Chapter 6
How Economists Measure Wellbeing: Social Cost-Benefit Analysis

A simple man believes every word he hears; a clever man understands the need for proof

(Proverbs 14:15)

Yet, in holding scientific research and discovery in respect, as we should, we must also be alert to the equal and opposite danger that public policy could itself become the captive of a scientific-technological elite.

– Dwight D. Eisenhower, Farewell Address, January 17, 1961

There is much confusion about how economists measure economic wellbeing – what economists refer to as 'welfare.' Governments usually measure the effectiveness of their policies by the number of jobs created. Employment estimates are inflated by taking into account the indirect jobs created upstream and downstream as a result of the public expenditures. Upstream jobs are created, for example, to satisfy demand for inputs required by a public project, while downstream ones arise as a result of spending by those employed by the public project. Thus, when the Canadian government provides a university professor with research funds, a crucial reporting requirement relates to the training of graduate students and the employment of technicians and support staff, numbers that are then inflated to account for the indirect jobs associated with the public spending on research. While important, jobs should not be confused with the true benefits of the research. The number of people paid by the research grant, like the numbers employed as a result of any public spending program, are simply one measure of the inputs required to achieve the program's targets, whether a research outcome, greater production of energy from renewables or improved health care benefits.

The job creation metric completely neglects alternative uses of public funds – the opportunity cost of funds. The money used to create jobs could have been spent in other ways that would also have resulted in expanded employment, and jobs created by government might well have crowded out private sector jobs. Indeed,

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had the funds been returned to taxpayers to spend as they saw fit, jobs would have been created, perhaps even more than those created by the public works project. These forgone jobs need to be taken into account in determining the true level of job creation; indeed, if the government expenditures are directed into the wrong areas, the number of jobs actually lost might exceed those created. Thus, it is important to take into account the opportunity cost of funds spent.

Employment is not even the correct measure of societal wellbeing, and job creation might even reduce overall social welfare. Jobs could be redistributed from current residents to immigrants who have specialized skills not available to current residents. Jobs could be lost in one sector, but created in another. In many cases, public programs and policies do little more than transfer jobs and/or income from one group to another. Unless 'wealth' is actually created, there is no benefit to society, and there is a loss (wealth destruction) if economic costs exceed benefits. This raises the question: How do economists measure costs and benefits, or changes in society's overall wealth? In this chapter, we review methods economists use to measure costs and benefits, particularly as these relate to climate change.

We begin in the next section by focusing on private cost-benefit analysis, or financial analysis, because economic agents will not generally take into account the greater good of society. We then focus, in Sect. 6.2, on the economic surplus measures used in social cost-benefit analysis. Given that environmental and other amenity values are important in the context of global warming, but environmental goods and services are not traded in markets, in Sect. 6.3 we consider how non-market amenity values can be measured. Because costs are incurred and benefits accrue at different points in time, it is necessary to weight costs and benefits according to when they occur so that costs and benefits can be brought to a common point in time (whether today or some future date). Without this weighting, it is not possible to compare costs and benefits, or one project with another. The weighting scheme is referred to as discounting and the weights are discount rates. This is the subject of Sect. 6.4. Finally, in Sect. 6.5 we consider extreme events and how to account for them in cost-benefit analysis.

6.1 Financial Analysis

Consider the perspective of the private firm. If a supplier of power to an electrical grid is considering the construction of an additional thermal power plant, for example, the costs of the project equal the up-front construction costs related to land, labor and materials; annual operating (fuel and other), maintenance and (routine) replacement (OM&R) costs; estimates of the costs of unscheduled breakdowns and the risks imposed by changes in fuel prices (and other input costs) over time; costs of meeting environmental regulations; and any costs related to the eventual mothballing of the facility. All costs are discounted depending on when they are incurred. Benefits are provided by the discounted stream of expected revenues from sales of electricity to the system operator (or directly to households and industry if the system operator is also the operator of the plant), plus any 'salvage' value at the end of the facility's useful life. As long as financial benefits over the lifetime of the project exceed costs, the private investor determines the investment to be feasible. That is, the rate at which the power producer weights the streams of costs and revenues is the rate of return that she hopes to earn on the investment, and equals the rate of return should the funds be invested elsewhere in the economy – the opportunity cost of the funds. Thus, if the weighted stream of benefits exceeds that of costs, the project earns a higher rate of return on the investment than could be earned elsewhere.

Financial analysis, or private cost-benefit analysis (CBA), excludes spillovers (also known as externalities) unless the authority specifically requires the firm to pay for access to unpriced natural resources, to pay compensation to those 'harmed' by the firm's activities, to pay an environmental tax, to purchase 'pollution rights', and/or to post a bond to offset society's potential future need to mitigate environmental damage caused by the firm's activities. These costs would be included by the firm in its financial analysis of a project. Further, a financial analysis uses market prices for natural resources, labor, land and other inputs instead of the (shadow) value that these resources have to society. Regardless of these limitations, it is important that public projects are valued from the perspective of private firms. For example, if the government wants to implement a given project and the financial performance of the project is attractive from a private perspective and it imposes little or no external costs on other economic agents, it is likely wise just to let the private sector pursue the project – to provide the good or service in question.

Projects are usually ranked on the basis of financial criteria such as net present value (NPV), the benefit-cost ratio (BCR), internal rate of return (IRR), and/or modified internal rate of return (MIRR).

6.1.1 Net Present Value (NPV)

For ranking projects on the basis of NPV, the following assumptions are needed (Zerbe and Dively 1994):

1. the discount rate is given and usually taken as the market interest rate;
2. capital is always readily available;
3. the interest rate for borrowing is the same as the interest rate for lending;
4. cash flow projections include all relevant costs and benefits, and taxes; and
5. projects are mutually exclusive (so that they can be evaluated separately). Any combination of projects should be considered as a separate option.

If these assumptions are valid, the NPV is the sum of the discounted benefits minus the sum of the discounted costs of the project over the project lifetime:

$$\text{NPV} = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r_t)^t}, \tag{6.1}$$

where B_t represents the benefits derived from the project in period t, C_t the costs in period t, T is the lifespan of the project and r_t is the interest rate in period t.

The interest rate or discount rate is generally assumed to remain constant in each period because it may be difficult to forecast future values of the rate.

If we are evaluating a single project and NPV is greater than zero, the project is worth undertaking as it increases net wealth. If we are evaluating several projects, the one with the highest NPV should generally be chosen, although that will depend on factors unique to each project. For example, some projects may be riskier than others, or projects have different life spans (in which case one might wish to annualize the net discounted benefits of each project in order to make the comparison).

6.1.2 Benefit-Cost Ratio (BCR)

This is the ratio of the discounted total benefits from a project divided by the discounted total costs of the project:

$$\mathrm{BCR} = \frac{\sum_{t=0}^{T} \frac{B_t}{(1+r_t)^t}}{\sum_{t=0}^{T} \frac{C_t}{(1+r_t)^t}}. \tag{6.2}$$

If the BCR for a single project is greater than 1, the project increases real wealth.

When comparing different projects, the problem of scaling appears. For example, a project with total benefits of $1 million may generate a greater increase in real wealth than a project with total benefits of $100, but the ratio of benefits to costs may not be as high. Thus, projects must have an equal outlay basis if they are to be compared. This is why in the case of choosing among several or many projects it is desirable to examine and rank projects on the basis of both the NPV and BCR criteria.

6.1.3 Payback Period

Given that costs are usually ‘front-loaded’, with only costs incurred in the first several periods while benefits do not accrue until after construction is completed, the payback period is the point in time when a project’s time-weighted total benefits exceed its time-weighted total costs. At that time, the project has ‘paid back’ its initial investment. The major problem with the payback method is that it ignores cash flows, including potentially negative ones (e.g., costs of clean up), that occur beyond the payback period. If the payback period is the only financial criterion taken into account, it is possible to accept a project that has a negative NPV. Nevertheless, the payback period is a useful indicator for firms that are unsure about future cash-flows and their position in the market. Obviously, firms prefer projects with a shorter payback period.

6.1.4 Internal and Modified Rates of Return: IRR & MIRR

The IRR is a popular criterion for private project appraisal. The IRR is the discount rate for which the NPV is zero – where the project's discounted benefits exactly balance discounted costs. In Eq. (6.1), it is found by setting NPV = 0 and solving for r (which assumes r does not change over time). The project with the largest IRR is generally preferred, subject to the proviso that the IRR exceeds the interest rate. Despite its popularity, the IRR criterion needs to be used with caution. First, for complex cash flows, there might be more than one IRR associated with a project. Second, the IRR approach assumes that the project can both borrow and lend at the internal rate of return. In other words, excess funds generated by the project can be invested externally at the IRR. This is certainly not the case.

The modified IRR (MIRR) is the average annual rate of return that will be earned on an investment if the cash flows are reinvested at the firm's cost of capital. Therefore, MIRR more accurately reflects the profitability of an investment than does IRR. To determine the MIRR, it is necessary to solve the following equation:

$$K_0(1+\text{MIRR})^T = \text{FV}_{\text{cash flow}}, \tag{6.3}$$

where K_0 is the capital investment (effectively calculated at time zero) and $\text{FV}_{\text{cash flow}}$ is the future (as opposed to present) value of the cash flow estimated using the interest rate that reflects the firm's cost of capital.

6.1.5 Informal Analysis

Depending on the manager or owner, and on the size of the project (the sums of money involved in the investment), a private company may decide to conduct an in-depth project evaluation, or it might eschew any formal analysis relying instead on the intuition of the manager or owner. But even intuition can be regarded as a form of project evaluation, and certainly 'paper and pencil' (or 'back-of-the-envelope') calculations would qualify. As the size of an investment project increases, formal analysis using tools such as those discussed above are more prevalent, although, again, there is nothing to prevent managers from relying solely on intuition and rough calculations.

Informal analysis is less likely for projects under consideration by government ministries and international quasi-governmental organizations, for example, although intuition and 'rough analysis' cannot be ruled out entirely in some cases (e.g., decisions sometimes announced by politicians in a media scrum). However, just because a government body conducts formal project evaluations does not mean that the criteria it uses differ much from those used in the private sector. Many government agencies are concerned only with the impact of decisions on their 'bottom line', and are much less concerned about the impact of their decisions on society more generally. The reason is that many government agencies, such as the US

Bureau of Land Management, US Forest Service, and Canada's Ministry of Native Affairs and Northern Development, operate under a broad mandate but in practice are concerned primarily about their own survival and influence. The same is true of international agencies such as the International Monetary Fund, World Bank and United Nations Environment Program. As a result, the evaluation of projects and policies is very much from the perspective of the agency – from a private perspective – rather than from the perspective of society as a whole. This is partly justified by the argument that the agency serves a particular clientele, while it is the job of politicians to ensure that the wellbeing of others in society is represented.

Social cost-benefit analysis is much broader in scope than private cost-benefit analysis because it takes into account the effect that projects have on all facets of society – on all citizens. However, the private perspective is not ignored in social CBA. In many cases, the private decision is adequate, and there is no need for public intervention. The only reason why the public authority would be involved in private investment decisions is if there are important externalities or spillovers, or if the private sector has no incentive to provide the good or service. If spillovers are small, the transaction costs of rectifying them might be too great to warrant intervention. If the spillover/externality is sufficiently large, or public provision is required, then criteria of social cost-benefit analysis are needed to evaluate government policies and public projects.

6.2 Measuring Social Costs and Benefits

Greenhouse gas emissions constitute the ultimate externality, and government intervention is required to rectify the problem and potentially reduce emissions to a socially optimal level. Intervention might take the form of regulations that require manufacturers to employ best available technology, electricity system operators to rely on renewable energy for some proportion of their power generation, and car producers to meet fuel efficiency standards for their automobile fleet. Regulations that require a certain proportion of biodiesel to be sold at the pump might be effective in encouraging biodiesel production, but such regulations impose no costs to the public purse. Alternatively, some investments in technologies that reduce CO_2 emissions and are considered worthwhile undertaking from a public standpoint might not proceed without subsidies or direct involvement by the authority. For example, the government might consider providing a subsidy to wind energy producers to encourage substitution of wind for fossil fuels in power generation, thereby reducing CO_2 emissions. In either event, such interventions must pass a social cost-benefit test, where a benefit of the action or policy is the reduction in CO_2 emissions.

There are alternatives to regulations and specific emission-reduction projects, although these are likely more in the realm of macroeconomic policy. Carbon taxes and carbon emission trading are two instruments that governments can use to reduce CO_2 emissions. These will be considered in Chap. 8. Here we are interested specifically in social cost-benefit analysis related to specific projects. The reason is that social cost-benefit analysis implicitly assumes that the policy or project has little impact elsewhere in the economy. If this is not the case, then general equilibrium analysis is a more appropriate tool to employ because general equilibrium models take into account how changes in one market affect prices and output in all other markets.

This highlights one of the main problems with estimates of the damages from global warming. General equilibrium models tend to be static, at least from the perspective of the long-term nature of the climate change problem; such models are difficult enough to calibrate over the short run, let alone attempting to calibrate them for future scenarios. As a result, economists rely on dynamic integrated assessment models (IAMs) that seek to maximize the well being of citizens, as represented by a social welfare or representative utility function, over a period of perhaps 100 years. (IAMs were considered briefly in Chap. 4 and are discussed in more detail in Chap. 7).

There are several oddities that should be noted. First, as noted in Chap. 4, the climate models themselves are driven by emission scenarios that are derived from economic models, many of which have elements that are similar to integrated assessment models. Second, integrated assessment models assume that damages are a function of temperature; that is, a relationship between temperature and damages is explicitly assumed, whether it is true or not. Third, the models assume a rate of technological change, although there is no way to predict where and how technology might change. Fourth, given that IAMs must project human and physical (perhaps even biophysical) relationships some 50–100 years or more into the future, the relationships in the model are either identities that must necessarily hold or relations whose functional form comes from experience in the theoretical realm and a parameterization based on what can best be described as ad hoc calibrations. Calibration amounts to nothing more than answering the following question in the affirmative: Are the results in the realm of the possible? Do the results seem reasonable?

Finally, as debate regarding the work by Nicholas Stern (2007) and his colleagues in the UK government shows (Chap. 7), the rate used to discount utility or wellbeing over the period in question is extremely important.

In this section, we examine three issues related to social cost-benefit analysis (CBA). First, we consider what constitutes valid measures of wellbeing, of costs and benefits. The short answer is that economists measure costs and benefits as surpluses; the longer answer requires some elaboration, which is done in the next section. Second, we discuss the methods used to measure the costs and benefits of amenities that are not directly traded in markets, such as spectacular views, nature, open spaces and recreation. Finally, we turn to the issue of discount rates.

6.2.1 Benefits and Costs as Rent and Surplus

Social cost-benefit analysis does not ignore financial costs and benefits, but it does proceed differently than private evaluation of costs and benefits. As discussed in Sect. 6.4 below, it employs a social rather than a private rate of discount, with the former generally lower than the latter. Further, social CBA considers opportunity costs (shadow prices) of resources as opposed to market prices. For example, market wage rates might be higher than social rates because of market impediments that

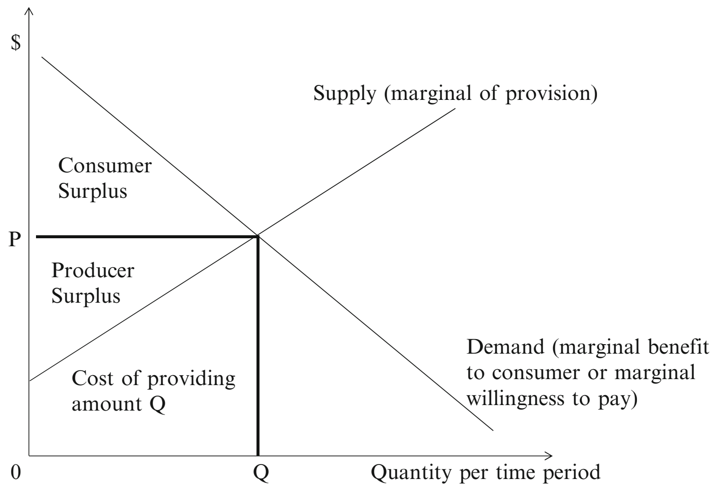

Fig. 6.1 Consumer and producer surplus

cause the wage rate to exceed the marginal value product – the value of additional output that the next unit of labor produces. In other words, the amount that labor is paid at the margin exceeds the value of what it produces. In that case, the economist recommends either that the wage rate be lowered (its shadow value is less than what is actually paid) or that less labor be hired as this will raise its marginal productivity, thereby increasing marginal value product. Where there exists a large pool of unemployed workers, the shadow price of labor is approximately zero.

In economics, costs and benefits constitute a surplus that is either lost (cost) or gained (benefit). There are four types of economic surplus.

1. *Consumer surplus* is the difference between the value that consumers place on goods and services – their willingness to pay – and the actual expenditure to obtain those goods and services. In essence, it is the difference between the total benefit that consumers derive (maximum willingness to pay) and what they pay. It can be measured by the area below the marginal benefit (demand) function and above price. It is illustrated in Fig. 6.1.
   Consumer surplus is not always directly measurable. Consider the case where a project does not affect consumer surplus in the market you expect. For example, it is unlikely that decisions concerning the harvest or protection of a single commercial forest landscape, or the development of a wind energy project, will affect the prices of timber products or power. Thus, the direct consumer surplus associated with such a project is unlikely to change; indeed, unless the project lowers price, the consumer is not going to gain surplus from the project. In that case, consumer surplus becomes relevant only in some other market, but not the market for lumber or energy. If, in addition to the market for lumber or energy, there is a demand for an environmental amenity that is somehow impacted by the

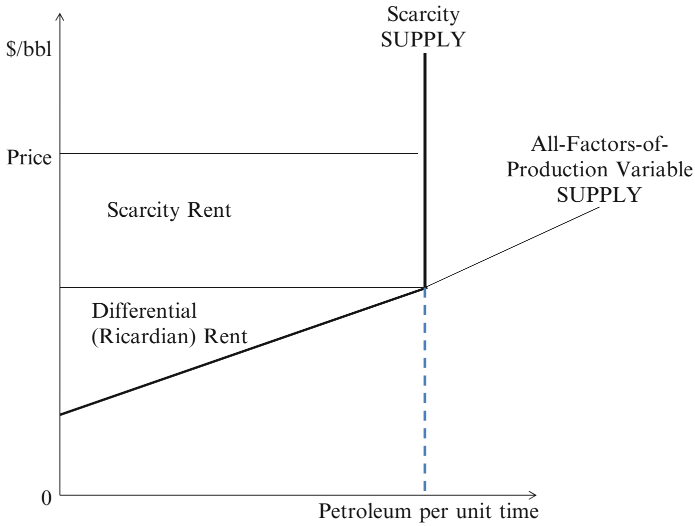

Fig. 6.2 Resource rent and its components

logging decision or energy project, then there may be surplus that needs to be taken into account in evaluating the logging or energy project. This would be an indirect cost or benefit associated with the project, which is discussed below as the fourth type of surplus.

2. *Producer surplus* or *quasi rent* constitutes the difference between total revenue and total variable cost. It can also be measured by the area below price and above the marginal cost (supply) function, as indicated in Fig. 6.1.[1] While constituting a true welfare benefit, producer surplus constitutes a rent accruing to fixed factors of production and entrepreneurship. That is, the supply curve in Fig. 6.1 is a short-run supply function, which means that returns to the fixed factors of production must come from producer surplus. Hence, attempts to tax this rent will adversely affect firms' investment decisions.
3. *Resource rent* accrues to natural resources and consists of two components that are often indistinguishable from each other in practice, and difficult to separate from the second type of surplus – the quasi rent (van Kooten and Folmer 2004). We illustrate the concept of resource rent with the aid of Fig. 6.2, noting in particular that the supply curve in this figure differs from that in Fig. 6.1.
   The first component of resource rent is *differential* (or *Ricardian*) *rent* that arises because of inherent or natural advantages of one location relative to another.

[1] Of course, the supply/marginal cost function is much flatter before the project is built than afterwards. Once the project is built, the construction cost is ignored in the determination of quasi-rent, as bygones are bygones.

Consider oil production. The price is such that the marginal oil sands producer earns at least an internal rate of return higher than the market interest rate. In comparison, Middle East producers earn a huge windfall, which constitutes a differential rent. Likewise, a woodlot located near a transportation corridor (highway, water transport) or a sawmill earns a windfall compared to one with the same amount of commercial timber volume and harvest cost structure, but located farther from the transportation corridor or sawmill.

Second, there is a *scarcity rent* that results simply from oil scarcity or a limit to the number of stands with commercial timber. That is, if the oil sands or timber producer, despite being the highest cost producer, earns a windfall over and above what could be earned elsewhere in the economy, there is a scarcity rent because price exceeds the marginal cost of production.

Resource rent is the sum of the differential and scarcity rents, and must be considered as a benefit in decisions about whether to harvest a forest, develop an energy project, or invest in a biofuels refinery. Interestingly, it is possible for government to tax resource rents without adversely affecting private investment decisions. However, because measurement of resource rents is difficult, government must be careful in taxing such rents lest quasi rents be taxed instead.

4. Finally, the *indirect surplus* refers to benefits or costs that accrue in markets for substitute and/or complementary goods and services. However, indirect benefits occur only if price exceeds marginal cost in one of the affected markets. Whenever price exceeds marginal cost, for example, this implies society values the good or amenity more than it costs to provide it. Hence, if the demand function in a related market shifts outward, more of the good or amenity is purchased, leading to a benefit; the opposite is true if demand shifts inward. If price equals marginal cost in each of the markets for substitutes and complements, there are no indirect effects (Harberger 1971, 1972).

We illustrate the concept using Fig. 6.3. Suppose the marginal cost of providing an environmental amenity is given by MC, but the amount of the amenity provided is less than what is socially desirable – provision is restricted to E_R while the optimal amount that should be provided is E*. At E_R, citizens' marginal willingness to pay (MWTP) for the amenity is $MWTP_1$, while the cost of providing an additional unit of the amenity is only *c*. The total cost of providing E_R is *h*, while total benefits amount to the area under D_1 up to E_R, or area $(a+d+f+g+h)$. The net benefit is area $(a+d+f+g)$.

Now suppose that logging a forest in one jurisdiction shifts the demand for the amenity in Fig. 6.3 outwards, from D_1 to D_2. Because the market is out of equilibrium since marginal willingness to pay (price) exceeds marginal cost, the social costs and benefits of logging timber in one region must take into account the indirect surpluses generated in the market for environmental amenities. Now the total benefit (total willingness to pay), given by the area under the demand function, is $(a+b+d+e+f+g+h)$ and the total cost of providing E_R is still *h*. Thus, the net increase in surplus is given by area $(b+e)$. To determine this benefit, it is necessary to employ one of the non-market

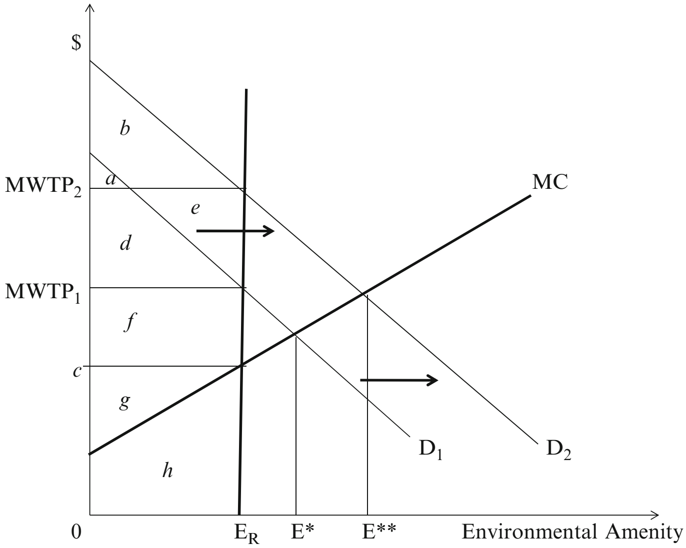

Fig. 6.3 Indirect surplus gain due to increase in timber harvests in other jurisdiction

valuation techniques described in Sect. 6.3. Notice also that the socially desirable level of the environmental amenity has also increased to E^{**}.

It is important to note that environmental spillovers, such as global greenhouse gas emissions, fall into the last category. Since markets are absent, price cannot possibly equal marginal cost. Therefore, it is necessary to determine the costs (benefits) in those markets using a non-market valuation method (see Sect. 6.3). It is also important to recognize that environmental damage is measured as a loss to consumers akin to consumer surplus.[2]

The cost of environmental damage is measured as lost surplus, which becomes a benefit (the damages avoided) of a project that reduces the environmental 'bad' (atmospheric CO_2 concentration). When all of the changes in surpluses resulting from a project are appropriately summed, the discounted net social benefit must exceed the project's capital cost.

Notice that the criteria for judging whether one project is preferred or somehow better than another from society's perspective is the same as that used under private CBA. That is, Eqs. (6.1), (6.2) and (6.3) remain valid. What differs between the private and social perspective is what one measures and includes as costs and benefits, and the discount rate that one employs (which is considered further in Sect. 6.4 below).

[2] Consumer surplus is not the theoretically correct measure in the case of non-market environmental amenities; rather, the correct measures are compensating and equivalent surplus (variation). A clear discussion is found in van Kooten and Folmer (2004, pp.13–25).

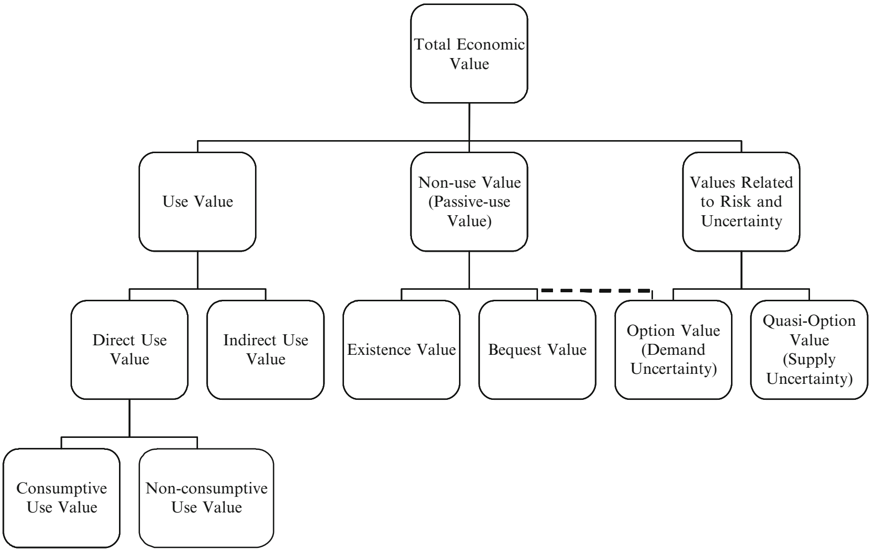

Fig. 6.4 Components of total economic value

6.2.2 Total Economic Value

Another way to look at social CBA is via the concept of total economic value (TEV), which is the sum of direct use values, indirect use values, non-use values, and the values associated with remaining flexible in the face of risk and uncertainty (e.g., see Pearce and Warford 1993; van der Heide 2005). A summary of the various types of values that comprise total economic value is provided in Fig. 6.4 (which is adapted from van der Heide 2005). In the figure, it is clear that many of the values that economists attribute to natural resources are ignored in private valuations, and even in the evaluation of public projects. In particular, the focus is generally on the far left branch of the figure, namely, on consumptive, direct use values. From Fig. 6.4, total economic value is given by:

$$\text{TEV} = \text{Total use value} + \text{total non} - \text{use value} + \text{value of remaining flexible},$$

where the value of remaining flexible is related to risk and uncertainty. All values are discounted so that they are in present value terms.

Consider the example of a policy regulating biofuel content in gasoline that causes wetlands, native rangeland and/or forested areas to be converted to crop production. Let E_t refer to the net environmental benefits that these lands provide in their original state at time *t*. These benefits include ecosystem services of wetlands in reducing soil salinity and seepage of nitrogen from adjacent cropped lands into ground and surface water, benefits of wildlife habitat and so forth. Of these environmental benefits, ecosystem services may be the most difficult to measure, while other benefits are easier to measure. For example, non-market valuation surveys and other evaluation techniques can be used to determine the values that recreationists place on wildlife viewing, hiking, hunting of waterfowl and ungulates, and so on; but the benefits of reduced soil salinity and nitrogen seepage can only be measured using a great deal of detective work and sophisticated theory and estimation techniques.

In the context of Fig. 6.4, E can be thought of as the various use values that the wetland, native grassland and forested areas provide; it consists of values related to consumptive use (hunting, grazing services), non-consumptive use (wildlife viewing, hiking) and indirect use (ecosystem services such as waste assimilation, water quality control). Then the cost-benefit rule for implementing a biofuels regulation that adversely affects marginal land currently in its natural state is:

$$\sum_{t=0}^{T} \frac{B_t - C_t - E_t}{(1+r)^t} > 0, \tag{6.4}$$

where B_t are the benefits from the policy in each period t, C_t are the OM&R plus capital costs of investments brought about by the regulation, and r is the social rate of discount. Benefits in this case would include the value of reduced CO_2 emissions brought about by the policy. The time horizon is T, which is the expected life of the project. In period T, there may be salvage benefits and/or environmental or other clean-up costs.

The variable E is treated as a cost separate from C in order to emphasize that the environmental costs are different from the commercial operating costs of the policy to regulate biofuel content in gasoline, with the latter borne by the energy provider but not the former. Depending on the project or policy, the environmental costs might also include costs associated with the transport and storage of hazardous wastes, potential radiation from and terrorist threats to a nuclear power facility, and the loss of visual amenities when a landscape is converted from its more natural state to the monoculture of energy crops (say corn). While one expects E to be positive because it measures lost environmental benefits, there might be situations when it is negative and not a cost to society (e.g., tree planting on denuded land with biomass used to reduce CO_2 emissions from fossil fuels).

In the context of the conversion of wetland, native grassland and forest to crop production, there are two further considerations. First, even in a deterministic world with no uncertainty about the potential future loss of these natural areas, they have existence and bequest value. People attribute value to the knowledge that these natural areas exist and can be passed to the next generation, even though they themselves do not visit or intend to visit them. In Fig. 6.4, we refer to such value as non-use value.

Second, however, there is likely to be uncertainty both with regard to supply and demand. Demand uncertainty is related to people's concern about the future availability of environmental services that may be threatened by the loss of wetlands due to the policy that converts the natural area to crop production. It results because future income and preferences are uncertain, so that individuals might value the environmental amenity more in the future. Option value (OV) is the amount a person would be willing to pay for an environmental amenity, over and above its current value, to maintain the option of having that environmental asset available in the future (Graham-Tomasi 1995; Ready 1995). Option value is usually measured in conjunction with existence and bequest value (as indicated by the dashed line in Fig. 6.4); indeed, non-market valuation techniques generally elicit all three at the same time making it difficult to separate them, although this can be done in survey methods by asking questions that specifically focus on separating option value into its various components.

Supply uncertainty is related to irreversibility, and its measurement is known as quasi-option value (*QOV*) (Graham-Tomasi 1995). The idea behind *QOV* is that, as the prospect of receiving better information in the future improves, the incentive to remain flexible and take advantage of this information also increases. Having access to better information results in greater revision of one's initial beliefs, so it is 'greater variability of beliefs' rather than 'improved information' that leads one to choose greater flexibility over potentially irreversible development (say, as a result of cropping marginal agricultural land). Thus, *QOV* is always positive.

The problem with *QOV* is that it is difficult to measure in practice, so its use in cost-benefit analysis is limited.[3] Rather, the concept provides support for the notion of a safe minimum standard of conservation, which suggests that an irreversible development should be delayed unless the costs of doing so are prohibitive. This concept is discussed in more detail in Sect. 6.5.

The cost-benefit model is extended to account for all of these costs and benefits. The decision rule to allow the conversion of 'natural' land, which currently serves as habitat for waterfowl and ungulates, to energy-crop production is now:

$$\sum_{t=0}^{T} \frac{B_t - C_t - E_t}{(1+r)t} - (TNUV + OV + QOV) > 0, \tag{6.5}$$

where *TNUV* refers to total non-use value, and the remaining terms in parentheses refer to the existence value of the marginal land and the benefits of keeping the land in its current state and remaining flexible as opposed to cropping the land. This formulation takes into account all social benefits and social costs associated with the proposed project.

6.2.3 Total (Average) Value Versus Marginal Value

Several caveats remain. What is neglected in the foregoing framework is the impact that the existence of alternative sites for producing energy crops and the availability of alternative amenities have on non-market (environmental) values. For example,

[3] For marginal agricultural land that provides wildlife habitat benefits and visual amenities, *OV* and *TNUV* (total non-use value) are measured using a contingent valuation device (see next section), while *QOV* can be determined using stochastic dynamic programming, for example, as demonstrated by Bulte et al. (2002) for the case of forest protection in Costa Rica.

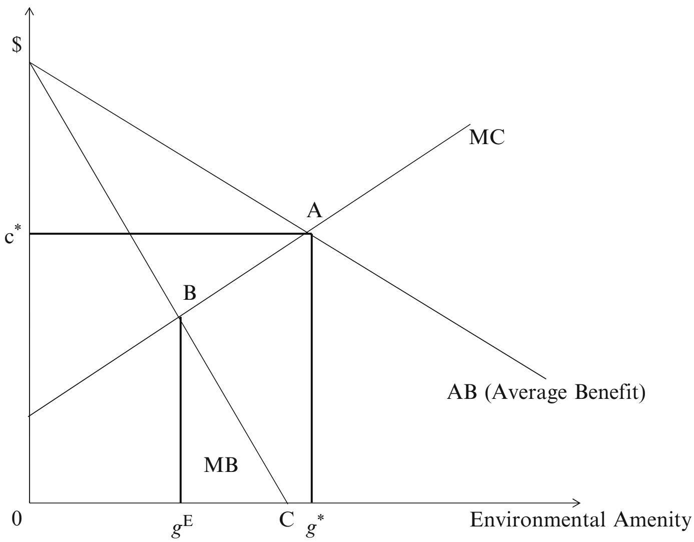

Fig. 6.5 Marginal versus average benefits of decision making

what someone is willing to pay for an option to visit a particular wetlands area is sensitive to the availability of similar sites in other locations. If there is an abundance of wetlands, one expects option value to be small; if there are few, option value is much larger. Hence, it is not the total or average non-market/environmental value that is of importance, but the marginal value. Too often the focus is on total as opposed to marginal value.

Making decisions on the basis of average or total value leads to loss of economic welfare, as illustrated with the aid of Fig. 6.5. In the figure, the curve labelled *AB* represents the average benefits from the environmental amenity (not to be confused with the demand function for the amenity), and is determined as the total area under the marginal benefit (demand) curve, labelled *MB*, divided by the levels of the amenity. The marginal cost (*MC*) of providing the environmental amenity increases as more of the amenity is provided; for example, if the costs of providing wetlands equal the foregone net returns from cropping, it is necessary to 'convert' increasingly higher quality cropland into wetlands, which increases the per hectare costs of providing the next amount of wetlands. A decision based on average or total value would lead to the provision of g^* amount of the amenity (determined from point *A*), while the correct amount to provide as determined by economic efficiency considerations is g^E. The social cost of providing the last unit of the amenity is given by c^*, but the marginal benefit to society of this unit is zero. The total loss in economic well being from providing too much of the amenity (the cost to society) is therefore given by area $ABCg^*$.[4]

[4] This is the difference between the area under *MC* (total costs) and that under *MB* (total benefits) between g^E and g^*. It is the net social cost (negative benefit) of providing g^* of the environmental amenity.

This thinking cuts both ways. Suppose, rather than an environmental amenity, it is output of energy crops that is the object. If a decision is made on the basis of average and not marginal returns, the last acre planted to energy crops would cost more to plant and harvest than it yields in revenue.

Finally, the dynamics of wildlife and the agriculture-nature ecosystem will affect both the value of the agricultural crop and the environmental service benefits. If wetlands can be recreated on cropped land after a short period of time, so that the former attributes of the nature are regained, planting energy crops is not irreversible and quasi-option value is negligible. If it takes a very long period of time to recover the wetlands, the development of cropland may essentially be irreversible, but the benefits of planting energy crops and converting marginal agricultural lands may still exceed costs and be worthwhile undertaking.

There is a conundrum here because the irreversibility of wetlands conversion to production of energy crops needs to be balanced against the potential irreversibility caused by climate change that the energy crops seek to mitigate. This issue is considered further in Sect. 6.5.

6.2.4 Conclusion

Social cost-benefit analysis assumes that everything of interest to the decision maker can somehow be measured in monetary terms. Nevertheless, there remain some things of importance to society that simply cannot be included in the money metric. Since these items are only important if they are somehow (directly or indirectly) affected by the project, these 'intangibles' must be evaluated or judged against the money metric. If the focus is on employment (which is not a true surplus) then any gain in employment that a policy or project brings about needs to be evaluated in terms of the net social loss, preferably measured in terms of the forgone opportunities per job created. If the focus is on CO_2 emissions, a project that reduces the amount of CO_2 in the atmosphere needs to be evaluated with respect to the change in a society's 'surpluses' (economic wellbeing broadly defined). Society might accept a project that removes carbon dioxide from the atmosphere at a cost of \$25 per tonne of CO_2 (t CO_2), but not at a cost of \$250/t CO_2.

6.3 Valuing Amenities: Non-market Valuation

Indirect costs and benefits occur when projects have, respectively, negative or positive spillovers (externalities) that are not taken into account in private decisions about resource use. Interestingly, externalities are just as often ignored by public decision makers, who are supposed to look after the wellbeing of all citizens in society but tend to focus on the clientele they serve. An externality occurs, for example, when surface water used for secondary or enhanced recovery in oil wells is not priced to take into account the value of water in other uses. Surface water injected into oil wells reduces stream flow, thereby affecting water recreation activities (e.g., swimming, boating), fish and other wildlife habitat, irrigators, and downstream generation of hydroelectricity. Likewise, farmers may not pay the true marginal cost of the water they use because losses to recreational users, the hydro facility and so on are neglected. Carbon dioxide emissions that result in climate change are a significant externality because costs are imposed on global society, but no individual agent or country has the incentive to reduce CO_2 emissions. The problem here is measuring the externality effects.

In the example of enhanced oil recovery using water, the surplus lost to agriculture and the electrical grid can be measured, with some effort, using market data, but the loss to water recreationists and the negative effects on aquatic species cannot easily be determined. These losses can be measured using a variety of non-market valuation methods that are now generally accepted and, in some countries, even mandated.

It is possible to distinguish approaches for measuring the value of non-market amenities according to whether changes in the environmental amenity in question leave traces in markets, whether market information can be used to estimate indirect surplus values.[5] Choice-based models employ information about a related activity (as opposed to the environmental amenity itself) to provide estimates about the amenity value. In particular, it may be possible to estimate a *cost function* or and *expenditure function* that includes both market goods and the environmental amenity as variables, and from it draw inferences about the demand for the amenity. Theoretically, if it is possible to estimate a cost function (in the case of production processes) or an expenditure function (in the case of consumers), so-called duality theory can then be used to derive the input or output demand functions, respectively. Since the price of the environmental amenity is effectively zero in most cases, the entire area under the relevant demand function between the amenity's with-and-without-project levels will constitute the surplus measure of benefit or cost (depending on whether the amenity increases or decreases). The best known of these methods are *hedonic pricing* and the *travel cost* methods, but they also include the *damage functions*. Each of these is briefly described below.

In many situations, however, market information cannot be relied upon to derive a cost or expenditure function because the environmental amenity is strongly separable in individuals' utility functions.[6] That is, increments or decrements in the environmental amenity are valued by individuals because it affects their wellbeing (utility), but such changes do not affect how they allocate their budgets. For example, suppose

[5] The term environmental amenity is used in a generic sense to refer to any good or service that is unpriced or priced well below its marginal cost of provision, whether that is wildlife habitat, water/air quality, wilderness areas, recreation sites, visual landscapes, risk of exposure to radiation, et cetera. All of these have value because individuals would be willing to pay something to have more of it or require compensation to put up with it. Of course, this presumes that the individual has some property right over the externality.

[6] A function $U(x_1, x_2, \ldots, x_n)$ is strongly separable if $U(x_1, x_2, \ldots, x_n) = U_1(x_1) + U_2(x_2) + \ldots + U_n(x_n)$. In this case, the marginal utility of x_i unaffected by changes in x_j, so $\partial^2 U/\partial x_j \partial x_j = 0$. This does not imply, however, that the price of x_j has no affect on x_i; that is, $\partial x_i/\partial p_j \neq 0$.

a forest that can be viewed from the road is now clearcut. For the person who travels this road, utility has gone down – she has been negatively impacted by the loss of the visual landscape and would likely be willing to pay some amount to have prevented the clearcut. Nonetheless, since she does not pay, she does not change the way in which she allocates her spending on market goods and services. To determine the value of her loss, we would need to ask her directly about the value she placed on the forest versus the clearcut. We require a survey instrument to elicit directly her *willingness-to-pay* (WTP) for the scenic amenity or her *willingness-to-accept* (WTA) compensation to forgo the amenity (put up with the clearcut), with the latter sometimes referred to as the *compensation demanded*.

Notice that WTP and WTA are alternative measures of consumer surplus, something discussed in more detail below. Here we simply point out that, since this approach requires individuals to respond to hypothetical questions, it is referred to as the *contingent valuation method* (CVM) if actual values are requested, or the contingent behavior method if a behavioral response is desired. Alternative approaches in this genre include contingent ranking, choice experiments (or *stated preferences*), which require respondents to state their preference between situations (much like in marketing surveys), conjoint analysis and other techniques that are briefly discussed below.

6.3.1 Cost Function Approach

The cost function approach to the measurement of environmental values relies on the estimation of a relationship between the output of some market traded commodity and the environmental amenity. For example, the output of an energy crop, such as corn for ethanol or canola for biodiesel, might be adversely impacted by soil salinity. By estimating what is known as a damage function, it is possible to determine the effect that different levels of soil salinity have on yields. Using this relationship and the price of the energy crop, one can estimate the costs that different levels of soil salinity impose. If salinity is related to certain land use practices, the spillover costs of such practices can be determined. Thus, increased salinity may be the result of cropping marginal land that, in turn, is brought about by regulations requiring greater use of biofuels. The damage function approach could be used to value one component of the environmental cost.

Another example of a damage function relates to soil conservation. Agricultural economists have estimated relations between soil depth and crop yield similar to that illustrated in Fig. 6.6. The damage function intercepts the vertical axis above zero because crops can grow in subsoil. Notice also that a drop in soil depth from D_0 to D_1 leads to a loss of y_0 to y_1, with the damage obtained by multiplying the crop loss by its price. If there is less soil on the site, similar soil erosion leads to a much greater loss in yield, as indicated by the downward arrow.

Finally, technology can mask the adverse impacts of soil erosion, making soil conservation appear less attractive, as indicated by the increase in yield from y_0 to y_2

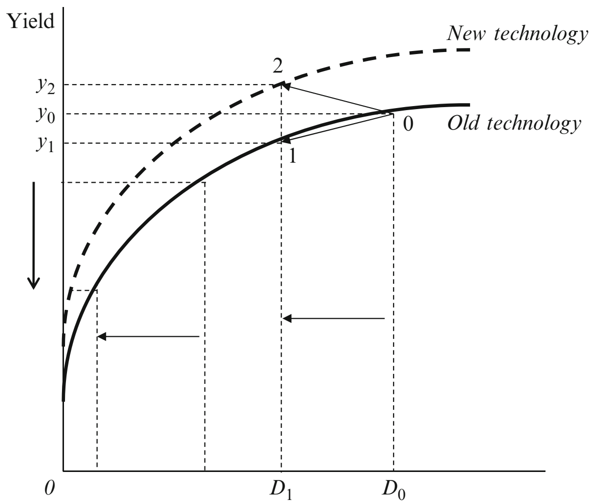

Fig. 6.6 Damage Function between Soil Depth and Crop Yield

when soil depth declines from D_0 to D_1 because technological change has shifted the relationship between soil depth and crop yield upwards. Rather, the true loss in yield is measured by the difference between y_2 and y_1. While this is a simple example of a damage function, it illustrates the difficulty of measuring environmental damages. In Chap. 7, we replace soil depth with temperature and crop yield with a variety of goods or services that are traded in markets.

Also falling into the category of non-market valuation are the costs of averting damages. Whenever people take action to avoid the adverse effects of spillovers (e.g., pollution in a big city, risk of exposure to radiation), the costs of such actions provide information about the value of the spillover. For example, if the municipal drinking water supply contains dissolved minerals or is contaminated with nitrogen, purchases of bottled water can be used to provide one estimate of the benefits of improving water quality, although it would be difficult to separate purchases of water for that purpose from those of convenience, the trendiness of bottled water and so on. Purchases solely to avoid the poor water quality provided by the municipality are an averting expenditure.

6.3.2 Expenditure Function

6.3.2.1 Hedonic Pricing

Hedonic pricing relies on market evidence related to property values to determine the value that people assign to improvements in access to public and quasi-public goods (e.g., police and fire protection, local parks) and environmental quality. It is assumed that individuals choose the amount of public goods and environmental quality they want by the choices they make concerning residential purchases. People choose to live in areas that have cleaner air or less crime, they choose to live near airports or along highways, and they choose to live on quiet or on busy streets. The choice is determined by what they are willing and able to pay for housing. Hedonic pricing exploits these choices by estimating implicit prices for house characteristics that differentiate closely related housing classes. In this way, it is possible to estimate demand curves for such characteristics or public goods as air quality and noise. The hedonic technique requires that the following three methodological questions are answered in the affirmative:

1. Do environmental variables systematically affect land prices?
2. Is knowledge of this relationship sufficient to predict changes in land prices from changes in air pollution levels, say?
3. Do changes in land prices accurately measure the underlying welfare changes?

If any of these is not answered in the affirmative, the methodology cannot be applied.

Hedonic pricing is a two-stage procedure (Freeman 1995; Smith 1997): In the first stage, the hedonic or implicit price function is obtained by regressing various house characteristics (such as lot and house size, number of bedrooms and bedrooms, etc.), neighborhood factors (e.g., nearness to schools, parks, fire hall) and environmental characteristics (e.g., air quality) on the property's price. The implicit price of any characteristic is found by differentiating the hedonic price function with respect to that characteristic.

In the second stage, then, the implicit price is regressed on income, quantity of the characteristic and other (instrumental) variables. This constitutes the inverse demand function. The area under the demand function between the current and proposed levels of the characteristic constitutes a measure of the (consumer) surplus associated with the proposed change.

Empirical studies that have used the hedonic pricing method to determine the effect of aircraft and traffic noise on housing prices find that there is a measurable effect. For aircraft noise, a one-unit change in the measure of noise (as related to human hearing and discomfort) resulted in housing prices that were 0.5–2.0% lower, while traffic noise reduced house prices by 0.1–0.7 % per decibel (Lesser et al. 1997, p. 281).

6.3.2.2 Recreation Demand and the Travel Cost Method

To assess benefits from recreation, the travel cost method emerged as perhaps the first technique for valuing non-market benefits (Clawson 1959; Thrice and Wood 1958). The travel cost method is a type of revealed preference model where

1. individuals are observed to incur costs so as to consume commodities related to the environmental amenity of interest, and
2. the commodities consumed are not purchased in a market where prices are determined by supply and demand.

A number of different approaches are available for estimating welfare gains/losses in what is termed the 'travel cost' framework. In general, the travel cost method assumes that costs incurred to travel to a site are identical to an entry fee to the site. This knowledge along with number of visits to a site (and in some variants visits to multiple sites on the same trip) can be used to construct a demand function for the site(s) in question. Again, the area under the demand function yields information about the consumer surplus, which is then used as a measure of benefit or cost.

The hedonic pricing method can also be applied to recreation demand estimation, but the problems involved are complex. Simply, total household expenditures on recreation at a particular site take on the role of property value in the hedonic or implicit price function. Expenditures by a large number of households engaged in recreation at more than one site are regressed on a variety of private and public characteristics of the various sites. Again, by differentiating the hedonic price function with respect to any of the public attributes, an implicit price for that attribute is obtained. In the second stage, the implicit prices for the attribute are regressed on household characteristics, particularly income, and the amount of the attribute available, howsoever measured. The resulting equation is the demand function for the attribute. The area under the demand function can then be used to measure the benefit of a change in the amount of the public good. In practice, it is not easy to implement hedonic travel cost methods.

6.3.3 Contingent Methods or Direct Approaches

It is generally thought that the damage function, travel cost and hedonic pricing methods provide reasonable estimates of true values because they rely on market data. Hence, they are best employed to estimate use values (see Fig. 6.4), which relate to the unpriced benefits environmental amenities provide in the production or consumption of some other good or service. For instance, a forest provides ecosystem functions such as flood control, water storage and waste assimilation, as well as recreational and other consumptive and non-consumptive (e.g., wildlife viewing) use benefits.

Measures of non-use or passive-use value, on the other hand, cannot be derived from market data. Non-use values include existence, bequest, altruism and other inherent values that are independent of people's spending on market goods and services. Existence value is the value of simply knowing that an environmental asset exists – people express a willingness to pay simply for the knowledge that the asset exists. Bequest value refers to people's willingness to pay to endow the future generation with the asset, while altruism refers to the benefit that a person places on the benefit another person gets from the environmental asset (and not explicitly identified in Fig. 6.4). Additionally, option value is often indistinguishable from bequest and existence values; it too cannot be derived from market data. Indeed, existence, bequest and option values are together often referred to as preservation value. Preservation values are determined primarily with contingent methods.

Contingent methods are required whenever the amenity to be valued leaves no behavioral trail in the marketplace. Therefore, contingent devices involve asking individuals, in survey or experimental settings, to reveal their personal valuations of increments (or decrements) in unpriced goods – constructing contingent markets. These markets define the good or amenity of interest, the *status quo* level of provision and the offered increment or decrement therein, the institutional structure under which the good is to be provided, the method of payment, and (implicitly or explicitly) the decision rule which determines whether to implement the offered program. Contingent markets are highly structured to confront respondents with a well-defined situation and to elicit a circumstantial choice upon the occurrence of the posited situation. But such markets remain hypothetical, and so too are the choices people make within these markets.

Because the constructed markets used by economists to elicit value are hypothetical, some argue that the values obtained using the methods described below are imperfect, so much so that they are essentially worthless. In most cases, the contingent valuation devices are used to value natural and ecosystem capital, and such capital clearly has value; indeed, natural and ecosystem capital may be of utmost importance to the long-term survival of society (Diamond 2005). Thus, it would be a grave error for decision makers to ignore the non-market services provided by forests, rangelands/grasslands, wetlands, lakes, rivers and riparian zones, and even croplands (Olewiler 2004), whether these services entail carbon storage and sequestration, commercial timber harvests, food production, maintenance of water quality, provision of wildlife habitat/refuge, or recreational and scenic amenities.

6.3.3.1 The Contingent Valuation Method (CVM)

The contingent valuation method was initially proposed nearly 50 years ago in an effort to value non-market amenities (Krutilla 1967). Subsequently, CVM has been approved by the U.S. Department of the Interior for implementing regulations under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 and its amendments of 1986. In 1990, the U.S. Oil Pollution Act extended liability to oil spills (as oil was not considered a hazardous waste). A 1989 decision by the District of Columbia Court of Appeals involving CERCLA in the case of *Ohio v. Department of Interior* affirmed the use of CVM and permitted inclusion of non-use values in the assessment of total compensable damages. In the early 1990s, an expert panel led by two Nobel prize-winning economists (Kenneth Arrow and Robert Solow) supported the use of the contingent valuation method for valuing non-market amenities (Arrow et al. 1993). Thus, in the U.S. at least, CVM is used both for determining compensation when firms or individuals damage the environment and in cost-benefit analyses.[7]

[7] In court cases, CVM can be used to estimate compensatory damages, but not the punitive damages that the court might assess.

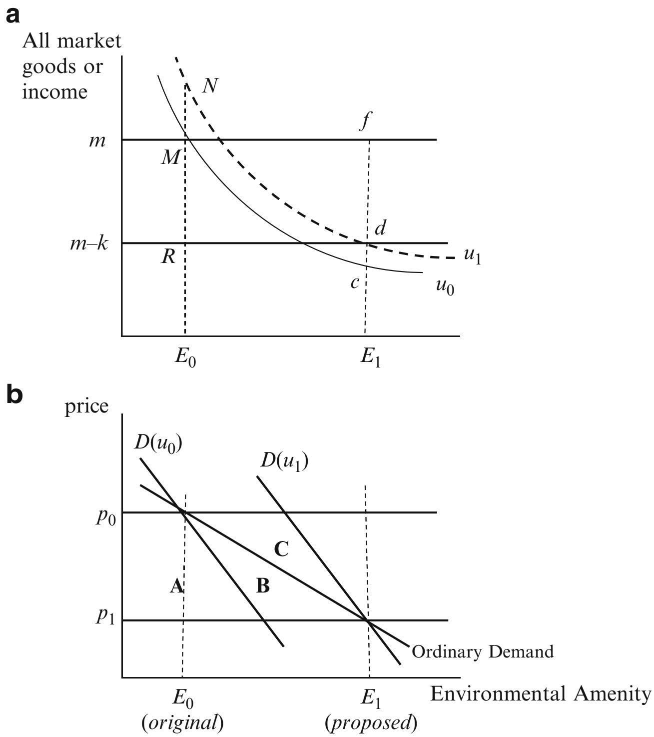

Fig. 6.7 Willingness to pay and willingness to accept compensation as surplus measures in the utility domain (panel a) and price-quantity domain (panel b)

Surveys are used in CVM to elicit information regarding the minimum level of compensation required by an individual to forgo an environmental amenity or public good (compensation demanded) or the maximum amount the individual would be willing to pay to obtain the non-market amenity. These measures are rooted in economic theory and constitute a surplus measure equivalent to consumer surplus as indicated below.

Suppose the current level of an environmental amenity is given by E_0 and we wish to know the benefit of a policy that causes the level to increase to E_1. In Fig. 6.7a, the wellbeing or utility of a respondent to a valuation question is given by u_0 at E_0. The combination of income m and amenity E_0 results in a utility of u_0. All combinations of income and the environmental amenity that lie on the u_0 curve lead to the same level of utility. However, if income is reduced to m–k from m while the level of the environmental amenity is increased from E_0 to E_1, the person's wellbeing increases to u_1. That is, the person is made better off by giving up k amount of income to move from point M to point d, thus gaining E_1–E_0 amount of the amenity. The maximum amount she would be willing to pay (WTP) for the move from M to d is measured by the distance cf; any proposed loss of income less that cf, such as amount k (=df), would be accepted.

Despite the fact that environmental amenities are not traded in a market, we draw three demand curves in Fig. 6.7b. These can be thought of as shadow demand curves that exist in theory but not in practice. Consider first the ordinary demand function. As discussed previously, the benefit of a policy that increases the amount of the environmental amenity is given by area **A** + **B**, which is the consumer surplus. However, since prices do not exist, we cannot estimate such a demand function. The other two demand curves are so-called compensated demand functions because the individual either gives up or gains income in order to remain at the same level of utility as the level of the environmental amenity is varied. As noted above, if a person starts at point *M* in panel (a) and moves to point *d*, her income would need to be reduced by amount *cf* to keep her at u_0; this keeps her on the compensated demand curve $D(u_0)$. The equivalent of *cf* in panel (a) is area **A** in panel (b) of Fig. 6.7. This is known as the *compensating surplus*.

Notice that in the above analysis the individual is assumed to have a right to E_0 and not E_1. However, if the person had the right to E_1 but was only able to access E_0, we would need to ask her what the minimum amount of compensation she would demand to put up with E_0 rather than the E_1 to which she is entitled. The minimum amount she is willing to accept (WTA) as compensation is given by distance *RN* in panel (a) and it too constitutes a surplus measure akin to consumer surplus. In this case, the appropriate compensated demand function is $D(u_1)$ and the appropriate surplus measure is given by area **A** + **B** + **C** in panel (b), which equals *RN* in panel (a). This area is known as the *equivalent surplus*.

In the case of environmental amenities, therefore, there are three measures of surplus from the standpoint of 'consumers' – consumer surplus (CS), compensating surplus (WTP) and equivalent surplus (WTA). These are given in Fig. 6.7b by areas **A** + **B**, **A** and **A** + **B** + **C**, respectively, so that WTP < CS < WTA. In theory, areas **B** and **C** are considered to be very small, so that WTP ≈ CS ≈ WTA – the three measures are approximately equal. However, studies consistently find that compensation demanded (WTA) is significantly greater than willingness to pay, so that the initial endowment or one's property right matters a great deal (see Horowitz and McConnell 2002).[8]

In the absence of market data, a contingent valuation approach, whether CVM or some other approach that relies on direct elicitation of value, is needed to determine the surplus from changes in the availability of an environmental amenity. While primarily used to determine non-use values, CVM can also be employed to value market-traded goods and services, which is useful for testing how well responses to hypothetical purchasing questions correspond to actual ones.

An important use of contingent valuation surveys is to determine preservation values for such things as tropical rain forests and wildlife. For example, Kramer and Mercer (1997) found that U.S. residents were willing to make a one-time payment of \$1.9–\$2.8 billion to protect an additional 5 % of the globe's tropical forests.

[8] We could just as well examine the case where the 'original' level of the environmental amenity in Figure 6.7 is E_1, and then ask what the associated measures would be. In this case, WTP would be a negative value (indicating that compensation is required), while WTA is positive (indicating the respondent would need to pay). By switching the subscripts in the figure, we then find that WTA < CS < WTP.

Preservation benefits for wildlife were estimated by Canadian economists to be in the neighborhood of $68 million per year for Alberta residents (Phillips et al. 1989), while preservation of old-growth forests is valued at perhaps $150 per household per year (van Kooten 1995) This suggests that ignoring these values in the management of natural resources can lead to substantial misallocation of resources.

6.3.3.2 Choice Experiments or Stated Preferences

Unlike the contingent valuation method, the approach of choice experiments (CE) or stated preferences does not require survey respondents to place a direct monetary value on a contingency (Adamowicz 1995; Adamowicz et al. 1998). Rather, individuals are asked to make pairwise comparisons among environmental alternatives, with the environmental commodity (alternatives) characterized by a variety of attributes. For example, a survey respondent is asked to make pairwise choices between alternative recreational sites or activities, with each distinguished by attributes such as the probability of catching a fish, the type of fish, the amenities available to fishers (e.g., whether or not there are boat rentals), distance to the site, and so on. It is the attributes that are important, and it is these that are eventually assigned monetary value. In order to do so, one of the attributes must constitute a monetary touchstone (or proxy for price). Distance to a recreational site might constitute the proxy for price (as in the travel cost method), but, more generally, one of the attributes will be a (hypothetical) entry fee or an associated tax. Once the values of all attributes are known (using the monetary touchstone and the pairwise rankings), the overall value of the amenity is determined by assuming additivity of the attributes' values. Of course, it is possible that the total value of the amenity is greater than the sum of its components, or vice versa.

While the methodology has been used primarily to value recreational sites, Adamowicz et al. (1998) apply CE to the estimation of non-use values. It is argued that CE avoid the 'yea-saying' problem of dichotomous choice surveys as respondents are not faced with the same 'all-or-nothing' choice, although recent advances in CVM questionnaire design have addressed this issue (Shaikh et al. 2007).

Another advantage of choice experiments over the traditional contingent valuation approach occurs when it comes to the transfer of benefits (e.g., transfer of estimated benefits for water quality improvements in one jurisdiction to those in another). This issue is discussed further below. Further, repeated questioning of the same respondent in CE enables consistency testing that is not possible in CVM where one valuation question is usually asked. CE may also be a means of getting around the embedding problem of CVM. Embedding is used to describe a situation where people state they are willing to pay $40 per year to protect grizzly bears, for example, but they are also willing to pay no more than $40 per year to protect wildlife per se. Of course, if asked to breakdown the latter into the valuation of various species or categories of wildlife, grizzly bears are worth much less than $40. Finally, by allowing some attributes to take on levels both above and below the *status quo* level, CE enables one to estimate both willingness to pay and the compensation demanded.

Conjoint analysis differs from CE because it asks respondents to rank all of the alternatives from highest (best) to lowest (worst). Such a ranking can then be used to infer the importance of the attributes that characterize each alternative within one's preference function. Conjoint measurement is a marketing technique that uses revealed choice among goods with different characteristics (as in hedonic pricing) with a survey that asks people to choose among or rank hypothetical alternatives (contingent ranking) to impute the values of the characteristics. It is used primarily to predict the potential for new products, but efforts are ongoing in the application of this technique to the valuation of non-market commodities in ways that different from CE (Smith 1997).

6.3.4 Benefit Transfer

Use of non-market valuation techniques to obtain surplus data for use in social cost-benefit analysis can be quite expensive and time consuming, especially with regards to administering a survey instrument. The decision maker needs to determine whether the expense is warranted. In this regard, Allen and Loomis (2008) offer some guidance as to when a valuation study should be undertaken or benefit transfers employed.

A further question that arises is: Can one use the values estimated elsewhere and apply them to the situation under consideration? Under certain circumstances, it is possible to avoid large transaction costs associated with the valuation of spillovers and yet provide reasonable values for decision making. That is, the benefits estimated in one jurisdiction might be transferable to other jurisdictions under the right circumstances. Indeed, in her study of the value of natural capital in settled regions of Canada, Olewiler (2004) employs estimates from a variety of sources and jurisdictions. The drawback is that the values are not as precise, but, in many instances, simple knowledge of a range of values is sufficient to take into account non-market costs or benefits. In other cases, it is impossible to determine the appropriate monetary values, in which case a description of the 'with-without' project attributes of the 'externality' under consideration will have to suffice.

Recent initiatives have sought to facilitate the use of benefit transfers. These have relied on meta-regression analysis of data from various studies of the same resource, such as the meta-analysis of wetland services conducted by Woodward and Wui (2001). These and many more studies have subsequently been collected by John Loomis and colleagues at Colorado State University in an effort to provide some notion of the non-market values that can be used for benefit transfer purposes.[9] An example of the types of values available is provided for the case of wetland services in Table 6.1.

[9] Information about the Colorado State University benefit transfer project and a toolkit can be found at: http://dare.colostate.edu/tools/benefittransfer.aspx (viewed February 12, 2011). Another effort to collect information for the purposes of benefit transfer is underway at Central Queensland University in Australia under the guidance of John Rolfe and Jill Windle; see 'benefit transfer' at http://resourceeconomics.cqu.edu.au/ (viewed February 12, 2011).

Table 6.1 Value of wetland services for benefit transfer purposes ($ per acre of wetland)

	United States				
	Northeast	Southeast	Inter-mountain	Pacific	Canada
Min	$33	$0.41	$6	$124	$51
Max	$908,492	$6,494	$456	$5,657	$198
Average	$49,873	$448	$80	$1,555	$137
Median	$618	$21	$17	$718	$149

Source: Calculated using data from http://dare.colostate.edu/tools/benefittransfer.aspx

6.4 Discounting and Choice of Discount Rate

Because costs are incurred and benefits accrue at different points in time, cost-benefit analysis relies on discounting financial flows (costs and benefits) to a common date so that they can be compared. Without discounting, for example, it would be possible to advocate spending a large sum today in anticipation of a larger benefit in the future, whether such a benefit came about in several years, 100 or 1,000 years. Clearly, it would be foolish to spend money today so as to obtain a benefit in 1,000 or even 200 years from now. Discounting is required so that rational decisions can be made concerning how we as a society spend and invest scarce resources.

To reiterate, it is necessary to measure and compare the stream of benefits and the stream of costs at a single point in time, whether that is at the beginning or at the end of the time horizon, or at some intermediate point. Further, since individuals prefer to delay pain (costs), while they are eager not to delay pleasure (benefits), it is necessary to weight gains and losses as to when they occur, a procedure known as discounting. Since $1 today is worth more to an individual (or society) than that same dollar received at some future date (say, next year), it is necessary to discount future dollars so that they are worth less today. And it is not only money that is discounted: clearly, it is preferable to remove CO_2 from the atmosphere today rather than next year or 100 years from now – CO_2 removal at a future time is worth less than its removal today. It is the purpose of the discount rate to weight future costs and benefits, no matter whether they are in monetary or physical units. The problem is to choose an appropriate discount rate that reflects society's preferences for current over future 'consumption'. Whether a project is desirable will depend to some extent on the discount rate – the outcome is sensitive to the rate of discount. What, then, is the appropriate rate of discount to use in weighting future costs and benefits? This turns out to be a rather difficult question to answer.

Compared to low interest (discount) rates, high rates encourage savings and investment that lead to higher future incomes. But high interest rates also cause one to focus more on the short run because gains and losses that occur farther in the future are valued less today (as they are discounted more highly). Despite some common sense aspects about interest rates and discounting, the economic literature on this topic is vast and, surprisingly, there is no ready consensus about what discount rate to use when analyzing public policies and projects.

On moral grounds, some advocate the use of a zero discount rate in comparing one generation with another (e.g., Heal 2009). Yet, people behave as if they discount the future because they prefer something today (the sure thing) over tomorrow (because it is unsure) – they exhibit an implicit rate of time preference, so that a future dollar is valued less than a dollar today. Economists get around the dilemma of discounting the value of future generations by arguing that it is wrong to discount the utility or wellbeing of a future generation, but that it is appropriate to discount their consumption. Consumption is related to the ability of the economy to produce goods and services, and growth in consumption is the result of investment in activities that enhance the economy's ability to increase output. Thus, the rate of growth in per capita consumption is sometimes taken as the starting point for determining the discount rate (see below). While consumption goods increase utility, utility goes beyond consumption as it addresses quality of life, and thereby includes environmental goods (e.g., clean air and water), biological diversity, the inter- and intra-generational distribution of income, et cetera.

A major problem in choosing a discount rate is that individuals have different rates of time preference, but even the same individual employs different discount rates. In determining a social rate of discount, not only is it difficult to reconcile the fact that different people use different rates to discount the future (although practically speaking individual rates are equated to the market rate at the margin), but evidence from behavioral economics indicates that people commonly discount future losses at a lower rate than future gains, and that they use higher rates to discount outcomes in the near future than those in the distant future (Knetsch 2000). In one survey, half of respondents were asked for the largest sum of money they would be willing to pay to receive $20 a year from now, while the other half was asked to provide the smallest sum of money they would accept today to give up receiving $20 a year from now. "The rate used to discount the future gain was, on average, about three times higher than the rate used to discount the future loss" (Knetsch 2000, p. 283).

There are other quirks associated with discounting, although these also relate to risk perceptions. People express greater willingness to discount environmental benefits from a government program at a lower rate than the benefits of a program that enhances future consumption of material goods. Individuals express greater willingness to pay to avoid extremely small risks of death from an environmental disaster (e.g., related to construction and operation of a nuclear power plant) than they do to avoid much higher risks of death associated with something with which they are more familiar (e.g., riding on a motorcycle) (see Fischhoff et al. 1981).

6.4.1 How to Discount the Future When Considering Future Generations

A particular controversy about the discount rate relates to the weighting of different generations. This is particularly important for climate change where future generations benefit from current investments in climate mitigation, but also bear the costs of reduced incomes from current investments that lock a future society into an inappropriate technology. Whatever society does today will have an impact on future generations.

Consider the following argument for a low discount rate in comparing across generations. An individual may require a payment of $1.05 next year in order to forgo receiving $1 today, which implies a discount rate of 5 %. However, the same individual may be willing to give up $1 in 20 years' time to obtain $1.01 in 21 years, implying a discount rate of 1 %. In other words, the discount rate declines as costs and benefits accrue in the more distant future – the discount rate declines as a project's or program's time horizon increases. This is referred to as 'hyperbolic discounting' in contrast to exponential discounting that uses a constant rate of discount (see Dasgupta 2002; Weitzman 1998, 1999). This notion has been used to argue that, when comparing investments that affect future generations, a very low rate of discount should be employed.

The problem with 'hyperbolic discounting' is that, in the above example, when the individual in 20 years' time needs to make the choice between $1 today and $1.01 next year, she will choose $1 today, *ceteris paribus* (assuming her current-period discount rate continues to be 5 %). The use of a declining discount rate leads to time-inconsistent decisions because the mere passage of time causes an individual to modify their choice. However, if the discount rate itself is uncertain because the world is uncertain, then there is always the possibility that "*ex ante* good decisions turn out to be regrettable *ex post*, once nature has revealed herself" (Newell and Pizer 2003, p. 10). The notion of uncertainty about the rate of discount is considered further below.

The long-run rate of growth in per capita consumption is often used as a starting point for calculating the discount rate to use in comparing inter-temporal costs and benefits related to climate change, because it indicates by how much the material wellbeing of the future generation can be expected to rise above that of the current one. To this is added a rate of time preference of 1 or 2 % – the rate that individuals might use in preferring to have something today as opposed to delaying it to a future time. Thus, if the rate of growth in consumption is 1.3 %, then the actual rate of discount might be 2.3 %. The Stern Report (Stern 2007) employed a discount rate of 1.4 %, with the result that future damages (which were already overstated) appeared much larger in current terms than under a more realistic assumption about the discount rate.

To put a technical perspective on the issue, let β be the pure rate of time preference and $C(t)$ the aggregate per capita (global) consumption at time t. Then, following Heal (2009), the discounted present value of per capita consumption over all time is given by

$$\int_0^\infty U(C(t))e^{-\beta t}dt, \tag{6.6}$$

where $U(C)$ is the instantaneous utility of consumption. Let $C'(t) = \mathrm{d}C(t)/\mathrm{d}t$ be the rate of change in consumption, which has generally been positive ($C'(t) > 0$). Further, assume $U' = \mathrm{d}U/\mathrm{d}C(t) > 0$ and $U'' = \mathrm{d}^2U/\mathrm{d}^2C(\mathrm{t}) < 0$, which tell us the following:

Given that, as consumption rises beyond some threshold (presumed to be low and not included in the mathematical derivations provided here), people will get less enjoyment (utility) out of an extra unit of consumption as consumption rises. Thus, the enjoyment that someone in the future would get from consuming material goods and services would be less as more becomes available to them; on the other hand, if it is assumed that environmental goods are declining over time as a result of climate change or other factors, then utility would actually fall. The consumption discount rate, r, is then given by $e^{-\beta t}\, U'(C(t))$, which can be written in such a way that the pure rate of time preference is independent of the changes in consumption and the utility function (Heal 2009, p. 277):

$$r = \beta + \varepsilon(t)C'(t). \tag{6.7}$$

where $\varepsilon(t) = -C\ U''/U' > 0$ is the elasticity of the marginal utility of consumption, which tells us how fast the marginal utility of consumption, U', falls over time as consumption rises. In essence, then, there are two discount rates to consider – the pure rate of time preference which is based on an ethical decision and the consumption discount rate which is endogenous.

The change in per capita consumption over time, $C'(t)$, can be determined using historical data, although we have no guarantee that consumption will continue to grow in the future as it has in the past. The choice of other parameters in the above equation is a matter of value judgment. Even the assumption that the rate of growth in per capita consumption is increasing at 1.3 % – that the second term in the above expression is growing at 1.3% – is a value judgment because utility is ignored. Including the consumption elasticity of marginal utility, however, implies that one needs to choose a functional form for utility and that is a value judgment.

Further, Heal (2009) argues that, from an ethical standpoint, the pure rate of time preference is zero, $\beta = 0$, because it deals with cross-generational comparisons. This is only partly true because the pure rate of time preference is as much intra as it is inter generational in context.

Finally, Heal (2009) points out that the above relation is based on a single consumer good or bundle. If there are multiple goods, the above expression needs to be modified, but essentially the same conclusion results. However, if a minimal level of some good is required for survival, such as threshold or minimal level of environmental services, then utility is not defined when provision of that good falls below the critical threshold. Thus, in the case of technological limits to the substitutability between produced goods and natural resources, for example, it is possible for the appropriate discount rate for discounting the costs and benefits of mitigating climate change to be negative.

6.4.2 What Discount Rate?

So what discount rate do we use? Consider, first, whether a nominal or real rate of discount is to be employed. While a nominal rate might be used in cases where one wishes to examine cash flows, it is generally preferable not to use a nominal rate of discount because it requires that inflation be taken into account. Since the allocation of investment and consumption over time is based on expectations, adjusting the nominal discount rate by *ex post* inflation is not quite correct. Further, it is not possible to predict inflation over the life of a project/program, which could quite well exceed 100 years. There is already enough uncertainty about the future real rate of interest (see below). In any case, economists generally prefer to use the real discount rate.

It also makes sense as a principle for choosing a discount rate to focus on consumption. Then, the consequences of government program/regulation "should be converted into effects on consumption (versus investment) and then these consumption effects should be discounted using a consumption rate of interest – the rate faced by consumers when they save, rather than businesses when they borrow" (Newell and Pizer 2003). In the United States, the real rate of return on investments by large companies over the period 1926–1990 was about 7%, after taxes, while it was 8% over the period 1926–1998. Given a corporate income tax rate of about 35%, the pre-tax rate of return is thus about 11–12%. Since individuals in the U.S. pay up to 50% in income taxes, the rate of return to individuals as owners of companies is closer to 4%, which can then be considered the consumption rate of interest – the rate at which people trade off spending over time. Interestingly, the U.S. Office of Management and Budget requires the use of 7% for valuing costs and benefits external to the government and 4 % for internal costs and benefits (Newell and Pizer 2003).

Despite this straightforward reasoning for deriving a (social) discount rate from market data, there are several problems that need to be considered. First is the ethical issue of discounting across generations, which was discussed above. Then it is necessary to recognize that the use of 4 % as the consumption rate of interest does not agree with actual behavior in many circumstances. People willingly invest their savings in Treasury bills and guaranteed investment certificates that yield perhaps as little as 2% after taxes (and perhaps even less). Of course, these are riskless investments.

Also, when a government invests in a natural resource project, for example, funds could come from income taxes (displacing an equal amount of consumption) or from increased public-sector borrowing. Funds borrowed by government displace an equal amount of private investment, so it might be appropriate to use the higher rate of 7–8 %. If borrowed funds originate with private savings or if income taxes are used, the lower interest rate is more appropriate. In practice, of course, public funds come from a mix of sources. Thus, it might be appropriate to calculate the discount rate as the opportunity cost of the funds. Suppose that a public investment project costs $100, and that $40 displaces private investment and $60 comes from consumption. If the rate of return to private investments is 10% and the consumption discount rate is 4%, then the opportunity cost of the funds is 6.4% ($=0.40\times 10\%+0.60\times 4\%$). The main difficulty in deriving the opportunity cost rate is that it is not easy to determine where *marginal* funds originate. Further, not all government revenues come from income taxes or domestic borrowing, as governments earn income through charges, tariffs on imported goods, and so on.

Further, society may choose to save more collectively than the sum of all individual savings decisions. The government is considered a trustee for unborn generations, whose wealth will (at least in part) depend on the state of the environment that they inherit, so real consumption (and rates of return on investments) may not grow, and may even decline, when we degrade the environment. Because of risk and uncertainty (giving rise to 'risk premiums'), society's rate of time preference will be lower than that of individuals, as society as a whole is better able to pool risks; certain individual risks are mere transfers at the level of society. While individuals face a real chance of dying, society does not face a similar risk. All in all, these more or less ethical arguments suggest that society's rate of discount is lower than that of individuals making up the society. The social discount rate is likely lower than the opportunity cost of capital rate (real rate of return on investments) or the marginal rate of time preference, but it is not immediately clear how much lower.

Based on the above reasoning, a case can be made for using a very low discount rate to discount consumption by future generations. Again, a 2 % rate of discount might be appropriate. This is a somewhat arbitrary low rate and might be considered to be the social rate of time preference.

Since any rate between about 2 and 8 % appears justifiable, what might constitute the appropriate social rate of discount for use in social CBA? Newell and Pizer (2003) make the case that rates in the lower end of this range should be employed. Their argument rests on an analysis of uncertainty about the future path of interest rates. Using Monte Carlo simulation and historical information on the pattern of inflation-adjusted interest rates, and assuming the stochastic process for interest rates is not mean reverting (does not trend towards a mean in the absence of exogenous shocks), they find that the value of $100 received 400 years in the future is worth many orders of magnitude more today if interest rate uncertainty is taken into account than if a constant discount rate is used (see Table 6.2). While a constant discount rate is to be used in CBA, the results indicate that, because actual discount rates vary in unpredictable fashion (i.e., follow a 'random walk'), the discount rate to be employed should be lower than in the absence of this consideration. Thus, if a 4 % consumption rate of discount is considered appropriate because it is market derived, the true (constant) rate might be 2–3% if uncertainty about future interest rates is taken into account. Indeed, "correctly handling uncertainty lowers the effective discount rate in the future in a way that all generations after a certain horizon are essentially treated the same".

Clearly, there is a strong case to be made for the use of a low discount rate in the evaluation of natural resource and energy projects. Given continued controversy about what might constitute an appropriate rate, one suggestion is to use a rate of 2 % for evaluating policies/projects that affect more than one generation, and then use sensitivity analysis about this rate to determine how choices might be affected if the future is somehow weighted differently.

Finally, consider a declining discount factor approach that partially addresses some of the issues raised above, including hyperbolic discounting.[10] Standard

[10] I am indebted to Brian Scarfe for suggesting this approach.

Table 6.2 Value today of $100 received in 200 and 400 years: comparison of constant versus random walk discounting, selected discount rates

	Constant discounting		Nonmean-reverting random walk	
Discount rate (%)	200 years	400 years	200 years	400 years
2	$1.91	$0.04	$7.81	$3.83
4	$0.04	$0.00	$1.54	$0.66
7	$0.00	$0.00	$0.24	$0.09

Source: Derived from Newell and Pizer (2003)

discounting generates adjacent period weights such that $\frac{w(t+1)}{w(t)} = \frac{1}{1+r}$, which is constant for all adjacent time periods. An alternative system for adjacent period weights can be constructed by first letting $w(t)=b/(b+t)$, where $b>0$ is a parameter. Then $\frac{w(t+1)}{w(t)} = \frac{b+t}{b+t+1}, t>0$. This ratio converges to 1.0 as $t \to \infty$ (t gets larger). Suppose one wishes to employ a standard discount rate to future costs and benefits for a period of T years, but one wants to weight years beyond T higher so as to favor future generations, say. That is, for $t>T$, the discount rate falls until it eventually is zero so that a period in the future is weighted the same as a current period. Such a scheme would weight costs and benefits in the years after T higher than if the standard rate were applied throughout the entire time horizon. In that case, one sets

$$\frac{b}{b+T} = \frac{1}{(1+r)^T}, \tag{6.8}$$

where r is the standard discount rate applied to the early period and T is the year when the weighting of the future begins to diverge.

Given r and T, formula (6.8) generates a unique value of the fundamental parameter b of the declining discount factor model. The weight attached to a future year is $w(t)=1/(1+r)$ for $t \le T$ and $w(t)=b/(b+t)$ for $t>T$. An illustration is provided in Fig. 6.8, where we assume $r=0.05$ and T takes on values of 10 and 30. Notice that the importance (weight) of a future year in the cost-benefit analysis initially declines quite quickly, but after T it declines slower than in the case of the standard discount model. Needless to say, the problem with this approach is it arbitrariness, especially in the choice of T.

6.4.3 Discounting Physical Entities

A second issue related to the use of a zero discount rate involves the weighting of physical things. For example, should physical carbon be discounted according to when it is released to or removed from the atmosphere? Interestingly, some economists object to discounting of physical carbon, although they accept discounting if

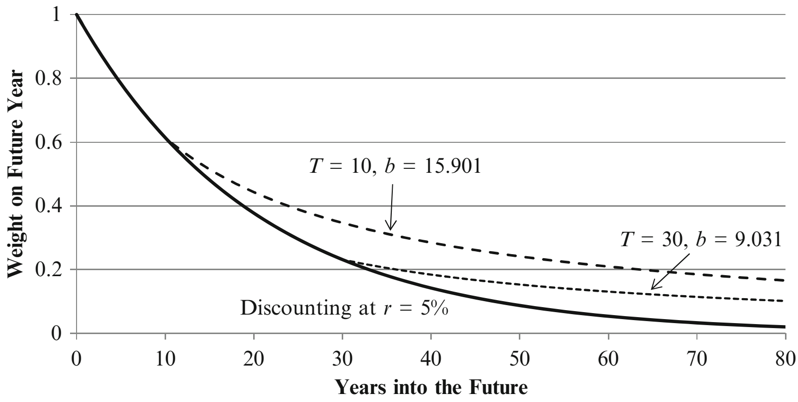

Fig. 6.8 Declining discount factor model, example with r = 5 %

the physical carbon is multiplied by an arbitrary constant that converts the carbon into monetary units. Discounting or weighting of physical units is clearly an acceptable practice in economics, as is evident from Ciriacy-Wantrup (1968) and subsequent literature on conservation. One cannot obtain a consistent estimate of the costs of carbon uptake unless both project costs and physical carbon are discounted, even if at different rates of discount.

Suppose a tree-planting project results in the reduction of CO_2–equivalent emissions of 2 tons of carbon (tC) per year in perpetuity (e.g., biomass burning to produce energy previously produced using fossil fuels). In addition, assume the project has a permanent sink component that results in the storage of 5 tC per year for 10 years, after which time the sink component of the project reaches an equilibrium. How much carbon is stored? Suppose the present value of project costs has been calculated and that these are then allocated equally across the years of the project – so that the discounted stream of the equal annual costs is the same as the calculated present value of costs. If costs and carbon uptake are compared on an annual basis, does one use 2 or 7 tC per year? Suppose the discounted project costs amount to $1,000, or annualized costs of $40 if a 4% rate of discount is used. The costs of carbon uptake are then estimated to be either $20/tC if 2 tC is used, or $5.71/tC for 7 tC.

Suppose instead that we divide the present value of project costs (or $1,000) by the sum of all the carbon that eventually gets removed from the atmosphere. Since 7 tC gets taken up annually for the first 10 years, and 2 tC per year thereafter, the total amount of carbon sequestered is infinite, so that the cost of carbon uptake is essentially $0.00/tC. Therefore, an arbitrary planning horizon needs to be chosen. If the planning horizon is 30 years, 110 tC are sequestered and the average cost is calculated to be $9.09/tC; if a 40-year planning horizon is chosen, 130 tC are removed from the atmosphere and the cost is $7.69/tC. Thus, cost estimates are sensitive to the length of the planning horizon, which is not usually made explicit in most studies.

Cost estimates that take into account all carbon sequestered plus the timing of uptake can only be achieved if physical carbon is discounted. Then, using the methods described in the previous section, the total discounted carbon saved via our hypothetical project amounts to 147.81 tC if a discount rate of 2 % is used, and the correct estimate of costs is $6.77/tC. If carbon is discounted at a rate of 4 %, the project results in costs of $10.62/tC.

Finally, what discount rate should be applied to physical carbon? Richards (1997) demonstrates that, if physical carbon is not discounted, this is the same as assuming that damages from rising atmospheric concentrations of CO_2 are increasing at the same rate as the social rate of discount, but there is no reason to think that this might be the case. It also implies that there is no difference between removing a unit of carbon from the atmosphere today, tomorrow or at some future time; logically, then, it does not matter if the carbon is ever removed from the atmosphere. Only if damages rise slower than the growth in atmospheric CO_2 is a positive discount rate on physical carbon appropriate. This issue is addressed again in Chap. 9.

6.4.4 Risk Adjusted Discount Rates

If outcomes are unknown but estimable with some probability, the decision-maker faces risk that is measured by the expected variability in outcomes. If variability of returns from one project is higher than for another project, it is said to be riskier. The variance and standard deviation are measures of variability or spread and, thus, measures of risk. Most decision makers are risk averse, or reluctant to take risks. Given equal expected net returns, a risk-averse individual will choose the project with the 'narrower' distribution of payoffs as there is more certainty on the outcome.

There are ways to account risk in investment projects. A commonly applied method is the use of risk-adjusted discounted returns. The Capital Asset Pricing Model (CAPM) requires that riskier projects have higher rates of return, surely greater than the market rate of return (market rate of interest). Otherwise, no agent would invest in them. The fundamental equation of the CAPM is:

$$r_{\mathrm{i}} = r_{\mathrm{f}} + \beta\,(r_{\mathrm{m}} - r_{\mathrm{f}}), \tag{6.9}$$

where r_{i} is the required return for risky asset i, r_f is the risk-free rate of return, r_m is the market rate of return, and β measures the investment's contribution to risk relative to the market.[11] Returns are assumed to be normally distributed, so β is estimated as the ratio of the covariance of the asset and market returns to the variance of the market return:

$$\beta = \frac{\mathrm{cov}(r_i, r_m)}{\mathrm{var}(r_m)}, \tag{6.10}$$

[11] Note that β here is defined differently than its earlier use in Eqs. (6.6) and (6.7).

*β*s are usually calculated from past behavior of the investment and market returns. If time series data are available on rates of return, β is the regression coefficient that compares the responsiveness of the investment returns with changes in the market returns. Published data on βs can be useful for private and public projects. For example, Merrill Lynch and Value Line publish βs for stocks of a large number of companies. For project evaluation, asset βs instead of stock βs are required, although the latter can be converted into the former by recognizing that the asset value of a firm equals debt plus equity. Thus, the β of an asset is the weighted sum of the stock β plus the debt β.

Consider an example of the use of CAPM in the energy sector (see Zerbe and Dively 1994). Suppose a North American investor is considering construction of a power plant similar to ones operated by others. By checking βs published by Merrill Lynch for other electrical generating companies, some idea of the relevant β for the project can be obtained. The average β for 23 large utilities in the U.S. is 0.45. Assume that the investor has 40 % of her assets as debt and the debt β is zero. Then, the asset β for the project would be 0.27. If the nominal risk-free rate is 9 % and the market rate is 8.8 percentage points higher than this, the required return for the new investment project using the above formula is: $r = 9\ \% + 0.27(8.8\ \%) = 11.4\ \%$. This means that the energy investment is worth undertaking only if its expected NPV is positive when future costs and benefits are discounted at a rate of 11.4 %.

Risk is often relevant when dealing with externalities. For example, the benefits of mitigating global warming depend on so many variables that scientists cannot accurately estimate costs or benefits. Also, it is often the case where the emission reductions resulting from a carbon mitigation project are risky (e.g., carbon sequestration in agricultural soils). Therefore, it is reasonable to think that private investors involved in carbon mitigation investments might require a rate of return that is higher than the risk-free rate.

6.5 Extreme Events and Irreversibility

There are three alternatives for addressing extreme events and the possibility of irreversibility resulting from a decision either 'to do something' or 'not to do something'. Climate change might potentially be considered an extreme event.

1. The first is to determine the cost of the extreme event or irreversibility and the probability of its occurrence, and then include the expected cost in a social CBA. If the probability of the event or its cost, or some combination of the two, is sufficiently high, the expected cost may be such that avoiding the extreme event or irreversibility will be the optimal decision. In other cases, the cost will be small and the social cost-benefit criterion indicates that the project should proceed. In cases where the probability of the extreme event/irreversibility is not known and/or the cost associated with it is vague, Monte Carlo cost-benefit analysis (simulation across the range of probabilities and possible costs) can be used to

determine the probability that the social CBA criterion is violated.[12] As argued below, this approach to extreme events is the most consistent.

2. Economists have long debated another criterion that is invoked only when dealing with extreme events and irreversibility, namely, the notion of a 'safe minimum standard' (SMS) of conservation (van Kooten and Folmer 2004, pp. 219–221). Begin by ignoring the probability that an event occurs, and consider the maximum potential loss (maximum cost) associated with any strategy under some state of nature. We could choose the strategy that minimizes the maximum loss – the min-max strategy. However, such a decision criterion would prevent us from choosing a project whose net benefit to society might be very large simply because there is a tiny risk of an extreme event that imposes large costs. It is also possible that we avoid choosing the 'conservation' strategy because it has a potential loss that is only slightly larger than the loss that would occur by doing nothing. That is, the min-max criterion could lead us to choose in favor of a strategy with high probability of a large loss over an alternative that has an extremely low probability of a slightly greater loss.
   Clearly, the min-max strategy is not in the best interests of society because it fails to take into account event/outcome probabilities and the scale of cost differences. The safe minimum standard of conservation addresses this and other shortcomings via the following decision rule: Choose in favor of the strategy that provides the greatest flexibility and smallest potential loss, unless the social cost of doing so is 'unacceptably large'. This rule places development of natural resources and impacts on the environment beyond routine tradeoffs, and it does not permit deferral of resource development, say, at a cost that is intolerably high. The problem lies with the term 'unacceptably large'. Who decides when the cost is unacceptably large? In some cases, society can readily agree to accept risks that are extremely small but the potential benefits are large. In other cases, it is difficult to make such a decision and it must be made in the political arena, with all of the facts made available to citizens.
3. The criterion that is most commonly applied to situations where there exists the potential for extreme events and/or irreversibility is the 'precautionary principle'. Environmentalists define it as follows: "When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically".[13] While the European Union has taken the lead in promoting the precautionary principle as a basis for making decisions about the environment, Hahn and Sunstein (2005) and Sunstein (2005) have pointed out the logical inconsistency of the precautionary principle. For example, a decision based on the precautionary

[12] For example, under the social CBA criterion, a project is desirable only if the benefit-cost ratio is greater than 1.0. Monte Carlo cost-benefit analysis might generate 10,000 benefit-cost ratios, of which some proportion are less than 1.0.

[13] Statement adopted by 31 individuals at the Wingspread Conference, Racine, Wisconsin, 23-25 January 1998 (http://www.gdrc.org/u-gov/precaution-3.html as viewed February 25, 2010).

principle would prevent China from building nuclear power plants, even though doing so would reduce health problems associated with pollution from coal-fired power plants, deaths from coal mining, and emissions of CO_2. Yet, if China relied only on nuclear power, a decision to mine coal and use it to generate electricity would be squashed on the basis of the precautionary principle – that electricity generated from coal could lead to adverse environmental consequences and that it is therefore preferable to rely on nuclear power.

If the precautionary principle is to be taken seriously, it would thus provide no direction for and paralyze decision making. By balancing costs against benefits, and perhaps applying the notion of a safe minimum standard, there is at least a foundation for making difficult decisions (see Hahn and Sunstein 2005).

The use of either the safe minimum standard or the precautionary principle implies that one no longer employs social CBA as the decision criterion. In the case of SMS, the social CBA criterion is jettisoned in favor of a somewhat arbitrary criterion whenever there is potential for a decision to bring about an irreversible change. In the case of the precautionary principle, no other criteria are employed unless there is no risk whatsoever to human health or the environment. The chances that this is the case in decisions are rare – wind turbines endanger birds, fossil fuels lead to global warming, hydro dams endanger fish, biomass energy encourages destruction of wildlife habitat as marginal lands are cropped, nuclear power plants might meltdown, and so on.

The economist will almost certainly favor cost-benefit analysis over other criteria for making decisions, even decisions that entail some probably of irreversible loss. The tacit argument is that it is technically feasible to monetize all of the costs and benefits, including spillovers; it is possible to use expert judgments of health and environmental risks; it is possible to account for the ranges of costs associated with spillovers; people's perceptions of risk can be included; and, subsequently, it is possible to calculate the probability that a project results in losses to society, and the distribution of those losses. This information can then be used to determine whether the risks are worth undertaking – whether the benefit associated with accepting the risk (of building a nuclear power plant, say) is 'sufficiently great enough.'

Yet, there is a large element of subjectivity in cost-benefit analysis, particularly as it relates to extreme events. As we will see in Chap. 7, social-cost benefit analysis can be adapted to take account of potential extreme events in several ways. There we find some climate economists recommending a policy ramp (slowly increasing carbon taxes over time) for mitigating climate change, while others recommend immediate and drastic action to control carbon dioxide emissions. The reasons relate to the underlying assumptions employed in cost-benefit analysis to deal with extreme events. The results in the next chapter are briefly discussed from this perspective, keeping in mind that the discounted present value of expected damages avoided by taking action to prevent global warming climate must, in the cost-benefit framework, exceed the costs of acting.

Given uncertain information, economists must decide upon the potential costs of action to mitigate climate change, the potential damages from rising temperatures, the probabilities that damages will occur (although these are supposedly available from climate models), and the discount rate. Costs of mitigation can be low or high; the relationship between temperature increase and damages can be linear, quadratic or exponential; the probability of an extreme event (catastrophic runaway global warming) could be elevated; and the chosen discount rate can make the current value of future damages seem large or small. The policy ramp strategy takes a middle-of-the-road position on these parameters, setting them in such a way that … well a slow policy ramp turns out to be optimal.

The government of the United Kingdom has long been a proponent of immediate action to prevent climate change. A study by the government assumes very large future damages, based primarily on estimates of irreversible ecosystem damages obtained from contingent valuation studies; it also assumes an unusually low discount rate for determining the present value of those damages. Along with presumed low mitigation costs, the forgone conclusion of the UK study is that immediate and drastic action to mitigate climate change is imperative.

Finally, while criticizing the UK study for using a low discount rate, Harvard economist Martin Weitzman argues that the potential for catastrophic damage is understated. In his view, the probability distribution of future damages should reflect high probabilities of extreme events – the distribution of future temperatures should reflect a high probably of extreme future temperatures. The probability distribution should be asymmetric with 'fat tails'. Along with an exponential relation between temperature and damages, the 'fat tails' story leads to extremely large expected damages. Surprisingly, a safe minimum standard type of policy is recommended.

While greater details are provided in the following chapter, each cost-benefit study relies on assumptions about the economic parameters (mitigation costs, temperature-damage relation, probability distribution of temperatures and discount rate) to reach what might be considered a preconceived conclusion. In this regard, there is little difference between the adoption of CBA or some other criterion, including even the precautionary principle, for reaching a decision when confronted by an unknown and unknowable future.

6.6 Discussion

Economists employ four measures of surplus in the evaluation of projects or government programs, including programs to mitigate climate change. While in many natural resource and environmental situations it is difficult to estimate economic surpluses, economists have been able to provide decent enough estimates to facilitate decision making. In the context of climate change, however, the measurement problems are more nuanced. As we will see in the next chapter, uncertainty about the potential damages from climate change in a variety of sectors is unusually large. Such wicked uncertainty makes it difficult to implement a straightforward cost-benefit decision criterion. How does one determine the costs and benefits of mitigating CO_2 emissions to prevent climate change when damages avoided occur decades from now?

To the inherent uncertainty in dealing with climate issues must be added the perhaps more puzzling aspect of discounting when time frames are on the order of many decades or even centuries. As the controversy surrounding a study for the UK government (see Chap. 7) indicates, small differences in the discount rate used in cost-benefit analysis can lead to significantly different policy conclusions. The problem is that the world changes greatly over the course of a half century or more. One hundred years ago, the automobile was only slightly more than a curiosity; today the economies of many industrial nations (and even some developing ones) depend on automobile production, and many countries spent billions of dollars in 2009 to prevent the collapse of their automotive sectors. Electricity, refrigeration, airplanes, radio, television and computers were largely unknown, but today we cannot envision doing without them. How can we predict the potential damages (or benefits) from climate change in 2050 or 2100, much less 2200, without knowing the technical, social and economic changes that will occur on a global scale during this period?

By far the best and most rational cost-benefit analysis of future climate change has been conducted by Bjørn Lomborg (2007). It is the only one of which we are aware that takes into account technical progress in assessing climate change.[14] Lomborg's approach is simple: He indicates that the climate change that has occurred in the past century is about what models predict for the next century, both in terms of global temperature rise and sea level rise. He then compares life at the turn of the twentieth century with that today, showing how well people have adapted, and considers it rational for people likewise to adapt to future changes in climate.

Given the obstacles that confront cost-benefit analysis of climate change mitigation, policymakers have tended to promote mitigation policies on the basis of the precautionary principle. In that case, economists need to examine the costs of various mitigation schemes – to focus on efficiency (minimizing costs as a surplus metric) in the implementation of policy. This is the topic of Chaps. 8, 9, 10, and 11.

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[14] This is not to suggest that Nordhaus and others ignore technological changes. Integrated assessment models of climate change do include parameters for technical progress, but these translate into rate of change as a function of time or income. They do not attempt to address technologies that change a society's very structure or the utility functions of individuals. The reason is simple: No one can predict what changes lie in the future, even the near future.

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