increment in one outcome variable may be affected by the levels of other outcome variables. As a consequence, the value associated with a change in, say, two outcome variables may be more or less than the sum of the values associated with a change in each separately.

valuations for health impacts, ecological resources and aesthetics.

Data Requirements: The damage function approach is probably the most complex type of analysis in assessing **nonmarket goods**. It requires a scientifically tractable and well-understood relationship between a pollutant and the associated environmental impact. These relationships always have a degree of **uncertainty** that should be identified and discussed in the analysis. The method requires an extensive effort to identify and value the range of features which are impacted by the pollutant. This means that significant consequences for market resources could be usefully modelled (e.g., accelerated paint deterioration requiring more upkeep, crop yield losses). Also, nonmarket resource valuations (e.g., respiratory ailments from air pollution) should be appropriately scaled to the pollutant impacts. For example, using **contingent valuation** results for the entire loss of a salmon run is not applicable to a situation where a small portion of a similar run might be lost. In most cases, damage function analyses rely on data from other studies to determine economic values in a process called **benefits transfer** (see "Can Values From One Setting Be Applied to Another?" textbox).

Common Applications: Because of the complexity of damage function analysis, it is usually reserved for situations where pollutants have a large and wide ranging impact on the environment. In California, the damage function approach has been used both in setting air quality regulations in the South Coast Air Quality Management District and in determining air quality values associated with electricity generation at the California Energy Commission.

Strengths and Weaknesses: The damage function approach is the next logical step in taking scientifically-estimated environmental impacts and applying these estimates to economically-estimated environmental values to calculate expected damages from specific contaminants, hazards or actions. Creating a damage function is a necessary step in developing an economic analysis for controlling particular pollutants or establishing various standards.

Damage functions focus on marginal changes in the environment from reducing or increasing pollution. This is in contrast to the focus on entire environmental assets embodied in **hedonic pricing, travel-cost models**, or **contingent valuation methods** (e.g., an old-growth forest, not on an *incremental* change in that asset such as harvesting ten percent of an old-growth stand). Damage functions evaluate incremental impacts by measuring the **marginal value** of changing an environmental **asset**. This is the preferred theoretical approach in economics.

While the damage function approach *per se* is theoretically sound, there are some reasons for concern as to whether the existing literature is adequate to support all of the specific dose-response and damage functions that are embedded in a model. In particular, two sets of questions arise:

(1) Are the studies used as the basis for the valuation functions of sufficiently high quality that they are reliable for this purpose?

(2) Is it valid to extrapolate from these studies when formulating model equations, and is the methodology **robust** enough to shift from one type of exposure application to another?

An important consideration in assessing whether to use linearly adjusted economic values — the typical method — associated with pollutant exposure is to determine whether the economic-loss function is **nonlinear** (i.e., it accelerates in intensity as the level increases) or if it is **discontinuous** (i.e., it achieves a certain threshold after which damages increase at faster rates). In the latter case, the issue is the ability of the system (e.g., a human body or the air quality of an air basin) to absorb and adjust to the stress of the effect. This can be measured in part by whether the peak incident approaches or exceeds the carrying capacity of the system.

The applicability of different dose-response studies also is important. For example, most economic studies of values associated with air quality levels have focused on **average** ambient levels over some period of time or at best daily maximums. This limitation is a result in part from a lack of scientific studies that attempt to measure the impact of peak exposures, the usual focus of regulatory action. Studies of peak exposure require either laboratory experimentation or a focus on a region in which large fluctuations in air quality can be predicted with some certainty. Symptoms manifested by prolonged exposure are likely to be different from those associated with acute episodes.

Another problem with the damage function method is the large uncertainty associated with both the scientific data and the economic valuations. Health and ecological impacts usually are based on applying laboratory results to theoretical environmental conditions. The inability to precisely measure environmental conditions can lead to large ranges in the estimated effects. The confluence of several environmental factors complicate this further. The uncertainty in economic valuation techniques, particularly those for nonmarket resources and amenities, likewise accentuates this problem. Thus, any damage function analysis can usefully include a range of possible valuation estimates and if possible, a distinction between the scientific and economic uncertainty.

4.5 VALUING A LIFE

A "statistical" life represents the **probability** that a certain event or action will cause the loss of a life. This might be measured as the number of deaths per million population or the percent probability of death each year for the exposed population. Three different techniques to value a statistical life are used most commonly today. These techniques draw on the nonmarket valuations previously discussed. The first, called the *human capital* approach, uses the expected future earning of an individual to estimate the value lost from their death. The second, called ***willingness to accept,*** relies on pay differentials for various occupations that have different types of risk. The third, called ***hedonic valuation,*** tries to value all aspects of the quality of life through various methods. This latter method is not yet well formulated or widely applied (see "To Be or Not To Be, That Is the Question" textbox).

The *human capital method* takes the net present value of an individual's expected future earnings and assumes that this sum reflects how much that individual valued the remaining years of their life. This method is still commonly used in wrongful-death lawsuits. While this approach may be useful for determining direct compensation for the death of a particular individual, it has three serious problems for policy applications. First, it values the life of a wealthy person more than a poor one, and when younger individuals are considered, it can not address the issue of unknown potential earnings due to a

TO BE OR NOT TO BE, THAT IS THE QUESTION

What is the value of life? Philosophers may ponder this question, religious leaders may deliver sermons on the subject, but economists believe they have the answer. Economists assume that individuals prefer leisure activities over work, and to give up their diversions, people must be paid a wage. Economists extend this concept to assert that individuals will also undertake more risk if they are paid an amount equal to how much they value the chance that they may die.

Decision makers continually put implicit values on life when they make choices about health and environmental safety. And decision makers frequently must trade-off one risk against another (e.g., allowing the sale of poisonous fungicides to prevent even more highly carcinogenic wheat fungi). Economists attempt to make these values explicit so that they might be debated more readily.

lack of knowledge about a person's abilities or goals. Second, it tends to value the life for a hypothetical "average" person, one which may not be representative of the type of person a specific policy might impact. And third, the human capital approach views the value of life solely in terms of **income** generated by an individual. The life of an impoverished artist or activist, such as Van Gogh or Mother Teresa, would have a low value despite the fact that the person might be making a significant contribution to our quality of life.

A more popular approach to valuing a life is based on the *willingness to accept* certain risks for extra compensation in various occupations. The willingness to accept method uses the same principles as hedonic pricing for nonmarket goods. First, an analyst chooses a set of occupations which have different death and injury rates but which includes similar **socioeconomic** groups, for example, firefighters and carpenters. Then the analyst compares the differences in **wages** between these occupations, calculates the difference between the expected death rates for each occupation, and divides the income difference by the death rate difference. The resulting sum theoretically equals the value each worker puts on his or her own life. For example:

Occupation	Annual Wages	Probability of Death
Firefighter	$40,000	2%
Carpenter	$30,000	1%
Difference	$10,000	1%

The value of a life would be $10,000/0.01 or $1,000,000 in this case. One can do a similar study examining the differential in automobile prices based on their level of safety.

To the degree that the increased risk can be isolated to the difference in occupations, this analysis captures the full economic valuation an individual places on the higher risk. This is true because the analysis focuses on a **marginal** change in risk levels rather than a total change in risk. Because people derive satisfaction both from goods and services purchased with income and from leisure, the human capital method cannot capture the value of leisure time. The willingness to accept method assumes that everyone's value for leisure is the same at the margin, and any change in wages is due solely to changes in risk levels. Thus, the value of leisure is separated from the problem.

Generally, estimates of the value of a statistical life derived from willingness to accept analyses range from $2 to $8 million. However, a recent U.S. EPA analysis found that the Agency placed an implicit value of between $45 and $100 million per life.

Beyond these wide ranges, willingness to accept has several other problems. First, it glosses over important factors which influence how people choose their jobs. Some people are thrill seekers and enjoy risky jobs, and others say "it can't happen to me" (also known as **cognitive dissonance**). A firefighter, police officer or skyscraper construction worker is probably attracted to the nature of the job, not the pay level. Others may view the higher income potential as the only way out of their economic poverty. A certain amount of tradition dictates job choices as well – sons tend to follow fathers into the coal mines.

Second, willingness to accept cannot adequately account for all the different factors that make jobs more or less desirable due to nonwage issues, such as responsibility, flexibility, other types of challenges, and impacts on leisure time. Third, people view risks that they believe they have some control over differently from risks that are "uncontrollable" or cannot be seen. For example, despite the better safety record for airplanes, most people feel less anxiety when they are behind the wheel of a large automobile.

Fourth, willingness to accept tends to lump an impacted population together as though it is represented by an "average" person. For policies that affect a broad population, this method may be appropriate, but if the focus is on certain socioeconomic groups or localities, the values may be inappropriate. And finally, the value for a statistical life (i.e., the probability that an additional life is saved from an action) is generally derived from accidental deaths rather than environmentally-related mortality. However, individuals are just as likely to put a value on *how* they die as *whether* they die.

4.6 GETTING THE MEASUREMENTS RIGHT

While policy analysts prefer using economic-based measurements even in cases where noneconomic attributes are of key concern, as discussed in Section 4.4, both economic and noneconomic measurements are used in **decision analysis** (see Section 5.4 "Decision Analysis"). However, combining economic and noneconomic **attributes** raises the issue of **commensurability** — the ability to compare across dissimilar attributes. In general, if attributes are to be quantitatively combined within an **objective function**, they must satisfy the following conditions:

- **Cardinality**: **Cardinal scaling** of an attribute implies that the attribute can be measured in **real numbers**. It is not enough to be able to say that alternative A is better than alternative B which is better than alternative C. Such a ranking represents an **ordinal scaling**. Instead, it must be specified how *much* better: for example A is 1.2 times better than B which is 3 times better than C. The later example constitutes a cardinal scaling (see "Addition of Rankings: A Cardinal Sin" textbox).
- **Common timeframe**: Timeframe refers to the interval over which the attribute is being measured. If attributes are to be commensurable, they must be compared over the same timeframe. And any accounting made for the **time value of money** — such as **discounting** — must also be applied consistently in and across analyses which compare alternatives (see Section 4.3.1). Timeframe related **assumptions** also affect estimates of how firms behave in the short and long terms, as follows:
  - In the short term, or in a truly **competitive market**, an analyst might assume that output levels and **prices** are fixed. In this case, the firm tries to maximize **profits** within the **constraints**, such as prices and input levels, at play. In the long term, however, the firm may maximize profits

given *flexible input and output levels.* As input or output prices change, the firm is allowed to change the input mix or production levels to maintain optimal profitability.

- **Common accounting stance**: An accounting stance refers to the spatial — geographic — and temporal — time horizon — boundaries of the analysis. These boundaries define what will be included in the analysis and what will be left out. For example, the population of interest must be identified. This is particularly important for state-based policies, in which California may benefit, but at the cost of Nevada. Likewise, in **benefit-cost analysis**, benefits and costs must be accounted for equally. The **baseline conditions** used in the analysis have critical implications to analytical findings, particularly when comparing outcomes between two policies or across time.

ADDITION OF RANKINGS: A CARDINAL SIN

It is not uncommon to find decision makers using the following inappropriate procedure for selecting the preferred alternative in a ***multiattribute decision*** *process:*

(1) Rank each alternative within each attribute (i.e., best equals 1, next best equals 2, etc.).

(2) Add up the attribute scores for each alternative.

(3) The preferred alternative is the one which has the lowest total score.

This procedure violates the need for cardinality in two ways. First, by adding rankings within an attribute, one implicitly assumes that the differences among the ranks are equal, which may not be the case. If alternative A saves ten lives, alternative B saves two lives, and alternative C saves one life, the ***ordinal*** *rankings would be A = 1, B = 2, C = 3. This mistakenly implies that it is just as important to move from C to B as it is to move from B to A. This faulty procedure only properly works in cases in which each ordinal interval happens to be equally important.*

The second fallacy of this method is introduced by adding rankings among alternatives. This action reflects the assumption that each attribute has equal weighting. Assume the second attribute is cost, where A costs \$3,000, B costs \$2,000 and C costs \$1,000 (in the case discussed above). The rankings are A = 3, B = 2 and C = 1 for this alternative. When the ranks for each alternative are added together, all three alternatives are tied at 4 points each. This suggests that the misguided decision makers are indifferent between saving one life at a cost of \$1,000, two lives at a cost of \$2,000, or ten lives at a cost of \$3,000.

Clearly, a cardinal measurement error has been made here.

5 ANALYTIC DECISION MAKING METHODS

Analytical decision making methods use the measurement techniques described in Chapter Four, combined with the systematic approach discussed in Chapter Three, to develop comprehensive assessments of proposed public policies. There are numerous analytic **decision making** methods available to environmental decision makers. A fairly complete — but by no means comprehensive — list of applicable approaches include the following:

- Cost effectiveness Analysis
- Benefit-Cost Analysis
- Least-Cost Planning
- Decision Analysis
- Risk-Related Analysis

Each of these techniques is described in the subsections that follow, including the method's theoretical basis, its data and modeling requirements, common applications, and strengths and weaknesses.

Ignoring environmental externalities can lead to unpleasant and dangerous consequences. For example, according to Alfred Kahn: "Our cities are clogged and decaying in large measure because automobiles are not charged their full marginal costs, including congestion costs. We confront the possibility of a new world energy shortage in large measure because we have not priced energy at its full marginal costs. We have become increasingly concerned about the destruction of our environment by a market system which fails to reflect marginal external costs in prices."

The need for analytic methods for environmental decision making in part stems from the existence of environmental externalities. These **externalities** arise when individuals make resource allocation decisions without taking into consideration the impacts of their choices on society (see "Environmental Externalities" textbox). Each of these methods is described in order of increasing complexity and required analytic resource needs and level of effort.

5.1 COST EFFECTIVENESS ANALYSIS

Description: Cost effectiveness analysis is a very straightforward and direct means of comparing alternative methods of solving a particular problem. A cost-effective solution is defined as the lowest-cost alternative which accomplishes a specified purpose. Cost effectiveness can also be viewed relatively. For example, it can be determined whether one measure is less costly than another in achieving a desired level of environmental protection.

Theoretical Basis: Cost effectiveness analysis is chiefly a matter of common sense. After all, common sense strongly suggests that it is economically **efficient** to use the least-costly method to achieve a given purpose. However, **economics** dictates that to achieve efficiency **utility** must be maximized within a **budget constraint**. To satisfy this condition, goods and services must be obtained for the lowest possible **price**. Cost effectiveness analysis enables policy makers to identify a "frontier," or group of efficient policies, thereby allowing decision makers to consider the trade-offs between means of achieving a goal.

ENVIRONMENTAL EXTERNALITIES

Environmental regulation focuses on minimizing damages to human health, welfare, and the environment. Another way to think about these damages is as societal ***costs****. Economists call the unreimbursed costs imposed on the environment by human activity "environmental externalities." These costs are "external" in the sense that those imposing the damages are not required to pay for them.*

Externalities *arise when individuals make resource allocation decisions without taking into consideration the impact their choice has on the rest of society. Environmental externalities may engender the need for public regulation. However, even after complying with government laws, private firms might still create externalities if permissible pollution levels cause damage to others.*

Data Requirements: Cost effectiveness analysis follows the steps outlined in Chapter Three: a goal is defined; a range of alternatives identified; and data collected to examine the alternatives. As with **benefit-cost analysis** (see below), benefits and costs must be accounted for equally and are usually defined in common terms.

Common Applications: Cost effectiveness analysis is frequently used in environmental policy evaluation. For example, the California Air Resources Board (CARB) estimates the costs per ton of reducing polluting air emissions associated with different air pollution control methods. Based on this analysis, CARB has determined that, if a pound of oxides of nitrogen can be reduced for $5, it is not efficient to require the expenditure of $10 per pound to obtain like emission reductions.

Strengths and Weaknesses: The main strength of cost effectiveness analysis is that it is simple to apply. The main drawback to this technique is that it assumes that the goal being examined is worth achieving. That is, cost effectiveness does not test whether a particular policy's benefits exceed its costs; it takes that as a given and simply seeks the least-cost method of obtaining the chosen objective. This limitation is especially troublesome in cases where decision makers do not fully understand the difference between benefit-cost and cost effectiveness analysis, and where even the least-costly option is expensive.

To make behavioral models tractable, economists have developed a set of simplifying assumptions, including transitivity. Transitivity is essentially a logic-based formula that states that if A is preferred to B, and B is preferred to C, then A is preferred to C. This technique makes choosing among alternatives through indirect comparison possible.

An additional weakness of cost effectiveness analysis arises when the cumulative effect of policies adopted based on cost effectiveness analysis acts to significantly impact the economy in unforeseen ways. In other words, policy-specific cost effectiveness tests do not necessarily protect a state or region from being overburdened by environmental regulations.

AVOIDED COSTS: HOW DO THEY MEASURE UP

Avoided costs *are used to compare the* ***cost effectiveness*** *of two alternative investments, one being the current standard practice for which cost information is readily available and the second being a new innovation. The first investment represents a cost that could be* ***avoided*** *by choosing the second one. The avoided-cost rate provides a ceiling on potential costs associated with alternative management solutions.*

The avoided-cost concept was first introduced in electricity resource planning in the 1970s. During this period environmentalists and private power developers began to ask utilities to consider using conservation, cogeneration or renewable energy instead of the usual fossil-fueled sources to generate electricity. Utilities and regulators responded by telling these groups that these alternative resources would be chosen if they could beat the "avoided costs" for new natural gas or coal-fired plants. The result was rapid development of conservation and cogeneration opportunities that cost less than traditional generating facilities.

The avoided-cost method is now being applied in other environmental forums. In solid-waste management, for instance, recycling expenses are compared to the avoided costs of expanding landfills due to diversion of the waste stream. Water conservation efforts are measured against the avoided costs of building new dams. Avoided costs are usually measured in a standard unit, such as cents per kilowatt-hour of electricity, dollars per ton of waste, or dollars per acre-foot of water.

5.2 BENEFIT-COST ANALYSIS

Description: Although its use is limited at Cal/EPA and its associated boards and departments, **benefit-cost analysis** (B/C) is the analytic decision making technique most widely used by public sector agencies. It is also the most frequently *misused* technique. In concept, B/C analysis simply seeks to determine whether an action's benefits will exceed its costs. The use of B/C analysis is intended to promote economic **efficiency**. In practice, there are many variations on what is meant by B/C analysis, and even more interpretations of how benefits and costs should be measured.

BENEFITS AND COSTS: WHAT'S THE DIFFERENCE, AT THE MARGIN, WHETHER A RATIO IS USED?

B/C is variously defined as a ratio, a difference or a marginal value. Historically ratios have been used to evaluate water projects. Generally, a B/C ratio greater than one justifies the adoption of a water project or environmental policy. Under this method, project costs and benefits are tallied, and a B/C ratio — dollar benefits divided by dollar costs — is calculated. This same application can be used for environmental control measures, except the cost is usually born by the polluter, while the benefits accrue to all of society (and vice versa: the costs of the pollution are born by society, and the benefits of polluting go to the polluter, as well as to the consumer in the form of lower prices). Regardless of who bears the costs and who reaps the benefits, a policy is considered to be economically ***efficient*** *if costs do not exceed benefits.*

Differences — defined as benefits minus costs — convey more information than B/C ratios because they take into consideration project scale. If there is a budget limitation — which there generally is — differences allow decision makers to rank all potential projects where benefits exceed costs in order of greatest net benefit. That is, in general it is net benefits that should be maximized, not the B/C ratio. A similar strategy using more approximate ratios would result in lower economic efficiency.

Perhaps the best use of B/C analysis is to estimate marginal, or incremental, benefits and costs. Under this framework it is economically efficient to increase environmental expenditures until the incremental costs of doing so equals the incremental benefit. ***Least-cost planning*** *reflects this principle (see Figure 5-1).*

Theoretical Basis: Economic activity frequently engenders pollution. According to economic theory, the optimal pollution level is the level that would result under the following conditions:

(1) The marginal, or incremental, cost of controlling emissions is equal to the marginal benefit of control (see textbox above).

(2) Control is achieved by the least-costly method available (cost effectiveness).

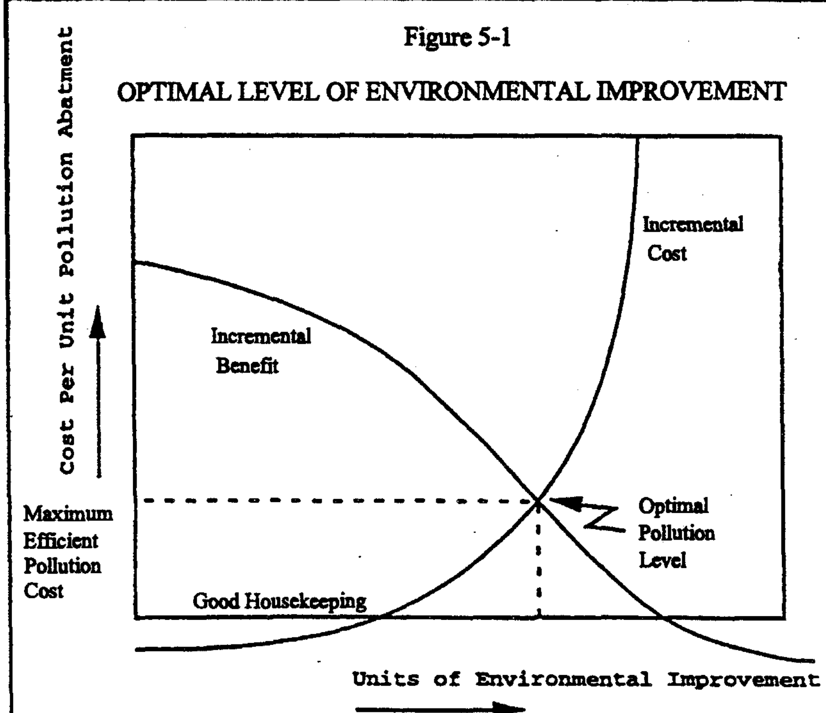
(3) Environmental control restrictions are equal over all emission sources. That is, no firm would be willing to pay another firm to reduce its pollution further to satisfy the first firm's requirements. This last condition is derived from the **Kaldor-Hicks efficiency criterion**.

Figure 5-1 illustrates a generalized pollution control situation: **marginal costs** trend upward while marginal benefits decline. The socially optimal pollution level is at the intersection of the marginal cost and benefit curves. Said differently, the costs to control each successive unit of pollution go from perhaps less than zero — implementing good housekeeping procedures — to greater and greater costs as more sophisti-

All of the methods described in this chapter combine measurement techniques discussed in Chapter Four into environmental decision making methods. These methods do not purport to mechanize or automate decision making, nor do they obviate the need for judgement and discretion. Use of these methods will, however, make what would otherwise be implicit decisions explicit; provide a logical and consistent framework for incorporating available technical data with subjective judgement; and create an orderly decision making procedure with a documentable record.

Figure 5-1

OPTIMAL LEVEL OF ENVIRONMENTAL IMPROVEMENT



cated methods are employed. Finally, these costs become almost infinite as it becomes technologically or physically impossible to reduce pollution further.

Data Requirements: The precise data requirements of B/C analysis depend on how it is being applied. However, in general deriving marginal cost — and especially marginal benefit — curves can be a very data-intensive undertaking. The analytical methods described in Chapter Four are used to estimate benefits and costs. Defining the **accounting stance** of the analysis is critical to this process. It is also important to clearly identify to whom the benefits and costs will fall. For example, some policies have statewide consequences, while others focus on particular groups. Whatever accounting stance is used must be applied consistently to benefits and costs, and to all alternatives being considered (see Section 4.6).

Common Applications: Although public sector agencies have relied on B/C analysis to evaluate resource projects for over a half-century, its application to environmental policies and programs has been slow to develop. Most of the applied B/C work done to date has focused on water and air quality issues, including comparing the costs of air quality compliance controls with the benefits from reductions in polluting air emissions. Academics have conducted substantial research on the use of B/C analysis in environmental problem solving, but this work is frequently of limited use to policy makers because it does not always focus on topical issues and often relies on inadequate data.

Strengths and Weaknesses: B/C analysis provides a consistent framework for organizing information and evaluating trade-offs. Likewise, the method defines what is an "efficient" outcome based on the economic assumptions

THE COSTS OF OBTAINING BENEFITS

B/C analysis can be conducted in a strictly monetary sense, or it can be understood from a broader perspective. From a stringently economic perspective, benefits and costs tend to be tallied in monetary terms. However, it is almost always more difficult to estimate the benefits of environmental polices than the costs. Although compliance costs can frequently be passed through to consumers, these expenses are initially borne by individual polluters, who tend to be well aware of their magnitude. Benefits accrue to all of society, and come in the form of cleaner air, reduction in health care costs, longer lives, greater productivity, and increased well-being. While all of these attributes are clearly worth something, their dispersed nature and lack of "tradeability" makes their value difficult to measure. Further, it is difficult to tie benefits to a particular control action — visibility in Los Angeles may not improve on a given day because of South Coast Air Quality Management District actions so much as due to weather changes. While economists are developing methods to address all of these problems, they continue to present problems to analysts.

discussed elsewhere in this handbook. In addition, the technique increases the objectivity with which decisions are made and as a result adds to the credibility of governmental decision making. However, B/C analysis has distinct limitations. These weaknesses do not act to debilitate the method as a decision making tool but should be kept in mind when using B/C analysis. Key deficiencies include:

- B/C — and other economic and financial — analysis tends to emphasize easily monetized costs and inadequately addresses more complex benefits. This is a particular problem for environmental policies, which are typically oriented towards generating broad social benefits that are not easily measured (see "The Costs of Obtaining Benefits" textbox).
- B/C and **cost effectiveness** analytical results are typically sensitive to a number

WHAT IS "SOCIAL WELFARE"?

Defining and measuring "social welfare" is the "Holy Grail" of economics. Although a single measure of social welfare has never been developed, economists make many recommendations to improve societal well-being based on presumed measures, which most often reflect changes in total tangible ***wealth*** *(i.e., income and material goods). This wealth-based approach has been criticized for excluding less tangible amenities, such as the environment and public health, and for ignoring how the distribution of economic gains and losses affects the social fabric.*

Policy analysts must consider other factors, such as institutional and organizational relationships, demographic trends, and issues of social justice, to fully evaluate progress toward social welfare goals. Economics can inform this analysis by rigorously defining and quantifying many of these dimensions. Claiming that these issues are too "fuzzy" to be rigorously examined ignores the many analytic tools available to an analyst.

of basic assumptions — including the **discount rate** and **price elasticities** used. As a result, sole reliance on a single B/C estimate can result in misleading counsel.

- By expressing values in monetary terms, B/C — as well as cost effectiveness — analysis tends to focus attention on efficiency issues, neglecting considerations of **equity** and **risk**. As a result, when using B/C analysis it is important for decision makers to separately and comprehensively weigh such concerns where applicable. While B/C analysis may indicate that a policies' aggregate benefits may exceed its costs, this does not mean that each individual is necessarily better off under the policy (see "What is 'Social Welfare'?" textbox).
- When not carefully applied, benefits can be double counted in benefit-cost analysis. For example, agencies may treat **transfer payments** from one entity to another as a benefit, when in fact the transfers cancel one another out.

5.3 THE "LEAST-COST" PLANNING APPROACH

Description: In **least-cost planning** (LCP), the costs (or savings) per unit of **pollution** (weighted by relative environmental damage) are calculated for each policy alternative. This process is derived from **cost effectiveness analysis.** The benefits of reducing environmental damage are also estimated with economic valuation techniques to derive a societal "demand" for environmental improvement. The options are then ranked by relative cost and the implementation level chosen through the planning process to the point where the cost equals the total economic benefit of adding the last option.

LCP was originally designed as an approach to minimize the total cost of electrical generation, including environmental damages. Utility companies who have many possible alternatives for meeting **demand**, each of which has a different set of capital and operating costs, use LCP to decide how to expand their system capacity to meet rising demand at the lowest cost. Government regulators use LCP to ensure that required utilities provide the lowest-cost energy to their customers. Utility companies also use the related short-term decision models, called **dispatch models** to decide which units to operate at any given time.

Theoretical Basis: The least-cost planning methodology is based on a fundamental assumption of standard economic theory: *that the results of least-cost planning by a central authority should be equivalent to the market-driven outcome if prices fully reflected social costs.* The benefits of reducing one more unit of pollution is balanced against the cost of reducing that unit of

POLLUTION PREVENTION: NEGAWATTS VERSUS MEGAWATTS

The goal of pollution prevention is to limit the use of toxic and polluting materials in production processes so as to reduce the ultimate amount of pollutants and waste. This principle is the same that guides energy conservation, where the amount of energy consumed is reduced through changes in the production process, choices of inputs, and types of products. The argument is made that pollution prevention should be done to the maximum extent possible. However, such an assertion implies the total cessation of economic activity unless an economically defined stopping point is chosen. While pollution prevention is an important method in achieving a better environment, it is not a goal by itself, just as energy conservation is one of several tools in managing energy costs and waste.

Many of the same analytic tools used to decide if energy is best conserved or produced can be applied to pollution prevention analysis. Analysis of energy conservation has evolved over the last 20 years since the first energy crisis, and much has been learned about what the right and wrong approaches are to the problem. In the case of conservation, energy use is reduced up to the point where the costs of conservation—"negawatts"—equal the avoided costs of producing the energy—"megawatts." Once it becomes more cost-effective to build, say, a new electric power plant, conservation is no longer a preferred option, and the power plant is built. This fundamental principle guides decision making at the California Public Utilities Commission and Energy Commission.

In the same way, pollution prevention can be evaluated using economic tools. The costs of reducing use of offending materials can be compared to the avoided costs of damaging the environment and producing goods using a polluting process. Once the costs of pollution prevention exceed the avoided costs or "benefits," pollution prevention is no longer the preferred management option.

pollution until the **marginal** benefits and costs are equal. In a hypothetical market, this is the theoretical price **equilibrium**.

In the case of electricity, when social or environmental costs are ignored, least-cost generating decisions inefficiently allocate generation capacity to polluting generation units. By including the full cost to society of the pollution from each unit, as well as its conventional operating costs, **externalities** are internalized.

Data Requirements: Two data sets are necessary when using least-cost planning for environmental regulation. The first data set includes the normal market-valued information on capacity, capital and operating costs, and reliability and availability constraints for each production technology. These data are readily available and comprise the inputs normally used in conventional least-cost planning models. The second data set includes the environmental costs associated with production from each unit. These include costs

A TALE OF TWO GENERATING UNITS

Least-cost planning relies on site-specific data on environmental and conventional costs. For example, consider an evaluation of two physically identical electric generating units. Both units have similar polluting emissions. However, one is located in an urban area, close to electrical load centers, and the other is in a remote rural area. The urban unit would have greater conventional economic benefits because its location near its load center would enhance its transmission reliability. The rural unit would impose lower environmental costs, because fewer individuals would be exposed to its emissions, but it would contribute less to system reliability. Given accurate site-specific data on the marginal benefits of system reliability and pollution abatement, least-cost planning analysis could be used to assist policy makers in choosing between the two plants.

Short-term timing could also be a factor. For example, suppose the two plants described above were both available to the system. During an inversion-induced air quality emergency, the importance of emission reductions may favor idling the urban plant, even if it was the least-costly resource under normal conditions. Conversely, when planned or unplanned outages degrade system reliability, it might be optimal to fire the urban unit despite its environmental costs.

for each contaminated media — air, water, and hazardous waste. **Functions** relating emissions by output and the associated external costs of these emissions need to be calibrated for each unit. This second data set is at present quite difficult to obtain.

Common Applications: Least-cost planning, including environmental consideration, has thus far been applied mainly to electrical generation. Many state commissions, including the California Energy Commission and the California Public Utilities Commission have used some form of this method to determine a relative ranking of fossil-fuel, renewable and demand-side management generating resources. A similar approach has been advocated for addressing the effects of global warming on the world economy. In California, urban water agencies are planning to use LCP to assess future needs and supplies. And during 1993 and 1994 CARB had several studies under review that could lead to the use of least-cost planning methods as part of air quality regulations (see "Pollution Prevention: Negawatts versus Megawatts" textbox).

Strengths and Weaknesses: The strength of least-cost planning is that it clearly identifies and ranks the available policy options on a common cost basis. It also represents the planning method that most closely approximates the **market** in balancing costs and benefits to achieve a policy goal.

However, least-cost planning has several drawbacks. First, the method's underlying assumption is that economic **efficiency** is the sole goal of the planning process. Other goals can only be accommodated if they are explicitly recognized. Second, least-cost planning is based on the assumption that the planner is all-seeing and all-knowing ("omniscient") (i.e., that all costs, availability and ramifications of each option are known and can be correctly incorporated into the model). To be comprehensive, the planner must know all affected parties' preferences and be able to properly weigh these preferences among individuals.

Common Pitfalls: While engineering or program costs are calculated and compared to existing **technologies** and behavior in least-cost planning, other important economic factors should also be considered in the analysis, as follows:

- How consumers and producers will react to new processes (e.g., assuming people will not, for example, cool their house to a greater extent if it is cheaper to do so ignores the basic economic principle borne out in the empirical literature on energy conservation and the "rebound effect").
- How demand for products and services depend on the counterbalancing effects of rising prices which depresses demand and rising incomes which increase demand.
- Shifts in the sharing and spread of risk — central planning tends to dissipate the advantages of risk spreading from having a diversity of decision makers (i.e., consumers) in the marketplace.
- The path of innovation adoption, and the turnover in aging stock which leads to natural improvements in efficiency.
- The effect of businesses making multiobjective **investments**, in which pollution control or energy efficiency is but a small part.
- The institutional relationships between individuals and organizations in society and the market.

In LCP analysis, technical potential for alternative energy sources should be distinguished from the economic potential, and a **supply curve** created for these technologies so that a resource plan can be developed. However, estimates of benefits and expected technological developments should be viewed skeptically in any analysis. The *economic* potential for alternative technologies (e.g., renewable generating resources) is substantially less than *technical* potential, as developing, for example, each additional megawatt of wind power becomes more expensive than the previously added megawatt. Eventually, additional development is no longer cost effective, although some available resources technically remain.

5.4 DECISION ANALYSIS

Description: Decision analysis (DA) is a formal and systematic means of evaluating a set of policy alternatives. The primary tool of DA is the development of quantifiable **utility functions**. Through such functions complex information can be organized so as to provide insight to decision makers. DA can be distinguished from other analytic decision methods both by its reliance on quantifiable utility functions, and by the fact that it addresses both objective information (technical data) — and subjective preferences — (**normative** inputs). Use of DA does not guarantee "correct" decisions but rather encourages rational outcomes given the identified goal, specified alternatives and available information.

In DA, the roles of the decision maker — whether an individual, group or commit-

BOOTLEG DECISION MAKING

*Although decision analysis mixes **positive** and **normative** values, the roles of the different parties engaged in the analysis must be clear and treated with respect.*

Example One. *A prominent decision analyst who worked for a major environmental consulting firm was hired to analyze a controversial U.S. Department of Energy (DOE) program for siting nuclear power plants. The technical consultant amassed a large amount of objective information on site-specific impacts and the risks associated with various siting alternatives. The decision analyst then requested that DOE staff provide a list of their subjective concerns, including how to balance trade-offs between health risk levels and cost implications. However, DOE declined, and instead requested that the consultant rely on technical experts to develop normative inputs. The resulting decision was represented as reflecting the decision maker's judgements and became part of national policy.*

Example Two. *A technical assessment was made of alternatives to reducing the risks of petroleum product spills associated with marine transportation. In addition, the decision maker was asked to develop a ranking of his preferred alternatives. The resulting analysis indicated that the optimal alternative was the development of a marine transit station. However, the decision maker was not happy with this recommendation and instructed the analysts to reconstruct the assessment using a different set of constraints. This revised analysis was ultimately adopted as policy.*

Both of these examples reflect a misuse of decision analysis. The first example illustrates the point that subjective choices <u>must</u> be made by decision makers, not by technical experts. In the second example, although the decision maker did his job (i.e., provided subjective input), he did not treat the resulting analysis with respect. In this case, it is apparent that the goal of the analysis was to legitimize a decision that had already been made, rather than to independently identify the appropriate alternative.

tee — the **decision analyst** and the technical analyst are clearly defined as follows:

- Either the *decision maker* or ***stakeholders*** are in the best position to specify what factors — or **attributes** — determine a better or worse policy outcome. Decision makers or stakeholders must also specify how combinations of different attributes should be ranked as part of an **objective function**. In this sense, the decision maker and the stakeholders are responsible for making all the necessary value, or normative, judgements.
- The *technical analyst's* role is to estimate what outcomes will result from various policy decisions. The technical analysts' judgements are limited to those which are **positive** — observable or theoretical— in nature.
- The *decision analyst's* role is to organize and facilitate the process. For example, the decision analyst assists the decision maker in selecting a comprehensive and discrete set of preferred attributes and in organizing these attributes into an **objective function.** The decision analyst should essentially make no judgements but rather serve as a neutral facilitator.

Theoretical Basis: Decision analysis derives its theoretic basis from a combination of **multiattribute utility theory** and **probability theory.** Utility theory describes how individuals make choices within **budget constraints**. According to this theory, people strive to "maximize their utility" by selecting the combination of goods and services that provides them with the greatest amount of satisfaction within their budget limits.

DISCRETE, CONTINUOUS, OR DETERMINISTIC ASSESSMENT?

There are three different types of ***probability*** *estimates:* ***discrete, continuous,*** *and* ***deterministic****. A discrete probability consists of mutually exclusive alternatives. For example, if a single bottom oil tanker loses its main engine, there is a 5 percent chance it will run aground, and a 95 percent chance of power being restored or of the ship making it to a safe harbor without further difficulties. This is a discrete probability distribution because it is comprised of mutually exclusive alternatives. Under a continuous probability there is an infinite number of possible outcomes. For example, if the oil tanker runs aground, the amount of oil that is likely to be spilled follows a* ***normal distribution****, with a* ***mean*** *of 1,000 barrels and a* ***standard deviation*** *of 300 barrels. Deterministic analysis assumes that actions will result in a certain outcome. For example, if the tanker runs aground, 1,000 barrels of oil will spill.*

In general, the choice of probability type to employ in a specific analysis is left to the analyst. Use of a deterministic model tends to make the ensuing analysis easier to develop and to understand, but at the cost of losing some information about the range of potential outcomes.

Probability theory is a branch of mathematics which addresses the likelihood that an event will occur. Methods for addressing conditional probability— the likelihood one event will occur simultaneously with another — and sequential chains of events are encompassed within this theory. Probability theory is used in DA only when **uncertainty** is an explicit part of the analysis. However, outcomes are frequently probabilistically related to actions (see "Discrete, Continuous or Deterministic Assessment?" textbox).

Data Requirements: Decision analysis necessitates the same pattern of information as discussed in Chapter Three. The method can incorporate the results of the analytic methods discussed in Chapter Four. However, DA's greatest strength is to structure problems. For this process most important "data" comes from values expressed by decision makers and stakeholders.

Common Applications: Decision analysis can be aptly employed in almost all policy analysis. In general, it is most useful in evaluating complex policies that, because of the nature of benefits involved, may not be good candidates for **benefit-cost analysis**.

Strengths and Weaknesses: Decision analysis has a large number of strengths, including the following:

- Decision analysis focuses decision makers' attention on the key attributes and alternatives of a policy outcome.
- Through decision analysis a rational decision can be developed, thereby adding credibility to the policy.
- When skillfully applied, decision analysis can provide a vehicle to achieve consensus, or at least reduce differences, within a decision making group. Decision analysis can move decision makers past divisive discussions of alternatives by focusing attention on defining the key attributes and evaluating outcomes. A decision making group — even one consisting of diverse stakeholders — can typically reach consensus on important attributes, enabling remaining differences to be resolved through some type of trade-off mechanism.

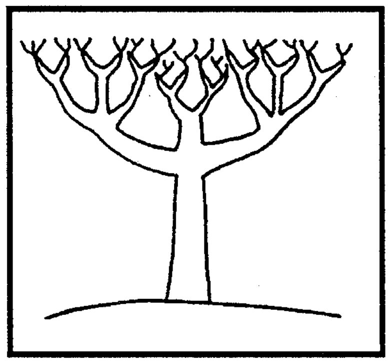
Decision analysis' primary weaknesses are as follows:

- Decision analysis at times forces policy makers to express their preferences in quantitative terms, even in cases where important considerations are essentially qualitative in nature.
- The technique may require significant time investment, particularly on the part of decision makers.

5.5 RISK-RELATED ANALYSIS

Description: In addition to the analytical methods described above, several other techniques are used in environmental decision making to address issues of **risk**. Methods that fall into this category include **risk-cost-benefit, comparative risk**, and **decision-tree** and **fault-tree analyses**:

- *Risk-cost-benefit* analysis is essentially a subset of B/C analysis, with the addition of specific consideration of the costs of risk mitigation.
- *Comparative-risk analysis* focuses on comparing the relative probability of harm associated with different risk factors. Comparative risk is a new concept and does not as yet have a complete definition. In general, this technique refers to a comparison of one risk factor with another, rather than a risk versus cost or benefit comparison. For example, the risks of leaving contaminated soil in place can be compared with the risks associated with transporting the soil over public highways to a disposal site.



- *Decision trees* provide a means of evaluating the probability of an event occurring as a result of a chain of events. Through the decision tree each event on the chain is assigned a probability of occurrence. At each event point the tree branches, depending on the incident outcome. The probability of each possible outcome can then be calculated as the product of the probabilities of each branch point.
- *Fault-tree analysis* is a special case of decision tree analysis in which the event whose probability is being calculated is a failure of a safety system.

Theoretical Basis: As with **decision analysis**, probability and **statistical theory** provide the basis for all risk-related techniques. Although probability and statistical theories are well-established, their application to complex environmental risks necessitates the use of considerable judgement. This is because environmental risks are composed of the complex interaction between the environment at issue and humans.

Data Requirements: Depending on the specific issue being examined, the data requirements to conduct risk analysis can be formidable. Scientists frequently reduce their data needs by focusing their analysis on extreme — or polar — cases. For example, rather than modeling how an air pollutant affects every single individual in an air basin, regulatory analysis is often designed to protect the most susceptible populations (e.g., children, the elderly) at the highest exposure rates. Similarly, safety systems for nuclear power plants are generally designed to protect the environment in the event of a worst-case combination of events.

Common Applications: Risk-cost-benefit analysis is frequently used to establish priorities for action on environmental issues, such as protection from the risks associated with radon and asbestos. Comparative risk evaluation projects have been undertaken by the U.S. EPA and a number of states, including California. **Fault-tree analysis** is frequently used in engineering and management to determine minimum allowable safety standards.

Strengths and Weaknesses: The greatest strength of risk-based methods is their ability to provide an orderly structure with which to examine uncertain — and frightening — environmental hazards. The greatest limitation to these techniques is the difficulty of predicting the risks associated with the complex interaction between humans and their environment.

5.6 SELECTION OF APPROPRIATE ANALYTIC DECISION MAKING METHODS

Determining which of the methods described in this chapter is appropriate for a given environmental decision making situation requires good judgement and some familiarity with the techniques. However, limited generalities can be made. Cost effectiveness and benefit-cost analysis apply best to situations in which economic **efficiency** is the sole factor of concern. Cost effectiveness and **least-cost planning** are only appropriate in selecting the least-costly means of achieving a specified goal, <u>not</u> determining whether a goal is worthwhile. Benefit-cost and decision analysis are the appropriate methods to be employed to determine whether or not a goal is worthwhile.

Benefit-cost and least-cost planning have difficulty incorporating nonmonetary environmental attributes, and special care must be made to ensure those qualities are considered. Decision analysis has the broadest application. Risk-related analysis can be incorporated into all of the other methods whenever outcomes can be expressed as probabilities.

6 KEY TERMS

Accounting costs are the out-of-pocket expenses, **depreciation**, and historical **costs** that are used in bookkeeping entries.

Accounting stance refers to the spatial and political framework within which a decision is made. Applying a consistent accounting stance to all alternatives under evaluation is critical to rational decision making. The appropriate accounting stance will vary with the objectives of the **decision makers** and **stakeholders.**

Ad hoc defines a decision making processing that is not systematic or can not be duplicated.

Adverse selection is when buyers and sellers have differing levels of information about a market transaction (e.g., the competence of a worker) so that when a trade actually occurs the participant with the better information has the advantage.

Anecdotal analysis is the reliance on a single incident or a collection of "stories" to infer cause and effect.

Arbitrage is the simultaneous purchase *and* sale of the same good or service in two different **markets** to take advantage of the price differential between the markets.

Asset rental price is the lease price that an **asset** would receive in a hypothetical market. This price changes from year to year to reflect **depreciation** and market conditions. The asset rental price differs from **levelized annual payments,** which reflect a constant price regardless of the condition of the asset or the market. For example, a homebuyer might have purchased a house for $100,000 at a 13 percent mortgage rate under a 30-year loan. The levelized payment scheme results in a monthly payment of $1,000 that does not change over time. However, using asset rental pricing, if the market price appreciates at 8 percent per year, the initial monthly payment would be $711 per month and would escalate at 8 percent per year, so the payment would be $768 the second year and so on. The asset rental price better reflects the value of an asset in the **market**.

Assets are a useful or valuable resource, **good**, person or quality. Assets may be tangible, such as cash or a forest, or intangible, such as client goodwill or the knowledge that a species exists.

Assumptions are aspects of a problem which are taken for granted as a basis for a line of reasoning or course of action. Assumptions are used to either make a complex problem tractable with available analytic methods or to fill gaps in **empirical** data. Assumptions generally derive from a **theory** about how a process works. Assumptions may be stated *explicitly*, particularly if they are specific to a situation, or be *implicit* in the approach being used. The use of implicit assumptions is inherent in relying on sophisticated analytic methods such as engineering economics, and other social sciences or decision analysis.

Asymmetric information is the situation where one party has more or better information than another party.

Attributes are distinctive characteristics that can bring value to an **asset**.

Average is a number used to describe in a single value the middle or the central tendency of a set of numbers. **Mean, median** and **mode** are types of averages.

Avoided cost is the cost for a current standard practice or facility that could be *avoided* by choosing an alternative strategy or investment.

Baseline conditions are defined as (1) the expected conditions into the future if no policy change is adopted, (2) the conditions in the initial year of the study, or (3) the "no-action" alternative in which no policy or strategy is in place. Baselines are an artificial construct about future conditions based on a set of **assumptions**. The baseline conditions provide the standard against which costs and benefits of policy proposals are measured (see bequest values and cognitive dissonance).

Bayesian analysis involves incorporating objective **empirical** and **theoretical** analytic results with **decision makers'** subjective prior beliefs about likely outcomes (called a *prior distribution*) to evaluate the desirability of various choices. Bayesian analysis is commonly used in **decision analysis**.

Benefit-cost analysis (B/C) generally describes a method used by public agencies to determine whether a proposed action is in the public interest by weighing expected **costs** against potential benefits. Normally in **economic** analysis when benefits exceed costs or the ratio of benefits to costs is greater than one, the action is considered beneficial from the standpoint of **efficiency**.

Benefits transfer is the use of study results to value **nonmarket goods** — environmental or health attributes — based on values derived from one problem or geographic area for a similar situation that differs in context or location. This method is most commonly used in damage function estimation but also is applied in specific policy making situations where budget or time resources are insufficient to develop original research on the problem.

Bequest values derive from the desire to leave a resource to future generations (e.g., that no development will occur on a distant lake) although a concerned individual may not visit the resource in their lifetime. While this concept is different cognitively from **existence value**, it has the same mathematical representation. Bequest values are typically derived in analysis through **contingent valuation methods**.

Biased estimates misestimate the "true" **expected values** of the population as a whole because the chosen **statistical** or **econometric analysis** method violates certain **theoretical** criteria. The problem of biased estimators can be addressed by either (1) redressing the original analytic problem or (2) identifying the direction and magnitude of the bias and adjusting the resulting estimators.

Binding constraints are **constraints** that limit the number of **feasible solutions** to an analytic or policy problem.

Bond ratings are an indicator of the creditworthiness of a specific bond issue. These ratings often are interpreted as an indication of the likelihood of default by bond issuers.

Budget constraint limits the resources available to acquire a **good** or provide a service. Budgets can be constrained by not only **income** and **wealth**, but also by time and other available resources.

Bureaucracy is a formal hierarchical organization with many levels in which tasks, responsibilities and authority are delegated among individuals, offices or departments, and tied together by a central administration. Bureaucracies are characteristic of many large organizations, for both **governments** and **corporations**.

Business sectors (see **economic sectors**).

Calibration is the process of matching the results of a **simulation** model to real-world data. This is done by adjusting **parameters** within the model after the initial formulation and estimation process.

Capital Asset Pricing Model (CAPM) is an **equilibrium** model of **asset** pricing which states that the **expected** return of an **investment** is a positive **linear function** of the investment's sensitivity to changes in the return for the entire **market portfolio** (i.e., all available investments of a similar nature).

Capital gain (or loss) is the difference between the value of an **asset** when sold or exchanged and the original cost of the asset adjusted for improvement or **depreciation**.

Capital goods are used in the production of commodities; also known as *producers'* goods.

Capital-intensive is a term that describes industries that employ relatively few laborers or energy units in comparison to the amount of **capital goods** or equipment they use.

Cardinal scaling is a measurement which can be expressed in real numbers (i.e., one, two, etc.) that represent absolute measurement or intensity and can thus be manipulated using arithmetic operations. A cardinal measurement which is twice as good will be exactly twice as high. This contrasts with **ordinal** measurements, which do not have this property (see **ordinal scaling**).

Cartels is an association formed by producers or consumers to limit output or purchases so as to control the price of a good in a **market** as a means of increasing their **profits** or **consumer surplus**. Producer cartels find it difficult to limit output because rival firms inside the cartel have trouble allocating the reduced output among themselves (each wanting a larger share of the output and profits), enforcing the limitation, and keeping other firms out of the market who are attracted by the higher profit potential. Cartels are easiest to maintain where entry into the market is difficult and the market has just a few firms.

Case studies are the application of **theory** and **empirical** findings to a specified situation to determine the validity of the findings under particular circumstances. Case studies can be used to illustrate the application of an analytic method or as a screening method to determine if an action might have a significant effect on a specified population.

Certainty-equivalent return is the return on a **risk**-free **investment** which makes an investor indifferent between the risk-free investment and an investment with a particular risk level.

Ceteris Paribus is the Latin term for the assumption "all other things equal," (i.e., all relevant factors in an analysis are held constant except for the variable or **variables** of interest).

Churning is the *gross* change in jobs or other resource use in an economy **induced** through an event, action or policy. Churning differs from the *net* change in jobs in that it measures how many individuals will lose their current jobs and how many new hires will be required. For example, a policy analysis may show that one million jobs are lost and another million created in different **economic sectors** through a policy. While the expected net job loss equals zero, the level of churning indicates that significant social dislocation may occur.

Coase Theorem states that an efficient allocation of resources can be attained in the presence of **externalities** through reliance on bargaining among the parties involved, if a series of strict **assumptions** hold. It is based on an article by Ronald Coase, "On Social Cost" (1960). Most important of the assumptions is the one stated by Coase that bargaining costs must equal zero, and that the parties value the externality the same whether they are paying for or accepting compensation.

Cognitive dissonance occurs when an individual ignores information that might affect their behavior and acts in opposition to the implications of that information. For example, a smoker might have a cigarette even though he knows the consequences of doing so. Cognitive dissonance leads to the belief "it can't happen to me."

Commensurability is the ability to be measured by a common standard or in units which have the same dimensions. Properly defining the **accounting stance** in an analysis aids in developing commensurability of report analyses.

Comparative-risk analysis is a procedure for ranking environmental problems and hazards by their seriousness or "relative risk" for the purpose of assigning them priorities for regulatory action. Comparative risk analysis is done by a team of experts who first list and sort the problems by types of risk–cancer, mutagenic, ecological. This list is then weighed based on legal and institutional requirements, the technological and economic feasibility of addressing each problem, and the level of public concern for each issue.

Competitive markets create the situation where the product and input prices are not influenced by the behavior of an individual firm. Competitive markets arise because either the number of firms and consumers is so large that the actions of a single individual are inconsequential, or the threat of entry by other firms or consumers forces firms or consumers in the **market** to accept the available prices.

Complements are two **goods** which relate in such a way that if the **price** of one rises, consumption of the other will fall. For example, if the price of bread increases, less bread will be purchased—**ceteris paribus**—and the consumption of butter will decline. (See also **substitutes**.)

Confidence intervals measure the likelihood that an observed estimate falls within a set range and, thus, that the confidence interval includes the actual value being sought. If the analysis was repeated a number of times, the percent of confidence is the proportion of times that one would expect the real value to be included within the confidence interval. (See **statistical significance**.)

Constant dollars are an economic convention that is used to measure industrial output and consumption over time while controlling for changes in prices owing to **inflation**. The use of constant dollars allows for a more accurate comparison across periods.

Constraint equations used in **mathematical programming** describe the **technologies** or management techniques available to reach the **objectives** and calculate how costs vary with input levels.

Constraints are limits on either the resource use or range of possible outcomes in a policy decision. Constraints can be described either mathematically or in qualitative terms.

Consumer goods are those that satisfy human wants and needs through their consumption or use, such as food and clothing.

Consumer Price Index is the cost-of-living index which tracks the prices for a representative market basket of **goods** and services purchased by U.S. consumers. CPI is one of the most common indicators of the **inflation** rate.

Consumer surplus is the difference between the total value consumers receive from using a particular good or service and the total amount they pay.

Contingent-valuation method (CVM) relies on directly asking people in a survey to make trade-offs between **nonmarket** and **market goods**, in such a way that their inherent preferences are revealed. CVM uses carefully structured surveys to ask individuals about the value that they put on an environmental asset, such as a forest or an animal. CVM enables analysts to value nonuse aspects, such as **existence values**.

Continuous functions follow a path over time or space that have no breaks or sudden changes in direction. For example, continuous-time **discounting** means that the **present discounted value** changes every single second and that change is calculated and measured by the discount function. Compounded **interest** is based on this concept.

Corporations are business organizations owned by a group of stockholders, each of whose liability for any losses incurred by the business is limited to the amount invested in the corporation's stock.

Correlation coefficient is a statistical measure of the degree of mutual variation between two **variables** with **random** characteristics. The coefficient is bounded by the values of -1 and +1, with negative values indicating that the variation is in opposite directions, and positive values indicating variation is in the same direction.

Cost-benefit analysis (see benefit-cost analysis).

Cost effective refers to an action which is the lowest-cost plausible means of achieving a specified end. An action which is cost effective is an **efficient** means of achieving a goal, but this does not imply that the goal is always worthwhile. Cost effective does not encompass comparison of the benefits to the cost (that would be **benefit-cost analysis**).

Cost of capital or funds rate is the return that investors or lenders expect from **investment** in a firm.

Costs are payments or opportunities forsaken by an **economic** actor to gain use of a resource.

Cross-sectional analysis looks for patterns of cause-and-effect across a spatial (e.g., geographic) or **socioeconomic**, dimension. Cross-sectional analysis assumes that the dependent variable is **commensurate** across localities at the same time. In **economics**, such analysis can be used to discern how differences in certain conditions (e.g., **prices**, local **attributes** or other factors) can lead to changes in consumption or production. This makes this approach useful for comparing alternative options. Cross-sectional analysis produces estimates of *long-term* impacts without any reference to how the impacts might evolve over time.

Culture is the sum of attitudes, customs and beliefs that distinguish one group of people from another. Culture is transmitted from one generation to the next through language, objects, rituals, art and institutions.

Decision analysis (DA) is a formal, structured approach to decision making which relies on multiattribute **utility** theory and the laws of **probability**. Decision analysis accounts for different decision rules (e.g., minimax or **Bayesian analysis**), the likelihood of certain outcomes, and the weighing of the relative importance of **constraints** and **objectives**.

Decision analysts are individuals trained in structured formal decision making. The decision analyst does not make decisions, but merely structures the information to assist the **decision maker** in making an informed, rational decision.

Decision makers are the individuals or groups responsible for making a choice from among alternative courses of action and who are accountable for the consequences of that decision. It is the decision makers and **stakeholders** who make subjective **value judgments** about the desirability of an outcome, rather than the technical or decision analysts whose purpose is to provide and organize information.

Decision-tree analysis is a method of evaluating the probable outcomes of actions which have several intermediate steps, each with a defined **probability**, upon which the final outcome depends.

Demand curve or function is a graph showing the relationship of potential prices and the amounts demanded at each **price** per unit of time, other things given. Demand curves usually slope downward from the left to right, indicating the most important property of the demand curve: the incentive to demand less as prices rise. The point at which the quantity demanded is equal to the quantity supplied—where the demand and **supply curve** intersect is the market-clearing price in **economic theory**. (See also **elasticity of demand or supply**.)

Depreciation is an accounting procedure that allocates the cost of an **asset** or **durable good** over the estimated useful life of the asset. In economics, it can be thought of as the cost of continuing possession of the asset (e.g., the longer we keep an automobile, the less its resale value is likely to be).

Deterministic functions are influenced only by variables contained in the equation with no **random variables** causing unpredictable fluctuations. As a result, the path of deterministic functions can be predicted at any point in time with complete certainty.

Diminishing returns to investment is the proposition that additional investments in a particular asset or policy will ultimately produce increasingly smaller additional or marginal returns.

Direct costs or impacts are imposed on individuals or firms who must respond directly to an action, event or policy. These costs can then create **induced** and **indirect** effects in the economy.

Discount rate is used to calculate the **present discounted value** of future benefits and costs. Benefits received in the future are not as valuable as the same benefits received today because they provide less **utility** or satisfaction, and, therefore, they have to be discounted. For example, if air pollution is reduced today, more lives will be saved than the same reduction at a later date—pollution reduced today is more valuable. The farther in the future benefits are received, the less value they have compared to receiving the same benefits today. The discount rate reflects the **time value of money** and the riskiness associated with future benefits and costs. Discounting is based on the principles that (1) people prefer receiving benefits now rather than later; (2) benefits received now can be reinvested to produce greater benefits in the future; and (3) technological progress will make future generations better off than today's. The discount rate can be derived several ways, including from a representative **market interest rate**; a time preference for an affected individual or firm; or a measure of the social value of deferring consumption to **invest**. (See **interest and rate of return**.)

Discrete or discontinuous functions change values at intervals in time or space in a single jump. These are often known as "step" functions. For example, discrete-time **discounting** calculates the **present discounted value** in each year on the assumption that a cash outlay is made once a year. Simple **interest** is based on this concept.

Dispatch models are used to determine which combination of electrical generating resources (or other productive resources) to use in order to most efficiently meet short-term system demands. When environmental impacts are considered in addition to direct cost, it is said to be an *environmental-dispatch* model.

Diversification is the process of adding investments to a portfolio in order to reduce the portfolio's **idiosyncratic** or unique (unrelated to the market) **risk** and, thereby, the portfolio's total risk.

Dominant solution is one which is superior to all other alternatives with respect to *all* criteria. Dominant solutions are unusual; most often solutions are better in terms of some criteria and worse in terms of others. As a result, **decision makers** usually must trade off among criteria when making a decision.

Dominated solution exists when at least one other alternative is found to be at least as good or better than all other solutions with respect to *all* criteria.

Duality is an **assumption** used in **economics** that in the short term or in a truly **competitive market, profit maximization** implies that a firm also minimizes costs. Duality occurs when one assumes that output levels and prices are fixed, implying the only way the firm can maximize **profits** is to minimize inputs. Duality is a useful analytic tool because the analyst can ignore the **revenue** portion of the profit function by assuming it remains constant, thus simplifying the analysis. Duality is also used in **mathematical programming** to find the **shadow values** for adding inputs or relaxing **constraints**.

Dummy variables can be used to represent explanatory variables that have **discrete** or dichotomous (i.e., "either/or") properties in statistical analysis. Typically, a dummy variable is used to assess the importance of a yes/no characteristic on the dependent variable (e.g., is an individual a male?) Typically, the variable is set at 1 if the answer is yes; 0 if no.

Durable goods are manufactured goods designed to have a long life or utilization periods, such as automobiles or appliances.

Dynamic analysis takes into account that economic, technological, institutional, and social relationships may change through time, in part through feedback effects or outside influences, and that **equilibrium** conditions may change over time as well. This is in contrast with static analysis which holds the current situation constant over time.

Econometrics is the application of mathematics and **statistics** to **economic** analysis. A major role of econometrics in environmental economics is to provide numerical values for the parameters in the formal mathematical equations used by analysts. These parameters can replace qualitative judgements and allow for easier testing of environmental **theories**, as well as providing more exact information.

Economic life is the **expected** remaining life for an **asset** given operating and maintenance costs versus the costs and benefits of replacing the asset. When the net **present value** of expected operating costs exceeds the net costs of purchasing a new asset the current asset should be retired for economic reasons. This differs from **accounting costs**.

Economics does not have a standard definition which is accepted by all economists. In general, it is the study of how people choose to satisfy their wants and needs given that they have limited time and resources and **constraints** imposed by **technology**, institutions and nature. In analytical terms, it can be thought of as a mathematical **optimization** problem (i.e., selecting instruments—variables—from an opportunity set so as to maximize an **objective function**). (See mathematical and linear programming models). Economics provides analysts with a method of ordering and arranging knowledge so as to allow for better decision making. In environmental analysis, economics is often used to place dollar values on selected elements of the environment as a means of standardizing diverse benefits and **costs** that otherwise could not be added together. In the economists' theory of value, the value of goods and services is not intrinsic, but rather is revealed by market-clearing prices. In environmental economics, the value of **nonmarket goods**, such as health and morbidity, are estimated by non-market means. (See contingent and hedonic valuation.)

Economic sectors are portions of the overall economy that are related to the production or consumption of goods and services. Broadly, economic sectors are usually divided into households (or consumers), producers (or firms), and the government. Within the production sector, the U.S. economy is analyzed by the Standard Industrial Classification (**SIC**) code.

Economy of scope occurs when it is less expensive to produce two goods or services simultaneously than separately. For example, cattle are raised to produce beef, hide and milk. Economy of scope is characterized by the use of common inputs to produce multiple outputs.

Ecosystems are collections of living things and the physical environments in which they live.

Efficiency in broad terms means the absence of waste or obtaining the maximum benefit from the available resources. It is often expressed as the ratio of output to input (engineering efficiency) or the value of output to the value of the input (economic efficiency). The higher the value of the ratio, the greater the efficiency. For example, one outcome is more efficient than an alternative outcome if it (1) creates more benefits at the same cost or (2) yields the same benefits at less cost. (See also **cost effective** and **efficient allocation.**)

Efficient allocation in a **market** economy occurs when exchange takes place to the point where no individuals can make themselves better off without making someone else worse off. (See also **Pareto Optimality and Kaldor-Hicks criterion.**)

Elastic demand or **supply** (see **elasticity of demand or supply**.)

Elasticity is the responsiveness of one **variable** to a change in another variable measured as the percentage change in one variable caused by a one percent change in another explanatory variable. Elasticity is used most often to derive how much the quantity demanded or supplied changes with a change in price (i.e., price elasticity).

Elasticity of demand or supply represents the responsiveness of quantity demanded or supplied to a change in **price**. Elasticity is normally different at each point along the **demand** or **supply curve** except in three cases where the elasticity is zero, infinite or one. One, the elasticity is zero or *perfectly inelastic* where there is no change in quantity when the price changes. In this case, the demand or supply curve is vertical. A vertical demand curve could be thought of as the demand curve for a "need" where a certain amount is needed regardless of the price (e.g., a new fuse to replace one that has blown and shut down a billion-dollar assembly plant). A vertical supply suggests a fixed **stock** of goods that the seller is willing to sell at any price to get rid of it (e.g., produce that is about to spoil). Two, the elasticity is infinite or *perfectly elastic* where the demand or supply curve is horizontal. In this case, buyers can get all they want at the given price so they will not pay more, and sellers can sell all they want at the given price so they would not sell for any less than the price. This implies a **perfectly competitive market** place where buyers and sellers are price takers rather than price searchers, for example, the exchange of stocks in the New York Stock Exchange. Three, the elasticity is *unitary* where the demand or supply curve is a rectangular hyperbola. In this case, the total **revenue** from sales does not change as price and quantity change. An example would be if a **cartel** chooses to control price and quantity so that revenue stays the same.

Empirical data or evidence is observed real-world data, often used in **statistics**.

Endogenous variables are the phenomena being explained by an analytic model. For example, in the analysis of product demand, the endogenous **variable** would be the quantity of the product demanded. Endogenous variables can be affected by policy choices. For example, a local government might treat its land-use patterns as endogenous from a planning perspective because they can influence these patterns through zoning and fiscal policy choices. An endogenous variable can be an explanatory variable for another endogenous variable. (See also **exogenous variables**)

Energy intensive is a term that describes industries that employ relatively large amounts of energy in comparison to the amount of **capital goods**, equipment or laborers they use.

Environmental equity is "the equal protection from environmental hazards of individuals, groups or communities regardless of race, ethnicity or economic status." *(U.S. EPA, February 1994)* This is a form of **horizontal equity**.

Environmental impact is a discernible human-induced alteration of an environment or **ecosystem**.

Environmental justice is "the fair treatment of people of all race, cultures, income and education levels with respect to the development, implementation and enforcement of environmental laws, regulations and policies. Fair treatment implies that no population of people should be forced to shoulder a disproportionate share of the negative environmental impacts of **pollution** or environmental hazards due to a lack of political or economic strength." *(U.S. EPA, February 1994)*

Equilibrium is a situation in balance where there is no tendency for change, such as when **supply** and **demand** are in balance (i.e., at an equilibrium price level where the quantity demanded equals the quantity supplied). In a realistic **dynamic** setting, equilibrium is never actually attained; rather the market is assumed to tend to move in that direction.

Equity analysis is the assessment of the distribution of gains and losses from an outcome across different dimensions, including social, spatial and temporal.

Estuary is a wide body of water formed where a large river meets an ocean. It contains a mixture of fresh and sea water. The San Francisco and Chesapeake Bays are examples of estuaries.

Ethnicity is identification with or membership in a particular racial, cultural or national group.

Ex ante means before the fact or event; looking to the future.

Excise tax is similar to a sales tax but is selectively imposed on certain goods, such as gasoline or luxury goods.

Existence values come from the knowledge that a resource continues to exist even though the individual may not actually use it (e.g., that a lake in Alaska remains pristine although the person has never visited Alaska). While existence values are different cognitively from **bequest values**, they are the same in its mathematical representation. Existence values are typically derived through **contingent valuation methods**.

Exogenous variables are controlled by events and influences beyond the scope of the policy model and are taken as given. These variables are not affected by policy choices, but are used to explain the behavior of **endogenous variables**. For example, a local government must take the U.S. interest rate as having an exogenous—and significant—influence on new housing starts.

Expected outcomes or value represent a defined midpoint or central tendency of a distribution of possible outcomes that might arise as conditions vary. The expected outcome formally equals the **mean** but it may be interpreted as the **median** of a **probability distribution**.

Expected utility is the average **utility** expected in an uncertain situation. Expected utility is computed by estimating the **utility** or **preference functions** for each possible outcome and **averaging** the utilities.

Exponential growth occurs when the amount being added to a quantity is proportional to the quantity already present—the bigger the quantity, the greater the absolute amount of growth. For example, if a one billion person population is growing at 2 percent a year, the first year growth will be 20 million. After 35 years at exponential growth the population will increase to 2 billion, with growth of 40 million people in the last year.

Ex post means after the fact or event; with a historical perspective.

Externalities can be thought of as unintended side effects of an activity. They can be either positive or negative. Externalties are impacts on one or more individuals resulting from an activity of another person or persons for which there is no corresponding compensation to or paid by those creating the impacts. For example, smoke from a factory may degrade the air quality of nearby homes, but the factory owner is unlikely to compensate the residents for damages, and the residents are unlikely to pay the factory to reduce its emissions. The **pollution** is an externality because no market exchange mechanism explicitly exists. Externalities are a form of **market failure**. (See market-based goods.)

Fault-tree analysis is a special case of **decision-tree** analysis in which the occurrence whose **probability** is being calculated is a failure of a safety system.

Feasible solutions are the set of possible outcomes in which *all* **constraints** are satisfied.

Final or consumptive goods are those that are sold for consumption and not used in producing another good.

Fixed costs are those that do not change as output level changes over the time horizon being analyzed. These costs include fixed or **capital goods**, land and long-term contract commitments. In the short run, fixed costs do not enter into calculation of marginal costs. In the long run, almost all fixed costs become **variable costs**.

Flow is the measure of the production or consumption or a good, service or resource through time. Flows come from a **stock** of available resources at a particular point in time. For example, *income* is a flow variable that measures the rate at which economic resources are accumulated; *wealth* is a stock variable that measures the amount of economic resources accumulated at a certain point in time. Flows can describe the harvesting of **renewable** and extraction of **nonrenewable resources**, or the use of **capital goods** in production. For example, timber harvesting is flow from the stock represented by a forest.

Functions are a mathematical expression of how one quantity is uniquely determined by another set of quantities.

Futures markets involve the setting of a contract for delivery of an **asset** on a specified date in exchange for either an immediate or promised payment.

General equilibrium analysis is when the operation of many **markets** is modelled simultaneously.

Goods in **economics** are anything that gives **utility** or satisfaction to someone (e.g., clean water, food, clothing, music). An economic good is a **scarce** good for which a person is **willing to pay** something to get more of it (e.g., public safety, peace and quiet). What is an economic good for one person—such as cigarettes or rock climbing— may not be an economic good for another. (See assets.)

Government is a complex of institutions, laws and customs created by a group of individuals to, at a minimum, define and protect rights of various kinds within certain geographic boundaries. As governments evolve they can direct resource allocation, redistribute wealth, or provide education in addition to other services. To maintain legitimacy, a government must have at least the tacit support of the individuals possessing or controlling the majority of political support in the geographic area.

Greenhouse effect is a term used to describe the heating of the earth's atmosphere due to the presence of carbon dioxide and other gases that absorb infrared radiation. The effect causes the climate to be about 30 degrees Celsius warmer than it would be without the atmosphere. The term is also used to describe the potential warming of the earth's climate above present-day temperatures due to the emission of various gases from human activity.

Hedonic valuation seeks to identify the value placed on a particular characteristic (e.g., air quality) by finding two similar **goods** which are the same except for the characteristic being considered (e.g., houses of the same size in different cities) and statistically analyzing the different values placed on these goods.

Heuristic analysis is a method of problem solving that relies on inductive reasoning from past experience or "rules of thumb" in the absence of a more rigorous approach.

Horizontal equity states that individuals in similar situations should be treated similarly.

Hypothesis is a proposed explanation for some natural or social phenomenon made in order to draw out and test its logical consequences. Hypotheses can be tested using **empirical data** and different analytic techniques, such as **statistics, econometrics** or **mathematical programming**.

Identification occurs in **econometrics** when the problem can be specified with a sufficient number of **variables** and equations to estimate the **parameters**. If the parameters can not be estimated, the model is *unidentified;* if several values can be derived for the same parameters, the model is *overidentified.*

Idiosyncratic risk is the portion of the total **risk** associated with holding an **asset** that is independent of movements in the **market portfolio** (i.e., the risk is not related to how the market moves). Whereas **systematic risk** involves risk that is common among all assets and thus cannot be diversified away, **idiosyncratic risk** from an asset can be diluted by acquiring a large number of different assets.

Income is in general the rate at which money is earned over time. In accounting, income is the money (revenue) or money equivalent earned or accrued from the assets of the business during an accounting period. Personal income is usually defined as money earned in a year in return for labor or services rendered or the proceeds from assets. In economics, income can be defined as a **stock** or a **flow**. As a flow it is either the accumulation or the returns from **wealth** (assets). The unconserved part of income is either savings or investment. Income as a stock is thought of as the **utility** or real income received from a basket of goods at a point in time (e.g., your psychic pleasure from knowing the Grand Canyon exists). (See indifference curve and existence value.)

Income effect from a change in the price of a good is the amount of a change in the purchase of a good or service caused by a change in the consumers' real income resulting from a price change for that good or service. (See also **substitution effect**.)

Incremental cost is the additional cost incurred from producing an additional increment (i.e., one or more units) of goods. **Marginal cost** is the measure for a single added unit.

Indifference curve is the combinations of goods and services that provide a consumer with an equal level of satisfaction or **utility**.

Indirect effects result from a change in how money is spent by individuals or firms who incur **direct impacts** from an event, action or policy. For example, expansion of an automobile fabrication plant will increase business activity by automobile parts suppliers indirectly through increased supply purchases.

"**Individualism**" is a doctrine underlying neoclassical **economics** that individuals are the decision making focal point, and for this reason, the public interest is best served by encouraging them to fully recognize all **costs**, private and social, and to act according to their own self-interest.

Induced effects are changes in an economic system — local, regional or national — caused by changes in spending patterns due to **direct** and **indirect effects**. Induced effects are the third component of the **multiplier effect**. For example, an expanded automobile factory creates a **direct impact** through increased wages, an **indirect** impact through increased demand for parts, and an induced impact through greater general spending in the local economy.

Inelastic demand or **supply** of a product implies that it is relatively unresponsive to changes in **prices**. If a good is inelastic, a one percent change in its price results in a less than a one percent change in quantity demanded or supplied. (See elasticity of demand or supply.)

Inflation is the rate of change in a price index (e.g., the **Consumer Price Index**) over a certain period of time that reflects a general increase in <u>all</u> prices so that the relative costs of different goods and services remain essentially the same. Or equivalently, inflation reflects the percentage change in the purchasing power of a dollar over a certain period of time, usually per year.

Input demand is the **demand** for a good or service required for the production of another good or service. Input demand can be shown as a **function** of the price and productivity of the input and the price and output level of a firm. For example, demand for labor is analyzed as an input demand.

Interest is the cost of borrowing money or the return for lending it. Interest represents the added return on repaying a loan that compensates the lender for the **time value of money** and the **risk** that the loan will not be repaid.

Interest rate is the price paid to receive goods or wealth at an earlier date. Interest rates reflect individuals' desire for earlier availability, and the **productivity** of **capital**, which can be used to increase **wealth**.

Intergenerational equity addresses the differences in impacts from various policy options on those currently alive versus those yet-to-be-born. A fundamental trade-off assessed in intergenerational equity is whether a portion of the cost of realizing some present benefit will be unfairly or inequitably shifted to future generations, or vice versa. The concern over deficit spending and national debt is largely a concern over intergenerational equity. In questions of natural resource policy, the focus of this inquiry is often on **sustainable development** and **irreversibility** of chosen actions.

Intermediate goods are those that are produced to be used in producing another good or service. (See **input demand.**)

Internal rate of return is the **discount rate** that equates the cost of a particular **investment** to the **present discounted value** of future benefits expected to be received from that investment.

Intertemporal analysis compares impacts between different periods of time and in the aggregate over a long time horizon. The analysis involves modelling **dynamic** processes and weighting values among time periods through use of a **discount rate**.

Investment is the acquisition of property or financial instruments in anticipation that its value will increase over time or it will generate a certain **income** level. Investment reflects the concept of sacrifice of a certain (or known) present value for a (possibly uncertain) future value.

"**Invisible hand**" is a phrase coined by **Adam Smith in the** *Wealth of Nations* (1776) to express the notion that a well-functioning **market** economy, with individuals acting out of self-interest, will direct as though "with an invisible hand" the production of those goods and services that will benefit society as a whole. This concept in concert with philosophers contemporary with Smith led to the doctrine of **individualism**. However, the presence of **externalities** and other market failures reduces the effectiveness of free markets and provides a rationale for **government** intervention into the market.

Irreversibility is when, once a decision is made, other opportunities are foregone and an investment can not be easily undone or dismantled without great cost. While virtually all investments are eventually reversible due to physical deterioration and the passing of generations, the amount of time required to remediate an action can vary substantially. Standard economic models assume that an action or investment generally can be reversed by selling it in the market, an assumption that probably is not valid in large-scale projects or programs.

Kaldor-Hicks efficiency criterion states that if the individuals who benefit from an outcome *could* in the aggregate compensate those who lose based on the measures of benefits and costs, then the outcome is **efficient**. This principle is the basis of **benefit-cost analysis**.

Keynesian economics is a branch of **macroeconomics** that attempts to explain why aggregate demand and supply do not achieve the full employment **equilibrium** conditions predicted by neoclassical **microeconomics**. For example, why does unemployment persist when the **wage** is set by the **market** at a rate that should be acceptable to all workers? Keynesian economics focuses on the "stickiness" of wages and **prices** (i.e., the tendency for these value indicators to readily rise but resist downward trends) as the cause for disequilibrium conditions. Keynesian economics leads to the conclusion that a general **market failure** exists that in some cases should be remedied through **government** intervention, such as stimulus of the economy. John Maynard Keynes first put forth these concepts in the 1930s. Keynesian economics failed to predict or solve the economic crises of the 1970s and has recently lost much of its support in academic and policy circles.

Labor-intensive is a term that describes industries that employ relatively large numbers of laborers in comparison to the amount of **capital goods** or equipment and energy.

Least-cost planning is a form of **benefit-cost analysis** in which a portfolio of strategies and technologies is selected based on the **cost effectiveness** of achieving a set goal while incorporating benefits of achieving other social objectives. For example, a least-cost plan for an electric utility might determine the most cost-effective way to generate electricity given that the societal benefits of reducing air pollution are valued and netted from the cost of more environmentally-friendly resources, such as wind power or conservation.

Levelized annual payments represent the constant annual payments required to recover the single, upfront costs of an initial capital **investment**, including **interest** and **principal**. This is the same principle used in determining the mortgage payment on a house. For example, if the initial investment is $1,000, the operating costs are $25 per year, the expected life is 20 years, and the interest rate is 5 percent, the investor would want to receive $101 per year to fully recover that investment.

Life-cycle analysis examines the costs of a policy option or technology choice over the entire **expected** lifetime of the technology or strategy. For example, a life-cycle analysis of an automobile would encompass at least the purchase price, fuel, maintenance, and scrapping costs aggregated in **present discounted value** terms over the typical ten-year life of a vehicle. Environmental and congestion costs might also be included in this example.

Linear functions are composed of a set of **variables** added or subtracted together in an equation, with each multiplied by a **parameter** and raised only to the exponential power of one. An example of a algebraic linear equation is:

$$y = 2x + 5z$$

If plotted on a graph, a linear equation would trace a straight line or a flat plane.

Linear-programming models are the simplest and most common form of **mathematical programming**. These models find the maximum **feasible solution** for a **linear objective function** given a set of linear **constraint equations**. Linearity allows for larger data sets and faster solutions to large-scale models. Linearity imposes restrictive **assumptions** about the type or form of economic phenomena being modelled. Linear constraints imply that the use of an input is *proportional* to the output that uses it, and the total usage of an input resource is *additive* across all outputs. A linear objective function implies that demand is perfectly "**inelastic**" or is nonresponsive to changes in product prices. (See economics and elasticity of demand and supply).

Liquidity is the ability to sell an **asset** quickly in a **market** without having to make a substantial **price** concession. This translates to the ability of investors or owners to convert an asset to cash at a price similar to the price of the previous trade in the asset, assuming no new information has arisen since the previous trade.

Long-term (long-run) analysis focuses on a long time horizon over which producers and consumers are able to vary all of the economic factors of interest, such as inputs to production or location. By focusing on the long term, economists attempt to derive **equilibrium** conditions that result from a policy change.

Macroeconomics attempts to explain the behavior of the aggregate economy using broad economic indicators of economic performance, such as the interest rate, unemployment rate, factor output and money supply. Much of this analysis has grown out of the apparent failure to adequately explain the behavior of aggregated individual decisions through neoclassical **microeconomic** analysis. For example, long-run sustainable unemployment should not occur according to neo-classical microeconomic theory. **Keynesian** analysis is probably the best-known macroeconomic approach, but has fallen from favor since the 1970s. Neo-Keynesian, neoclassical and new growth theory are now the main schools of macroeconomic theory.

Marginal cost is the additional cost incurred by producing one more unit of output. This concept is similar to **incremental cost**.

Marginal rate of substitution is the rate at which an individual is willing to trade one unit of a good or service for another while remaining equally well off as measured through the **utility function**.

Marginal revenue is the additional revenue received when one more unit of output is sold.

Marginal revenue product is the additional revenue received when the output produced by one more unit of input is sold. For example, if one added hour of labor produces a hundred more units of output, the marginal revenue product is the additional sales revenue from that output.

Marginal tax rate is the amount of taxes, expressed as a percentage, paid on each additional dollar of taxable income, production or consumption.

Marginal utility is the extra **utility** or satisfaction that an individual receives from consuming one more unit of a good or service.

Marginal value product is the **marginal revenue product** when the output is sold in a **perfectly competitive market** (i.e., the price of the output does not change as supply increases).

Market-based goods are those that are traded in a **market** with explicitly identified buyers and sellers who agree on a mutually-satisfactory price at which they exchange. The **property rights** of market goods are clearly defined so that exchange of possession is not usually disputed. (See externalities.)

Market failure occurs when either no **market** exists for a potential transaction, or a transaction results in an outcome distorted from what is predicted by **economic** theory as the most **efficient** result. Market failures lead to a divergence between private individual choices and "optimal" or preferred social outcomes. **Externalities** are a form of market failure.
If the use of a **public good** reduces its value but this is not captured in the market price of the offending private good, then an externality is imposed on the public. For example, if the **cost** of polluting the air is left out of fuel prices, this is a market failure.

Market portfolio consists of an **investment** in all available and relevant **assets**, most commonly defined as financial securities. The proportion invested in each asset equals the percentage of the total market value represented by the asset. The market portfolio is used as a benchmark for **risk** and return in the **capital asset pricing model**.

Market power is the ability of a firm to raise and sustain its price significantly above the **competitive** price level.

Markets are where individuals, firms or other organizations come together to exchange resources such as **goods** and services. Markets can take many forms, including dealerships, financial asset and stock exchanges, stores, bulletin board listings, and brokerages. How well the market works can affect the level of **transaction costs** involved in consummating an exchange.

Mathematical programming simulates a firm's or organization's decisions to allocate limited resources among competing activities in the "best" possible combination based on prospective costs, revenues and production information. The model is formulated to find the maximum **feasible solution** for an **objective function** given a set of **constraint equations**. A set of technology costs are calculated for a range of outputs, and the technology which allows for the highest profit level is chosen through a mathematical search process. The model produces a **normative** analysis of "what should be." Model types include **linear, quadratic or nonlinear programming**.

Maximin decision rule is for choosing a strategy in which the minimum payoff or benefit will be as large as possible in all possible situations.

Maximum return at minimum risk is a financial analysis paradigm in which a portfolio of assets is compiled that first minimizes **risk** to the investor and then maximizes **expected** return within the minimum risk constraint.

Maximum sustainable yield is the rate at which a **renewable resource** can continually produce the maximum amount of harvest at a constant level. This rate is dictated by the natural population and reproduction rate. Maximum sustainable yield, unlike **optimal yield**, does not account for human consumption preferences over time.

Mean is one method to calculate an **average**. It equals the sum of all values for a data series divided by the number of values. The mean is the **expected outcome** for a **random variable** when calculated from a sample of a population. Outlying sample observations may cause the mean to poorly reflect the "true" central tendency of a population, particularly if the sample is small and the distribution of observations large.

Measurement error involves **uncertainty** about the historic information on which **theories** are constructed and tested.

Median is one method to calculate an **average**. It equals the middle value for a data series ordered from highest to lowest. This is also known as the "fiftieth-percentile" observation. The median can differ substantially from the **mean** because the influence of "outliers" is reduced to be equal to that of all other observations in a sample. For example, mean income is usually larger than median income because the income of millionaires carries more weight in calculating the mean than the median.

Microeconomics focuses on decisions made by individual persons and firms in the economy on consuming or producing goods and services in an isolated **market**. These decisions can then be aggregated as the building blocks for analyzing an **economic sector**. Neoclassical, institutional and Marxist economics are the most prevalent schools of microeconomic analysis.

Mode is a method to calculate an **average**. It represents the most commonly observed value in a data set or population. This value need not have any other relation to the rest of the data series and can equal the highest or lowest value in the data series.

Monopoly is where an industry or market sector has only one *seller* of a particular good. That seller can exercise **market power** and is a "price searcher."

Monopsony is where an industry or market sector has only one *buyer* of a particular good. That buyer can exercise **market power** and is a "price searcher."

Monte Carlo simulations involve starting with a theoretical **statistical** model of a process, generating simulated samples of data consistent with the process, developing estimates of the unknown **parameters** consistent with one or more rules, and analyzing the estimates to determine statistical characteristics. In the **simulation**, the analyst plays the role of "nature" and assumes that the true **mean** and **standard deviation** of the population is known. A **random** number generator is used to produce several samples. This approach can be used to develop a distribution of forecasts based on the statistical characteristics of historic data. For example, the probability that a future river flow might exceed a certain level can be forecasted using data on past flows and a Monte Carlo simulation.

Multiattribute utility analysis is a type of **decision analysis** which relies on consumer **utility** theory to logically combine several **attributes** into a single figure of merit, so that alternatives can be compared across a number of attributes.

Multicollinearity occurs in **regression analysis** when two or more **independent** or explanatory variables are highly (but not perfectly) **correlated** with each other. While multicollinearity does not **bias** the **parameter** estimates, it does distort the measure of their **statistical significance**. As a result, the relative importance of their cause-and-effect relationship to the dependent variable cannot be separated.

Multiplier effect estimates how many times an additional dollar of **investment** or spending will be spent as it works its way through the economy. This effect measures the increase in the regional income and consumption **induced** by the initial amount. Typically, this value is estimated at between 2 and 2.5 over the long run.

Myopic literally means "near sighted"; it is used in economics to describe the **assumption** that economic actors consume or produce based solely on today's conditions without looking to how those conditions might change in the future.

Net present value (see present disounted value).

Nominal or inflated value of dollars is the value of a good expressed in the terms of currency for the year in which the good is produced or consumed (i.e., the value is not adjusted for **inflation**). For example, when asking the question in 1994 what the nominal price of a good will be in 1999, the inflation rate is estimated over that time and added to the good before examining how much its **real** price changes.

Nonlinear functions are composed of a set of **variables** in which the **parameters** may be multipliers or exponents, and the relationships of the variables are not limited to being additive or subtractive as is the case with **linear functions**. An example of an algebraic nonlinear equation is:

$$y = 2x^2/5z^3$$

If plotted on a graph, a nonlinear equation would trace a curve or an undulating surface.

Nonlinear mathematical programming models, such as quadratic programming or positive mathematical programming (PMP) use nonlinear **constraints** and **objective functions** that allow for more flexible modelling of economic phenomena. For example, quadratic and nonlinear models can incorporate demand responsiveness where **linear programming** cannot.

Nonmarket goods are **scarce** resources to which people attach value, but due to difficulty in defining the **property rights** are not traded in a **market**. Most often these are a type of **public good**. These goods can include environmental **assets**, such as a vista or a species of animal, or human health and well being. Because these goods are not traded in a market, no explicit price exists that describes their **marginal values** to people; other valuation techniques are required to infer those values.

Nonrenewable resources have a total **stock** available to humans which is fixed or finite for the foreseeable future. These resources are also considered *exhaustible* (i.e., they can be fully depleted through consumption).

Normal probability distribution is a symmetric "bell-shaped" **probability distribution** of outcomes that can be completely described by its **mean** and **standard deviation**. The normal distribution is significant because the Central Limit Theorem of statistics states that regardless of the type of probability distribution that describes the underlying population, in the case of sufficiently large samples, the sample mean is distributed approximately normally and is equal to the population mean, and the **variance** is proportional to the population's variance. This property allows for simple statistical tests in most cases about the mean or variance of the sampled population.

Normative analysis is when a position is taken on how participants in the economy or society *should* act. Normative analysis is prescriptive in nature, in contrast to **positive analysis**, which analyzes how things *are* rather than how things should be. For example, with regard to an environmental regulation positive analysis might estimate how many jobs are created or lost; normative analysis might suggest whether or not the effects of the regulation are desirable. The reliability of normative statements cannot be tested unless some measurable standard of desirability has been estimated. Normative judgements are usually personal views of the world and vary from one person to another.

Objective functions are a means of expressing progress toward a specified goal. The objective function must consist of measurable quantities if it is to support a quantitatively analytic decision process. Objective functions may include economic variables (such as cost), health variables (such as lives saved), environmental variables (such as habitat created) and many other possible considerations. In **decision analysis**, the objective function evaluates the achievement of various policy objectives and how those objectives might be traded-off against each other. In **mathematical programming**, the objective function measures the net revenues from economic activity, with the objective being to find the largest difference between revenues and costs or to maximize profits.

Oligopoly is where an industry or market sector has only a few sellers of a particular good. Those sellers may be able to exercise market power, particularly if they create a **cartel**.

Opportunity costs are the true costs faced by a **decision maker**, measured as the highest valued (best) alternative that is foregone when an action is taken.

Optimal solutions in **mathematical programming** are those among the **feasible solutions** that generate the highest value of the **objective function**.

Optimal yield for a resource is the economically **efficient** rate of extraction or harvest, which depends on the **discount rate**. This differs from the **maximum sustainable yield** in that human consumption desires enter into the production decision.

Options are the ability to purchase a specific **asset** at a specific cost within a specific time period. The value of an option can be evaluated by estimating the **expected value** at the end of the time horizon, the **probability distribution** of possible values, and the value of an alternative asset which can be purchased with certainty over the same time horizon. If the value of the option falls below the value of the alternative asset, then the option is not exercised.

Option value reflects society's **willingness to pay** to protect a resource from **irreversible** development or demise (e.g., harvesting a stand of old-growth redwoods) thereby retaining the option to use the resource at a later date. Option value may be thought of as an insurance premium against **uncertainty** about future preferences, incomes and technologies that may make the **discounted present value** of future alternative uses for the resource greater than the present value of its current or proposed use. (See quasi-option value.)

Ordinal scaling applies to measurements which can be placed in relative order but cannot be measured on an absolute or **cardinal scale**. Thus an ordinally-scaled measure of 2 is not necessarily twice as good as a 1. Ordinal values are usually expressed as rankings (i.e., first, second, etc).

Ordinary least squares (see **regression**).

Parameters are the mathematical values that describe the relationship in a model between the dependent or endogenous variable and the independent or **explanatory variables**. The parameters are generally derived either from **econometric** or **mathematical programming** estimation, from **theory**, or by **assumption**.

Pareto optimality criterion defines an efficient choice as one where *everyone* is at least as well off after a chosen action as before, and certain individuals are better off—there are no losers from the policy. This is the strongest measure of an **efficient allocation**.

Parity price is the price benchmark used by the U.S. Department of Agriculture in setting its commodity price support levels. It is designed to give American farmers the same purchasing power as they had between 1910 to 1914, a period described as that of agricultural prosperity.

Partial-equilibrium analysis considers only the immediate affects on a portion of the economy from a change in economic conditions, (i.e., it does not consider changes that might occur outside of the affected market in other markets). In other words, the analysis examines how a change in price might affect demand or supply on a single market assuming that all other conditions are held constant and not influenced substantially by the change within that market.

Per capita literally means "by head"; it is used to describe data on a per person basis (e.g., per capita U.S. income levels).

Perfect competition is the **assumption** that there are a sufficiently large number of buyers and sellers in the **market** such that no one individual or firm can influence the market price significantly, and thus all are "price takers." Perfect competition is perhaps the most common assumption used in economic modelling.

Perfect information implies that an economic actor has all of the information with certainty about the past, present and future necessary for a market transaction. Economists often assume that information about the future can be conveyed through "rational expectations" by all participants through market prices, thus incorporating perfect information into the **market**.

Poisson distribution describes the **probability** of when an "event" will occur within a certain time interval if the probability of each "event" occurring is independent of the others. For example, the likelihood that a person will join a queue often can be estimated with a Poisson distribution.

Pollution is the contamination of a natural environment by waste from human activity. For example, the atmosphere can be polluted by automobile exhaust or rivers by industrial plant wastes.

Pooled time-series analysis is a combination of **cross-sectional** and **time series analyses**. It draws data compiled over time from different but comparable settings (e.g., consumer behavior in several states over the last 20 years). Pooled time series analysis can give important information about both trends and policy alternatives.

Positive analysis seeks to explain and predict actual events and decisions based on observed and **hypothesized** behavior. Positive analysis is descriptive in nature, versus **normative analysis**.

Present discounted value or net present value is the current value in today's dollars of a sum of money that will be expended or received sometime in the future. NPV takes into account the **time value of money** as measured by the **discount rate**.

Price in economics is what has to be given up to obtain something. "The price of a sunrise is but an hour's sleep." If an individual is unwilling to pay the price for something, that person will not obtain it unless they resort to unlawful means, and pay a price of a different sort. In environmental economics, and according to demand theory, if polluters have to pay a price to pollute, they will pollute less than if they are allowed to pollute freely. One reason given by economists for the massive pollution of the environment is that until recently polluting has been free of charge.

Price discrimination is charging different prices to different buyers of the same product. It occurs whenever a buyer or seller is able to use "market power" to separate related **markets** for the same good or service and to institute different pricing policies in each market. These markets are resistant to **arbitrage**.

Principal is the original amount of a loan that is paid back over time. **Interest** is added as a fee for the use of the principal.

Prisoner's Dilemma is a situation where two individuals each must make choices that affect the other person, but each is **uncertain** about the other's behavior. As a result of a Prisoner's Dilemma, each person may decide to follow the **maximum** course of action which limits potential losses (poses the least **risk**). However, if both individuals choose this strategy, the outcome is less beneficial to each than if they could have coordinated their actions. The classic example is where two (guilty) suspects are brought in for questioning by police. In this situation three outcomes are possible:

(1) If both prisoners refuse to cooperate, they will both be set free;

(2) If both prisoners confess, they will both get moderate-length sentences; and

(3) If one prisoner confesses to the crime, but the other prisoner refuses to cooperate, the first one will get a

light sentence while the second will be locked away for life.

While outcome (1) is the preferred cooperative solution, outcome (3) is the maximin or "Nash" solution. The dilemma is whether to trust the other prisoner to make the best choice.

Probability distribution is a mathematical description of the relative frequency of possible values that a particular **random variable** can take.

Probability theory is a branch of mathematics which addresses the likelihood that an event will occur. The underlying assumption is that the occurrence of **random** events over time will fall into a general pattern called a **probability distribution.**

Production functions define relationships between inputs and their associated output. They are a mathematical representation of the **technology** of the production process that describes how the maximum product amount can be achieved from different combinations of inputs given current technology at a point in time. They summarize the substitution possibilities in production.

Production possibility frontier is the envelope of all maximum combinations of outputs that can be produced with fixed amounts of productive inputs given available resources and technology.

Productivity is a measure of the output produced by use of an input, particularly labor measured in terms of output per hour.

Profit functions are simple models of a firm's financial and technological traits that relate inputs to output. The profit function includes **revenues** which equal the price of the product or service times the quantity of output; costs which equal the price of inputs, such as labor or investment, times the quantity of inputs; **constraints** on resource availability; and a **production function**.

Profit maximization is the assumption that firm owners and managers are motivated to achieve the highest profit level, which equals **revenues** minus costs or net revenue.

Profits in **economics** are the difference between the total **revenue** a firm receives and its total economic (or **opportunity**) **costs** of production (versus **accounting costs** and profits). The economic costs include "normal" returns to investors (i.e., what they could earn if they invested in an alternative activity). The **assumption** under **perfect competition** is that economic profits equal zero. In this case, accounting profits would be positive and equal to the normal **rate of return**.

Progressive taxes are those that take a higher proportion of **income** and **wealth** as income and wealth increases (i.e., the **marginal tax rate** increases with income and wealth).

Property rights are the legal specification of ownership and the **rights** of owners to specific **assets**. Weak or nonexistent property rights are a major cause of environmental pollution and degradation (e.g., dumping the wastes of industrial production into waterways and the atmosphere or overfishing of the oceans).

Public goods are those which, once produced, are available to everyone on a *nonexclusive* basis, that is, can not be denied (e.g., natural defense). Public goods are often nonrival as well, meaning that consumption by one person does not affect consumption by another individual (e.g., a sunset). With private goods, more for one person means less for someone else (e.g., tickets to the Super Bowl). Some goods have features of both, such as the Super Bowl and the San Diego Freeway. One can be excluded from the Super Bowl, but once in the stadium one's viewing does not reduce the amount left for someone else to view. Although one may not be excluded from the San Diego Freeway, use at 5:00 a.m. may not reduce someone else's use. But during the congestion of the evening rush hour, it does. As a result, at 5:00 a.m. there are no restrictions to limit freeway use, but at 5:00 p.m. there are (e.g., car pool lanes and ramp metering). Private goods are normally rationed by prices in markets. The classic example of a public good is provision of a national army where everyone is made secure within a set of national boundaries whether they pay for the army or not. How many people reside within the nation makes no difference to the security level.

Public utilities are either a government agency or a government-regulated private **corporation** that provides basic services that require an extensive and capital-intensive network, such as water, sewers, electricity, natural gas, telephones and cable television. The motive for government intervention is the belief that these services can be provided **cost effectively** only through a **monopoly**, which is a classic form of **market failure**.

Quasi-option value is related to **option value** but is a risk-free measure of the **expected value** to society of information gained from postponing an **irreversible** development. Quasi-option value is based on the concept that a resource's value and appropriate uses are discovered through time, and that irreversible development that destroys the resource cuts short this discovery process. Quasi-option value is the amount society is **willing to pay** to guarantee that this learning process continues.

R-squared (R^2) is the proportion of variation for the dependent or **endogenous** variable of a **regression** that is "explained by" the independent or explanatory variables, which may be **endogenous or exogenous**. R^2 values are between 0 and 1.

Random variables take on alternative values according to chance. Such variables may have part of their behavior explained by other forces, but a portion of the behavior is described by a **probability distribution**.

Rate of return is the rate at which an **investment** made today can be transformed into **income** or benefits in the future. For example, a 10 percent rate of return indicates that a dollar of consumption foregone and invested today will yield $1.10 of benefits next year.

Real value of dollars is the value of a good expressed in the terms of the currency for a single **baseline** year (i.e., the value is adjusted for **inflation**). For example, when determining in 1994 what the real price of a good will be in 1999, the inflation rate is subtracted over that time before looking at how much its price changes, in contrast with **nominal or inflated** dollars.

Regression is a **statistical** model of the relationship between dependent and independent random variables in which the dependent variable is **hypothesized** to be mathematically related to the others. A linear regression, also known as *ordinary least squares* (OLS), estimates this equation by minimizing the sum of the squared deviations between the observed and fitted values of the dependent variable.

Regressive taxes are those that take a smaller proportion of **income** and wealth as income and wealth increases (i.e., the **marginal tax rate** decreases with income and wealth).

Renewable resources have a **stock** that is replenished on a regular basis. These resources can be biological, as in the case of agriculture, timber and fisheries, or geophysical, as with rainfall or sunshine. If the rate of harvest or extraction is sufficiently high to deplete the stock, the resource can be *exhaustible*.

Rent is the payment to a "factor" of production (e.g., land, equipment or labor) that is in excess of the amount necessary to keep it in its current employment. This means that the factor is being paid more than its **opportunity cost**.

Returns to scale (or scale economies) classifies **production functions** by how output levels change proportionately as inputs change. *Decreasing returns* are when the costs of producing each additional unit *increase* with total output—each added unit becomes more expensive because more input is required for the same unit of output. *Increasing returns* are when the costs of producing each additional unit *decrease* with total output—each added unit becomes less expensive. *Constant returns* occurs when a unit increase in input translates into a *constant proportional* output unit.

Revenues are the gross monetary returns from selling a quantity of goods at a given price, as measured over a period of time (i.e., total revenue is the price of a good times the amount sold). Revenues are used in calculating **profits**. Maximizing revenues does not imply that profits are being maximized. (See **marginal revenue** and **marginal revenue product**.)

Rights define one person's recognized legal position with respect to the legal positions of all other individuals. A right exists only when all people have a duty or obligation to respect that right.

Risk is the potential loss that could result from an **uncertain** outcome. Risk is driven by the uncertain value associated with an asset or policy.

Risk analysis uses **risk assessment** as a starting point, but adds judgment regarding the significance of the risk, and **risk communication**. Significance determinations place an importance or priority on the social consequences of the risk.

Risk assessment is the technical evaluation of the magnitude of the **risk** posed by a particular substance, hazard or event in a specified situation. It involves quantifying the amount released, determining the environmental dispersion, measuring the dose received by the receptor, and observing the receptor's response to this dose.

Risk aversion is when consumers or producers prefer certainty over risky situations.

Risk communication involves conveying risk-related information from technical experts to public **decision makers, stakeholders** and the public.

Risk management is a further extension of **risk analysis** which involves controlling elements of risk to minimize harm given various **constraints**. Risk management incorporates the results of **risk assessment** with information on technologically feasible responses and social and **economic** consequences of both the risk and the response.

Risk neutrality occurs when an individual or a firm is indifferent between two choices that have the same **expected outcomes**, regardless of whether one outcome may involve *higher risks* than the other.

Robust models are not highly sensitive to changes in the underlying **assumptions** and data, meaning the results stay relatively stable. **Sensitivity testing** can be done either directly or as a side calculation to test a model's robustness.

Royalty is a payment for a **right** or a privilege to use an **asset** owned by someone else. For example, a royalty can be paid by a publisher to an author for the right to sell a book, or it can be paid by a mining company to recover minerals from government held land.

Scarcity occurs when allowing people free access to **goods** results in more being demanded than can be provided. Scarcity means not having enough, for example, old-growth redwoods, clean air, jobs, adequate health care, or whales. Scarcity implies competition for the limited resources available—redwoods or whales—and hard choices, such as when employment clashes with the desire to protect endangered species. Scarcity drives the fundamental **economic** problem of what to produce, how much to produce, and who gets what is available. For example, a high **price** for a scarce good such as water would encourage production and discourage consumption.

Scenario analysis begins with a series of plausible future economic conditions, or "scenarios," estimates the **probability** of their occurrence, and determines an **expected outcome**, reasonable bounds on outcomes and, possibly, a **probability distribution**.

Second best is the "best" allocation of resources that is achievable when various constraints preclude reaching true economic **efficiency**. The theory of the second-best states that if constraints within the economic system prevent some of the efficiency conditions from prevailing, it is not always desirable to have the optimum conditions hold elsewhere. For example, if an industry pollutes, economists suggest putting a fee on that pollution to reduce the amount of pollution to the optimal level, where, from an economist's viewpoint, the marginal benefits of a unit of abatement are no longer greater than the additional abatement costs. If an industry which pollutes is also monopolistic, rather than charging a fee or tax on the pollution, the second-best solution may already be in place because monopolists restrict output, and thus pollution, relative to competitive firms.

Sensitivity tests measure how **robust** model results are as **assumptions** change about **parameters** and data. If the model has a "knife-edge" characteristic, slightly altering an assumption may actually reverse the direction of the results from, for example, positive to negative net benefits.

Shadow values are the increase in the value of the **objective function** when a **binding constraint** is relaxed in **mathematical programming**. The shadow value represents the **opportunity cost** of holding a constraint constant.

Short-run (short-term) analysis focuses on near-term events and results and assumes that most influential factors remain fixed (e.g., in **economics**, the relative importance of individual inputs to production will be unchanged).

SIC or Standard Industrial Classification is used to classify establishments by type of activity. Typical SIC codes are as follows:

Two-digit SIC	Economic Sector
01 - 09	Renewable resource production and agriculture
10 - 19	Nonrenewable resource production and construction
20 - 33	Raw resource processing
34 - 39	Finished manufacturing
40 - 49	Transportation and utility services
50 - 59	Retail goods
60 - 89	Retail and professional services
90 - 99	Government services

Simulations are experiments on social, physical or biological processes conducted by abstracting the essence of a process to assess its underlying structure and simulating its operation over time. Simulations are used to examine especially complex problems by breaking the problem down into its individual components, identifying those components that have predictable versus random behavior, and specifying the relationship among components. Simulations allow analysts to examine how changes in **parameters** and **assumptions** impact outcomes and to compare **statistically** a set of experimentally generated data. Simulations can be conducted either on computers, particularly for physical and biological processes, or through various role-playing forums for social analysis.

Sinking fund is a fund into which governments or businesses place money to redeem their bonds and other forms of indebtedness.

Adam Smith is acknowledged as the founder of modern Western economic thought. His book, *Wealth of Nations* (1776), described the basic principles of **economic** analysis still used today. He advocated reliance on **markets** as a method to further general social well-being.

Social welfare functions measure aggregate benefits and costs to society as a whole based on assumptions about how well-being can be compared among individuals. Social welfare functions are a hypothetical construct of how society views **equity** among individuals.

Socioeconomic status is an individual's or group's position within a hierarchical social structure. Socioeconomic status depends on a combination of traits, such as occupation, education, income, wealth, ethnicity and location. Socioeconomic status can be used as a broad indicator of likely behavior in social and economic analyses.

Spot markets involve the immediate exchange of assets for cash, versus a type of **futures market**.

Stakeholders are parties and individuals who hold a stake in the outcome of a policy decision. Most frequently stakeholders are identified as key interest groups that represent collections of individuals most affected by the potential outcome. Stakeholders may give **decision makers** input on how policy analyses should be weighed in the decision making process based on **value judgements**.

Standard deviation measures the dispersion of possible outcomes around the **expected outcome** of a **random variable**. The standard deviation equals the square root of the sum of the squared deviations from the **mean** (or the **variance**) for the observations.

Static analysis assumes that the world is in a "steady state" (i.e., tomorrow's circumstances will be the same as today because all influential forces are in **equilibrium** or unchanging). Some economists argue that a static analysis is equivalent to the end result over the **long term**. If the system is not in a "steady-state equilibrium," then a more complex **dynamic analysis** may be preferred.

Statistically valid describes whether a particular analysis meets certain **statistical** criteria, such as sample size, sampling technique, sample-to-population characteristics, and **parameters**' characteristics obtained from the analysis.

Statistical significance is the expression of the probability that the result of a given analysis represents the "true" results that would be obtained by using a hypothetically perfect data sample. Statistical significance can be expressed as a margin of error, as is done with public opinion polls, or as a **confidence interval**.

Statistics is the mathematical analysis of the collection, organization and interpretation of numerical and **empirical** data. Statistics is the analysis of how real-world or **simulated** events and trends relate to each other given that a certain amount of **random** chance intervenes. Statistics relies on **probability theory** to develop measures of the *most likely* explanation of cause and effect for certain events. Statistical applications include analyses of population characteristics or social phenomena by inference from sampling.

Steady state (see **static**).

Stock is the unused economic value associated with a resource. The stock can grow or fall depending on the **flow** of resources in and out of the stock. For example, the stock of timber is the stand or forest of trees. Stock can be thought of as the holding of **capital goods** for the use in production of other goods or services.

Subsidies occur when one party pays (or receives) a price for a good or service that is below (or above) its **opportunity cost** because another party either makes a **transfer payment**, or misprices the resource and absorbs the economic loss in value. Many examples of subsidies by the U.S. government exist where individuals or companies have access to natural resources (e.g., forests, developed water supplies or minerals) and pay **prices** substantially below the true costs of their provision.

Substitutes are two goods such that if the price for one increases, **demand** for the other increases in response (e.g., public and private transportation. If the price of private transport increases, consumers will look for less expensive alternatives, and the demand for public transportation—ceteris paribus—will increase). (See **complements**).

Substitution effect is the change in quantity demanded of a good which results from a change in its price relative to the price of other goods, exclusive of the **income effect**. Substitution effect gives rise to the standard statement that "when price goes up, the quantity demanded goes down."

Sunk costs are costs that are not recoverable after their expenditure. These costs should be disregarded in making a choice about an asset or policy. For example, if $1 million dollars was spent to unsuccessfully repair a facility, those costs are sunk from the perspective of whether to continue to operate the facility. Only the future expenditures necessary to successfully repair the facility should be considered, because the decision maker has control over those funds.

Supply curve or function is a graph showing the relationship between a good's price (usually on the left-hand axis) and the quantity provided to the market. Supply curves usually slope upward from the left to right, indicating the incentive to produce more as price rises.

Sustainability is the maintenance of an existing **ecosystem** so that consumption can continue into the future without destroying that system. Younger and future generations do not have equal bargaining strength with the older and present generations, and must rely on the latter's altruism and patience. **Bequest value** as well as **intergenerational equity** are concepts used in analyzing sustainability.

Sustainable development means a constant or growing quality of life based on a social and economic system that enables this rate to be maintained indefinitely.

Systematic risk is the portion of the total risk associated with holding an asset that is related to or correlated with movements in the **market portfolio** (i.e., the value of the **asset** increases or decreases as the market portfolio increases or decreases in value). This risk cannot be diversified away with combinations of assets.

Tariffs are either (1) a government tax on imports, intended to raise revenues and/or to protect domestic industries from foreign competition, or (2) prices set by government regulators for private companies that are either public utilities or transportation common carriers, such as railroads and trucking.

Tax incidence identifies who ultimately bears the burden of a tax, which could be quite different from those charged statutorily with paying the tax to the government. For example, a tax charged to employers on the basis of their labor costs is likely to be borne, at least in part, by workers; thus part of the incidence is on labor.

Technological or production possibility frontier defines the minimum combinations of inputs needed to produce a given output level with available resources and technology. The choice set of available policy options is similarly constrained by the technological possibilities of reaching a set goal. (See **production possibility frontier**.)

Technology in an economic **production function** includes not only the machinery necessary but also the management process, information and knowledge required to produce a good.

Theories derived by scientists, whether natural or social, provide a simplified understanding of the problem. Theories are developed from **hypotheses** using **empirical data** and different analytic techniques, such as **statistics, economet-**

rics or **mathematical programming**. Theories provide the basis for developing and assessing policies in policy analysis.

Timeframe is the temporal period over which an alternative is to be evaluated. It is important to maintain a consistent timeframe within an analysis of alternatives.

Time series analysis is the **statistical** evaluation of the variations in a single or combination of **variables** over time. Time series analysis used in **economics** can estimate how preferences or technology choices change over time and assess the importance of different factors in this transformation. Time series analysis focuses on trends. It can estimate both *short-term* and *long-term* impacts given that a particular development path has been chosen. Time series analysis assumes that the environment in which a choice is made is most important regardless of the goods or services being studied.

Time value of money reflects the principles that (1) people prefer receiving benefits from spending money now rather than later, and (2) money received now can be reinvested to produce greater benefits in the future. This concept is used in developing the **discount rate**.

Transaction costs are the costs beyond those simply for production or reflected in the price for a good or service incurred from participating in a **market**. Transaction costs include (1) searching and information gathering, (2) bargaining and decision making, and (3) monitoring and enforcement of contracts, including gaining legal approval. Examples of transaction costs include searching for a buyer or seller; identifying legal and physical characteristics of the commodity, such as title searches; negotiating the price; financial constraints on the participants; and a regulatory approval process. The existence of high transaction costs reduces the amount of mutually beneficial exchanges. This is particularly true for environmental pollution. For example, if it is costly to negotiate and police contracts with regard to restrictions on emitting pollutants onto private property, there will be fewer restrictions and more pollution. Many of these costs can be reduced through an efficient market structure, but others may be inherent in the laws and regulations defining the **property rights** for a commodity.

Transfer payments are the direct transfer of money or economic value from one party to another without an exchange of goods or services in return.

Transitivity of preferences implies that consumers make well-ordered, consistent choices among goods and services (i.e., if they prefer A over B and B over C, then they prefer A over C). This trait is a basic principle in the development of consumer **utility theory** and **decision analysis**.

Travel-cost method (TCM) assesses how much individuals are willing to expend in time and on transportation to reach a particular destination. This expenditure is used to find the revealed preferences for consumers of public goods, and their **willingness to pay** for those goods.

Uncertainty is a lack of knowledge about potential future outcomes.

Use values are based on direct interaction through recreation (e.g., fishing in a lake), or proximity (e.g., having a home on a lake). Use values can be measured either through revealed **nonmarket** valuation techniques, such as **hedonic pricing** or **travel-cost modeling**, or direct inquiry, also known as **contingent valuation methods**.

Utility is a measure of the satisfaction that an individual gets from consuming a **good** or service.

Utility or preference functions are a mathematical representation of the way individuals rank alternative bundles of **goods** and services based on their preferences. Generally, economists make several restrictive **assumptions** about utility functions to simplify modelling. The mathematical forms used to estimate the **functions** also have implications about how people are assumed to rank their preferences. Most often, economists assume that the utility of other people does not enter into an individual's utility function, and that the utility for a single good can be separated from that of other goods.

Value judgement is an assessment of a person, situation or event that either reveals or is based on the values of the person making judgement rather than on the objective characteristics of what is being assessed.

Variable costs can change in response to changes in the output level by a firm. These costs include such things as energy use, hourly labor and supply purchases. As the time horizon of the analysis expands, more costs become variable.

Variables are composed of data points and included in equations as either **explanatory** or **dependent**. Variables are combined with **parameters** to explain mathematical relationships among the variables.

Variance measures the dispersion of possible outcomes around the **expected outcome** of a **random variable**. The variance equals the sum of the squared deviations from the **mean** for the observations.

Vertical equity states that those in dissimilar or unequal situations are likewise treated dissimilarly but in a way defined as equal by society.

Von Neuman-Morgenstern utility ranks the outcome of **uncertain** situations on the basis of individuals' **expected utility** functions.

Wage is the cost of hiring one worker for an hour.

Watersheds are areas drained by a particular water system. Usually, watersheds are divided by high ridges of land so that two areas are drained by two different riverine systems, either on the surface or underground.

Wealth is the current stock of economic **goods**. It is usually measured by the market value of these goods. The total value of the wealth of a society includes the people and their health, and their environment, but those goods are not measured unless they are bought and sold. This is one reason why the usual measure of a society's wealth—gross domestic product, or GDP—is often criticized as not being a true measure of a society's wealth. GDP is the sum of money values of all final goods and services provided by the economy in a year. (See **income**.)

Willingness to accept is what an individual will accept as payment in return for giving up a resource, **good** or provide a service. Willingness to accept need not be constrained by an individual's **income** level, although it can reflect the **opportunity cost** of holding an asset, particularly if it is a private good rather than a **public good**.

Willingness to pay represents what an individual would pay to acquire a resource, **good** or service. Willingness to pay will be **constrained** by an individual's level of **income**, and reflects the **opportunity cost** of acquiring an **asset**.

Zero sum is when the benefits of the gainers equals the losses of the other economic actors.

Acronyms Used in the Handbook

B/C–benefit-cost analysis

CAAA–Clean Air Act Amendments

Cal/EPA–California Environmental Protection Agency

CAPM–Capital Asset Pricing Model

CARB–California Air Resources Board

CARM–California Agricultural Resources Model

CEC–California Energy Commission

CFC–chlorofluorocarbons

CGE–computable general equilibrium

CPI–Consumer Price Index

CVM–contingent valuation method

DA–decision analysis

DCF–discounted cash flow

DOC–Department of Commerce

DOE–Department of Energy

DOI–Department of Interior

DPR–Department of Pesticide Regulation

EPA–Environmental Protection Agency

GDP–gross domestic product

IMPLAN–U.S. Forest Service's Impact Planning

I/O–input-output

IRR–internal rate of return

LA-CBD–Los Angeles Central Business District

LCP–least-cost planning

mph–miles per hour

NOAA–Commerce Department's National Oceanic and Atmospheric Administration

NPV–net present value

OLS–ordinary least squares

OMB–U.S. Office of Management and Budget

OPEC–Organization of Petroleum Exporting Countries

PMP–positive mathematical programming

PPE–partial pareto efficiency

PRP–politically revealed preferences

PVDR–present value discounting rate

RECLAIM–South Coast Air Quality Management District's marketable permits program

REMI–the Regional Economic Modeling, Inc. EDFS Model

RIMS II–U.S. Department of Commerce's Regional Impact-Output Modelling System

SCAQMD–South Coast Air Quality Management District

SIC–Standard Industrial Classification

SOx–sulfur dioxide

TCM–travel cost method

U.S.–United States

U.S. EPA–U.S. Environmental Protection Agency

VMT–vehicle miles travelled

WTA–willingness to accept

WTP–willingness to pay

7 ANALYTIC RESOURCES

In addition to this handbook, readers are encouraged to seek out and use the many analytical guides and information resources that are currently available. One key resource is Cal/EPA's bibliographic database of decision analysis documents. This database contains more than 100 abstracts describing analytical documents that relate to Cal/EPA-regulated issues. Topical articles on environmental issues can be found in *EPA Journal*, published by the U.S. Environmental Protection Agency, and *Resources*, published by Resources for the Future. Other sources of economic data include the following:

- California Employment and Development Department maintains data on tax returns and employment.
- California Department of Finance issues economic and demographic reports.
- California's Franchise Tax Board publishes *Bank and Corporation Franchise Tax Statistics.*
- California's Office of the State Controller publishes data on local government financial transactions.
- California's State Board of Equalization publishes taxable sales data.
- President's Council of Economic Advisors maintains information related to the national economy.
- U.S. Department of Commerce publishes *U.S. Industrial Outlook.*
- U.S. Department of Commerce (DOC), Bureau of the Census, provides a wide range of business statistics, including data on retail and wholesale trade, service industries, transportation, manufacturers, and the mineral and construction industries. DOC also maintains comprehensive demographic data.
- U.S. Department of Commerce, Bureau of Economic Analysis, tracks the nation's leading economic indicators.
- U.S. Department of Labor maintains information related to inflation and employment.

- U.S. Department of Treasury, Internal Revenue Service, publishes *Corporation Source Book of Statistics and Income*.

In addition to these data resources, accessible academic textbooks and articles can provide more detailed descriptions of the analytical methods described in this handbook. Popular textbooks and journal articles which may be useful are listed below.

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Portney, Paul R., editor. *Public Policies for Environmental Protection.* (Washington, D.C.: Resources for the Future, 1990)

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York: W.W. Norton and Co., 1978)

BENEFIT-COST ANALYSIS

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With offices in Oakland, Sacramento, and San Francisco, California, M.Cubed is an economic consulting firm specializing in natural resource and public policy issues. M.Cubed professionals have substantial experience evaluating and recommending local, state and federal policies. M.Cubed staff have worked for the U.S. Congress and the Executive Office of the President and have testified before state legislatures, public utility commissions and other regulatory bodies. Recent notable projects include recommending possible water infrastructure financing strategies in California; developing cost effectiveness guidelines for environmental regulations; and examining the economic benefits associated with public sector investment in research and development.

Steven Moss, M.Cubed partner, served as project manager and principal author for chapters one, two and three. Richard McCann, M.Cubed partner, and Marvin Feldman, a Resource Economist with Resource Decisions, served as lead writers on chapters four and five. Mr. McCann was also chiefly responsible for the handbook glossary. Gregory Adams, of the University of California, Berkeley, and Frank Neuhauser were responsible for conducting the analysis of the case studies that appear in the handbook. Alan Dechert and Adam Diamant of KI Associates designed and completed the literature review database from which many of the case study examples were derived. Mr. Diamant also assisted with case study development. Consulting assistance was provided by Robin Gregory of Value Scope; Dallas Burtraw of Resources for the Future; and Michael Hannenman, of the University of California, Berkeley. Duo Studio created the handbook format and graphics. Malcolm Dole provided the photograph for the handbook cover.

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