# RESOURCE ECONOMICS AND POLICY ANALYSIS: APPLICATION OF WELFARE ECONOMICS

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# CHAPTER 1. INTRODUCTION

Despite nearly 75 years of development, confusion about how to evaluate projects from an applied welfare economics standpoint continues. We see it especially in debates about the environment and climate change where sometimes outrageous claims are made on the basis of applied welfare economics.[1] The here is to help students in agricultural and forest economics, and perhaps those in other fields of study as well, understand the economic theory used to analyze government intervention. In agriculture, for example, governments have intervened to reduce risk and stabilize farm incomes, often in contravention of trade agreements under the auspices of the World Trade Organization (WTO). In forestry, government policies have resulted in log export restrictions in Russia, Canada, the United States and elsewhere, U.S. restrictions on Canadian softwood lumber exports, and subsidies aimed at the use of wood biomass to generate electricity (e.g., van Kooten 2002, 2014). It is important to have knowledge of applied welfare economics and international trade to facilitate better understanding of the costs and benefits, as well as the income transfers, associated with existing and proposed policies. As such, the aim here is not to strive for complete coverage of the nuances of welfare economics, but rather to focus on a selected number of key elements that are useful for analyzing policy.[2]

In selecting issues for inclusion in the current study, three criteria were used: (1) the available literature on applied welfare economics, also referred to as cost-benefit analysis, and issues that still lead to debate; (2) the methods used to analyze the implications of trade intervention (which is common in agriculture and forestry); and (3) upcoming issues and challenges in the application of economic models, particularly in agriculture, forestry, climate and energy. In addition, several issues of current relevance will be considered, including the valuation of ecosystem services and the role of climate change.

The current document is structured as follows. In Chapter 2, we introduce private financial

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[1] One example concerns the debate around the costs and benefits of mitigating climate change (see Stern 2007; Tol 2006; Weitzman 2007). Other discussions are found in McKitrick (2010) and van Kooten (2013).

[2] For more conceptual foundations of cost-benefit analysis, its theoretical underpinnings and a framework for general application, see, for example, recent works by Just, Hueth and Schmitz (2004), Boardman et al. (2011), and Hanley and Barbier (2009). Arguably the best reference work is that of Boadway and Bruce (1984), who provide the economic theory underlying welfare analysis and a clear discussion of what economists should measure in conducting cost-benefit analyses.

methods of evaluating projects, and include a discussion of the main ranking criteria that are employed (e.g., net present value, internal rate of return, benefit-cost ratio). However, the major focus on this chapter is on development of the theory behind social cost-benefit analysis (CBA). We demonstrate how total economic value can be decomposed into use and non-use values. In doing so, we also examine the multiple accounts framework for evaluating projects, which originates in the United States; the multiple accounts framework is a helpful device for introducing elements into a CBA analysis that are relevant but difficult to quantify. Alternative approaches to project evaluation, including cost-effectiveness analysis and life-cycle analysis, are also discussed, although economists tend for the most part to ignore these methods. The chapter concludes with an examination of how extreme events, and possible irreversibility, are handled in project evaluation.

Because choice of a social as opposed to a private rate of discount is so important to the outcome of a cost-benefit analysis, Chapter 3 is devoted to discounting. Two important topics are included, namely, intergenerational concerns and discounting of physical entities such as carbon dioxide ($CO_2$). Does it matter if $CO_2$ emissions are reduced today or in the distant future? If so, should society place a greater weight on carbon fluxes – that is, discount future carbon flux?

The environmental benefits of mitigating climate change are often considered to be the most important in justifying high costs of reducing global society's reliance on fossil fuels. But how does one define and then measure the costs to the environment of increasing levels of $CO_2$ in the atmosphere? At a more mundane level, what is the value of the ecosystem services that farmers provide to society when they choose not to drain wetlands or when they convert cropland to grassland, thereby reducing soil erosion while enhancing wildlife habitat? Ecosystem services, visual amenities, wildlife, clean air and water, open spaces, et cetera, are not traded in markets, which is why economists talk about 'non-market' goods and services. The valuation of the environment and other 'non-market' goods and services is the topic of Chapter 4.

In chapter 5, we develop the tools most often used by agricultural economists to analyze policy. These tools are rooted in notions of excess supply and demand derived from models of international trade. We indicate how restrictions on agricultural trade or liberalization of trade as a result of international negotiations, impact prices and economic wellbeing.

## CHAPTER 2. PROJECT EVALUATION CRITERIA

It is important to distinguish between private and social cost-benefit analysis (CBA). If we "consider all of the costs and benefits to society as a whole, that is, the social costs and the social benefits," we refer to this "as social cost-benefit analysis," or sometimes simply as CBA (Boardman et al. 2011, p.2). Economists employ social CBA for evaluating public policies because it is solidly grounded in economic theory, with many of the controversial aspects having been sorted out over a period of some seventy-five years. In the jargon of economics, a full social CBA of a nature, environmental, energy or climate mitigation project balances all benefits to whomsoever they accrue against all costs, regardless of who bears them. Any redistribution of income brought about by the project is ignored and no distinction is made between rich and poor; it does not matter if a dollar accrues to a rich person or a poor one, it is treated the same.[3] Further, it is assumed that the project is sufficiently small so that prices elsewhere in the economy are unaffected. If only prices of substitutes and/or complementary goods and services are affected, the effects in the markets of those goods can be taken into account. These constitute the proper indirect effects of the project. However, if prices elsewhere in the economy are impacted, general equilibrium modeling would be necessary.

Social cost-benefit analysis is built on financial analysis, or private methods of evaluating projects. Therefore, we begin with the private perspective as private costs and benefits are a component of social costs and benefits.

### Private Financial Analysis

Consider the perspective of the private firm. For example, if an electric system operator is considering the construction of an additional thermal power plant, the costs of

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[3] This is the assumption of constant marginal utility of income. Some argue that income distribution is the domain of macroeconomic (tax) policy. Others apply weights to measures of economic wellbeing depending on who in society bears the costs or receives the benefits. Social theorists argue that this can be done by specifying appropriate utility functions (that might include altruism as a parameter) or social welfare functions, but in practice such decisions are political and beyond the purview of project evaluation, except that project evaluation or CBA can help identify the gainers and losers of a policy.

the project equal

- the up-front construction costs related to land, labor and materials;
- annual operating (fuel and other), maintenance and (routine) replacement costs, usually referred to as the OM&R costs;
- estimates of the costs of unscheduled breakdowns and 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 households and industry, 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 system operator weights the streams of costs and revenues is the rate of return that he or she hopes to earn on the investment. 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.

Private project evaluation excludes spillovers unless the authority specifically requires the firm to pay for access to natural resources, to pay compensation to those ‘harmed’ by the firm’s activities, to pay an environmental tax, to purchase ‘pollution rights’, or requires the firm 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 private evaluation uses market prices for natural resources, labor, land and other inputs instead of the opportunity costs of those resources. 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, it might be wise just to let the private sector pursue it.

*Financial ranking criteria*

Private 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).

*<u>Net Present Value (NPV)</u>*

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

- the discount rate is given and usually taken as the market interest rate;
- capital is always readily available;
- the interest rate for borrowing is the same as the interest rate for lending;
- cash flow projections include all relevant costs and benefits, and taxes; and
- 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:

$$\text{(2.1)} \qquad \text{NPV} = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r_t)^t},$$

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 $t$ (although the interest or discount rate is generally assumed to remain constant in each period). If we are evaluating a single project and NPV is greater than zero, the project is worth undertaking. 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 annualize the net discounted benefits of each project in order to make the comparison).

*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:

$$(2.2) \qquad \text{BCR} = \frac{\sum_{t=0}^{T} \frac{B_t}{(1+r_t)^t}}{\sum_{t=0}^{T} \frac{C_t}{(1+r_t)^t}} .$$

If the BCR for a single project is larger than 1, then the project increases real wealth. When comparing different projects, however, 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.

*Payback Period*

For the vast majority of projects, costs are incurred before any benefits are realized, which is why the term ‘cost-benefit analysis’ is preferred here to ‘benefit-cost analysis’. During the construction phase of a project, a firm incurs costs only – costs are ‘front-loaded’. Benefits do not usually accrue until construction is complete. The payback period, therefore, is the point in time when a project’s total benefits exceed its total costs. At that time, the project has ‘paid back’ its initial investment. Both costs and benefits should be discounted when estimating the payback period. The major problem with the payback method is that it ignores cash flows – costs and benefits – that occur beyond the payback period. If this is the only financial criterion taken into account, it is possible then 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 tend to prefer projects with a shorter payback period.

*Internal Rate of Return (IRR) and Modified Internal Rate of Return (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 equation (2.1), it is found by setting NPV=0 and solving for $r$

(assuming $r$ 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 for a single project. And 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:

$$(2.3) \qquad K_0\,(1+\text{MIRR})^T = \text{FV}_{\text{cash flow}},$$

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.

*Conclusion*

A number of different criteria are used by private firms and even government agencies to evaluate whether a particular course of action – construction of a new manufacturing facility, purchase of another business, investment in a sports facility, et cetera – meets the entity's goals or (more specifically defined) objectives. In this section, we considered only financial criteria, such as net discounted returns (discounted profits), internal rate of return, or the time required for an investment to be paid back. We have ignored such intangibles as the contribution that an action makes to a firm's 'goodwill'. For example, some forest companies have been known to pay for research into the effect of logging practices on amphibians, and how practices can be changed to take any adverse impacts into account. Clearly, there is no financial benefit that can be readily identified; indeed, it may increase logging costs. However, the firm may prevent erosion of market share for its products if this activity leads a retailer to treat the company's wood products as or more favorably than those of a rival. Likewise, a government agency charged with providing recreational activities for citizens might simply use anticipated number of participants per unit of expenditure to determine the 'best' means of spending a limited budget.

The narrow focus on the firm's or agency's purpose is what characterizes 'private evaluation', whether such an evaluation is based on financial or non-financial factors, or some mix of the two. The criteria used by these economic agents or entities in making decisions ignore the impacts that their decisions have on other elements in society. They ignore social costs and social benefits more broadly. They ignore spillovers and distributional impacts. It is important to recognize that it is not only private firms that fail to include social costs and benefits in their analyses. Often government agencies (e.g., Bureau of Land Management in the U.S.), publicly-owned (crown) corporations (BC Ferries), and government departments have their own clientele and are generally more concerned with their survival than they are with the overall 'public good'. Yet, taking into account all costs and benefits, social and private, is the task of applied welfare economics – or simply (social) cost-benefit analysis.

**Society's Perspective: Social Cost-Benefit Analysis**

This 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. If spillovers are small, the transaction costs of rectifying them might be too great to warrant intervention. If the externality is sufficiently large, a case can be made for public intervention. Intervention might take the form of regulations that prevent the project from going forward, or regulations that modify the project (and change the cost-revenue balance sheet for the private investor) so that spillovers are addressed. An example of the latter might be a requirement to install scrubbers to remove $SO_2$ and other harmful pollutants from a power plant's smoke stack. Alternatively, some investments that are considered worthwhile from a public standpoint might not proceed without subsidies or direct involvement by the authority. For example, the public authority might consider providing a subsidy to biodiesel producers to encourage substitution of biodiesel for fossil fuels, thereby reducing $CO_2$ emissions. Alternatively, mandates (regulations) that require a certain proportion of diesel sold at the pump to include biodiesel might be just as effective in encouraging biodiesel production, but at lower cost to the public purse. In either event, such interventions must pass a social cost-benefit test, where a benefit of the action/policy is the reduction in $CO_2$ emissions.

*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 section 3 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, the market wage rate might be higher than social wage rate because of market impediments that cause the wage rate to exceed the marginal value product – the value of the 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 the marginal value product. If a large pool of unemployed workers exists, the shadow price of labor might well be zero.

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

*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 Figure 2.1.

Consumer surplus is not always directly measurable. Consider the case where a project does not affect consumer surplus because the market price is unaffected. 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 electricity. 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. Suppose that, in addition to the market for lumber or energy, there is a demand for an environmental amenity that is somehow impacted by the logging decision or energy project. In that case, 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.

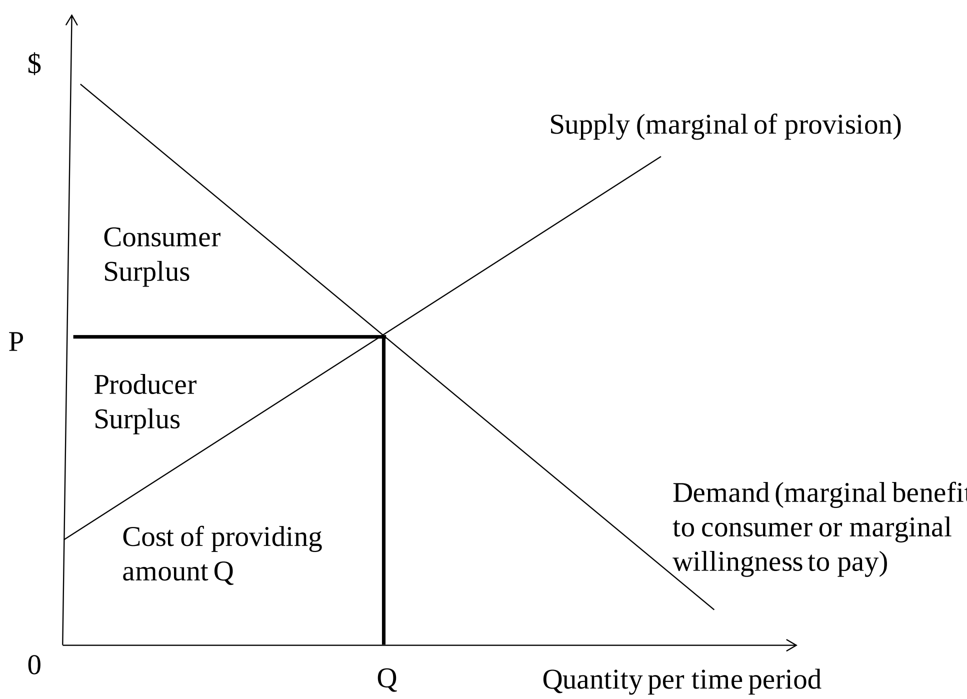


*Figure 2.1: Consumer and Producer Surplus*

*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 Figure 2.1.[4] While constituting a true welfare measure, producer surplus constitutes a rent accruing to fixed factors of production and entrepreneurship. That is, in the construction of Figure 2.1, the supply curve is taken to be 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.

*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 Figure 2.2, noting in particular that the supply curve in this figure differs from that in Figure 2.1.

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. 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.

[4] 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.

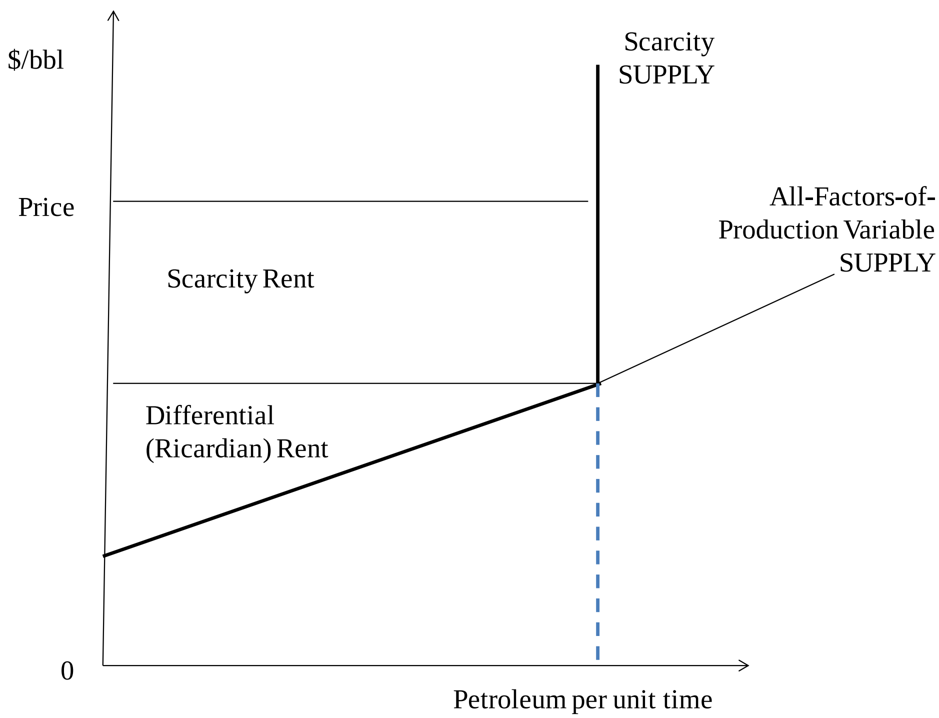


*Figure 2.2: Scarcity and Differential Components of Resource Rent*

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.

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 (Boadway and Bruce

1984, pp.252-255). Whenever price exceeds marginal cost, 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 Figure 2.3. 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 given by area *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 Figure 2.3 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 valuation techniques described in Chapter 4. Notice also that the socially desirable level of the environmental amenity has also increased to $E^{**}$.

We can summarize the results provided above using a simple relationship. Consider Figure 2.4 where a policy shifts the supply curve for good $q_1$ from $S^0$ to $S^1$, causing the price of the good to fall from $p_1^0$ to $p_1^1$. The total welfare effect of the policy, $\Delta W$, can be decomposed into the direct benefit measured in Figure 2.4 plus the indirect benefits as follows (Boadway and Bruce 1984, p.254):

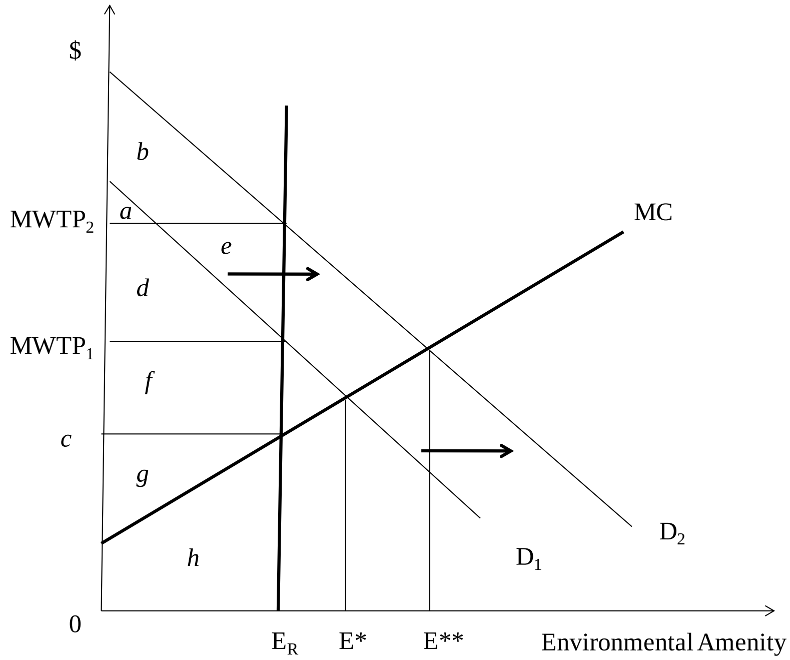


*Figure 2.3: Indirect Surplus Gain due to Increase in Timber Harvests in Other Jurisdiction*

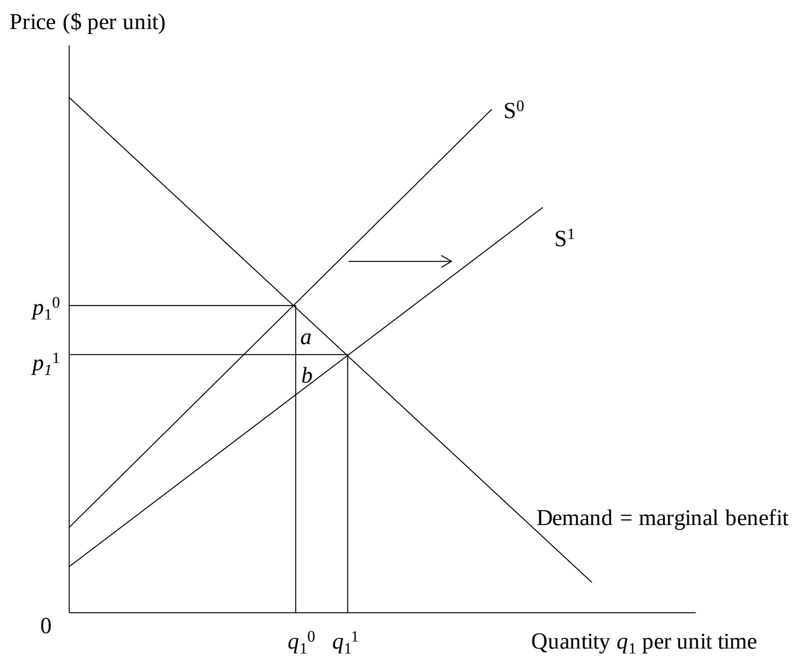


*Figure 2.4: Surplus Gain due to Government Policy that Increases Supply*

(2.1) $$\Delta W = \text{area } (a+b) + \sum_{j=2}^{n}(P_j - MC_j)\Delta q_j \, .$$

Area ($a$+$b$) is the sum of the consumer (area $a$) plus producer surplus (area $b$) in the market for $q_1$. The second term in the equation refers to the indirect benefits measured in the $n$–1 markets impacted by the change in the price of $q_1$ – that is, the distorted markets of goods and services that are complements or substitutes with respect to $q_1$. In some cases, therefore, the second term will offset the increase measured by area ($a$+$b$) in Figure 2.4, but $\Delta W$ can never be negative as a result because this would indicate that the original budget allocation was not optimal.

It is important to note that environmental spillovers, such as global greenhouse gas emissions, fall into the category of 'indirect surplus'. 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 Chapter 4). It is also important to recognize that environmental damage is measured as a loss to consumers similar to lost consumer surplus.[5] The cost of environmental damage is measured as lost surplus, which becomes a benefit (i.e., the damages avoided) of a project that reduces the environmental 'bad' (e.g., reduces atmospheric $CO_2$ concentrations). When all of the changes in surpluses resulting from a project are appropriately summed, the net (discounted) social benefit must exceed the capital cost of the project.

Finally, the criteria for judging whether one project is preferred or somehow better than another from society's perspective are the same as those used under private CBA. That is, equations (2.1), (2.2) and (2.3) remain valid. What then is the difference between the private and social perspective? The difference is what one measures and includes as costs and benefits, and the discount rate that one employs (which is considered further in section 3).

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[5] 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 provided in van Kooten and Folmer (2004, pp.13-25).

*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 Figure 2.5 (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 Figure 2.5, total economic value is given by:

(2.2) TEV = Total use value + total non-use value + 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 (see, e.g., Millennium Ecosystem Assessment 2003, 2005). 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.

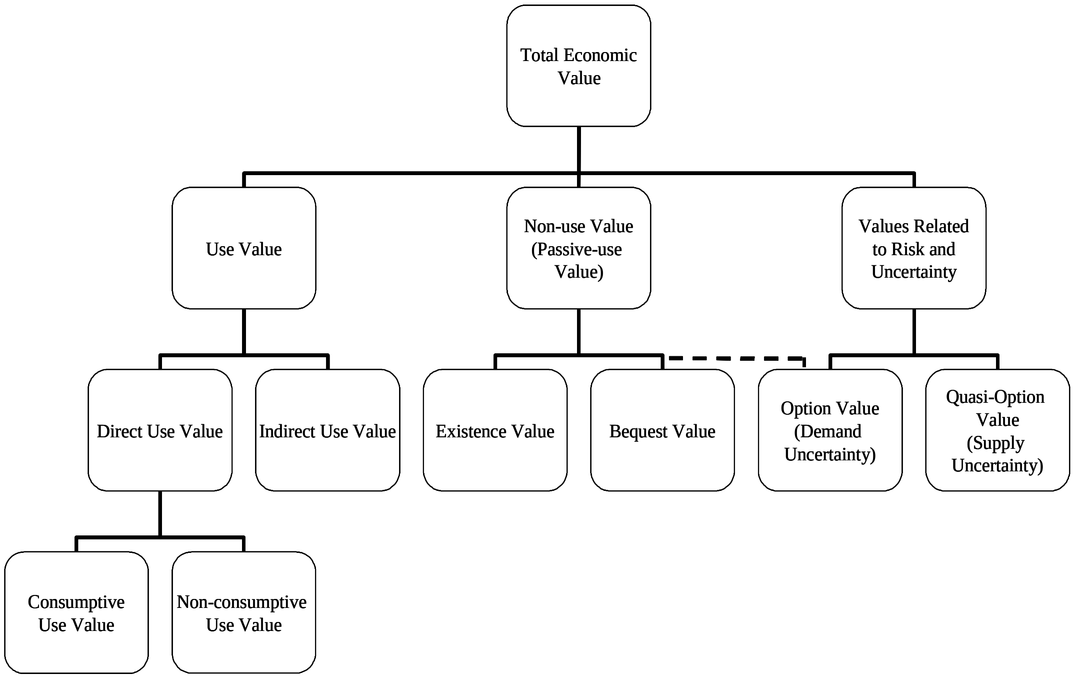


*Figure 2.5: Components of Total Economic Value*

In the context of Figure 2.5, *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 and water quality control). Then the cost-benefit rule for implementing a biofuels regulation that adversely affects marginal land currently in its natural state is:

$$(2.3) \qquad \sum_{t=0}^{T} \frac{B_t - C_t - E_t}{(1+r)^t} > 0,$$

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 regulating biofuel content in gasoline, with the commercial costs but not environmental costs borne by the energy provider. Depending on the project or policy, the environmental costs might 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 such as corn. While one expects $E$ to be positive because it measures lost environmental benefits, there might be situations where 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 wetlands, native grassland and/or 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 Figure 2.5, 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 Figure 2.5); 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 surveys 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.[6] 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 below.

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:

$$\sum_{t=0}^{T}\frac{B_t - C_t - E_t}{(1+r)^t} - (TNUV + OV + QOV) > 0, \qquad (2.4)$$

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 developing land by growing crops on it. This formulation takes into account all social benefits and social costs associated with the proposed project.

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[6] 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 section 4), 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.

*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, 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 wetlands elsewhere, option value is much larger. Hence, it is not the total or average environmental (non-market) value that is important, but the marginal value. Too often the focus is on total or average value 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 Figure 2.6. 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 wellbeing from providing too much of the amenity (the cost to society) is therefore given by area $ABCg^*$.[7]

This thinking cuts both ways. Suppose, rather than an environmental amenity, it is

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[7] This is the difference between the area under *MC* (which equals 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.

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.

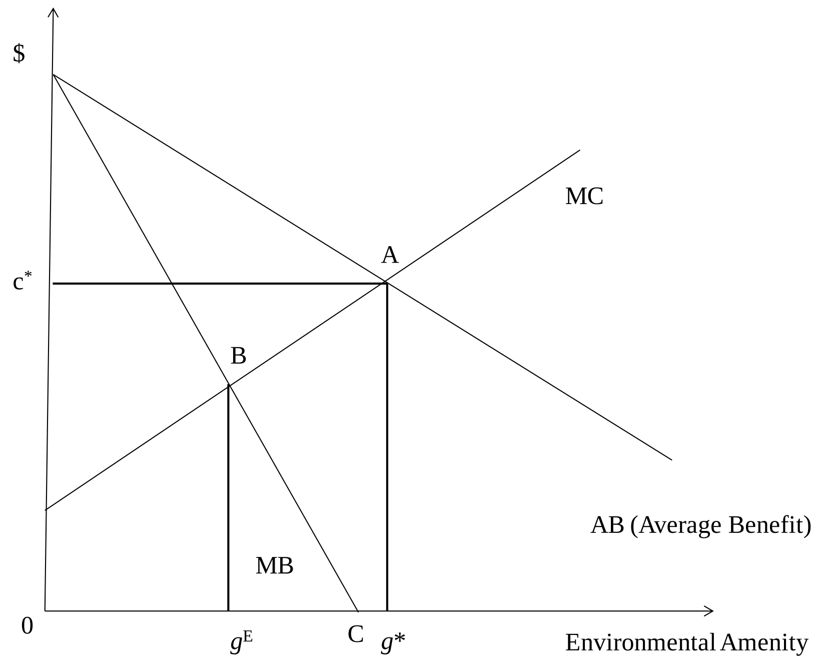


*Figure 2.6: Marginal vs. Average Benefits of Decision Making*

*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 economic welfare measure), any gain in employment that a policy/project brings about needs to be evaluated in terms of the change in the 'surpluses' that result when jobs are created. This is preferably measured in terms of the forgone opportunities (loss in economic surpluses) 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 $CO_2$ ($tCO_2$), but not at a cost of $250 per $tCO_2$.

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 the climate change that energy crops seek to mitigate. This issue is considered further in the final subsection in this chapter.

In the next subsection, we examine the issue of 'intangibles' in the context of what has been referred to as multiple accounts analysis. In such an analysis, the surplus and rent measures discussed in this section constitute one account, while various 'intangibles' constitute the other accounts. These so-called intangibles may nonetheless be measured in monetary terms, but one must take care not to include such measures in the 'cost-benefit account,' which is considered to be the economic efficiency account (or the net economic benefit account). The separateness of accounts is clearer in the case where measurement is in non-monetary units, because the distinctiveness of accounts is clear and aggregating across accounts is not possible.

## Multiple Accounts and Alternative Criteria

The multiple accounts framework departs from social cost-benefit analysis in subtle ways, but two points remain relevant: First, social CBA and the measurement of spillovers or externalities form an integral component of multiple accounts analysis.

Second, because some stakeholders will have greater affinity for one account over the others, the existence of several accounts should not become an excuse for denying the need to trade off 'intangibles' against the money metric of social CBA. Failure to do so by considering no 'account' as the standard against which all other 'accounts' are to be judged can result in a decision-making deadlock.

Project evaluation originates in the United States as legislators sought guidelines to determine whether publicly-funded resource development projects were likely to achieve their aims. One guideline developed by U.S. legislators in the Flood Control Act of 1936 required that the benefits of water development projects, "to whomsoever they may accrue," should exceed all the social costs related to the project. This requirement subsequently developed into the U.S. Water Resources Council's (WRC) 'Principles and Standards' (P&S) for water project evaluation, which appeared in the *U.S. Federal Register* in 1973 and 1979 (WRC 1973, 1979). In 1973, the WRC identified four objectives for project evaluation:

All the benefits and costs of a project had to be considered in the evaluation, regardless of who bore the costs and who received the benefits. This is the objective of national economic development (economic efficiency).

Impacts on the environment had to be calculated and included in the cost-benefit analysis. This implied that the non-market benefits of recreation, environmental degradation, et cetera, had to be taken into account.

The regional benefits of resource development projects were to be included explicitly in the analysis, making it possible to justify a project on the basis of its regional development benefits.

Finally, the impact of a project on social wellbeing had to be taken into account. For example, the analyst or planner was to take into account the impact of the project on certain groups in society (e.g., on African Americans or on those with lower incomes). This objective, then, required explicit consideration of social issues in evaluating resource development projects.

The 1973 P&S for evaluating projects focused only on the first objective. The 1979 P&S attempted to extend the evaluation methodology to the second objective by including methods for monetizing some non-market values, particularly recreational values (viz., water recreation on reservoirs) and some environmental values related to improved water quality. Unlike in 1973, the 1979 P&S included detailed instructions for evaluating projects. However, the last two objectives were not addressed, perhaps because the WRC did not feel these could be handled within the P&S framework then proposed.

The 1979 P&S were replaced by the 'Principles and Guidelines' (P&G) (WRC 1983). Since it was imperative to include items 2, 3 and 4 into the evaluation process, the 1983 P&G did so by recognizing non-commensurability among the various objectives, which was not explicitly done in the earlier P&S. Thus, the WRC adopted a *multiple accounts* approach to project evaluation.

Four accounts are identified in the P&G, and these are similar to the four categories indicated in the P&S. The important difference between the approaches is the recognition that the various accounts deal with different issues and are not commensurable. Thus, the 1983 P&G include a description of methods for displaying the different accounts. The four accounts are as follows:

National Economic Development (NED) Account

Environmental Quality (EQ) Account

Regional Economic Development (RED) Account

Other Social Effects (OSE) Account

Cost-benefit analysis is used only to evaluate those items that can be monetized, namely, those found in the NED account and the components of the EQ and RED accounts that could be quantified in monetary terms. This is not to suggest, however, that the monetary values are commensurable (as shown in the discussion about employment and multipliers below). Items that cannot be monetized are to be presented in each of the EQ, RED and OSE accounts and are briefly described in the following paragraphs.

*Environmental Quality*

According to the P&G, environmental items that are to be displayed in the EQ account are ecological, cultural and aesthetic attributes. Ecological attributes include functional aspects of the environment (e.g., assimilative capacity, erosion, nutrient cycling, succession) and structural aspects such as plant and animal species, chemical and physical properties of air, water and soil (e.g., pH of rainfall), and so on. Cultural attributes are evidence of past and present habitation that can help in understanding and propagating human life. Aesthetic attributes include sights, scents, sounds, tastes, impressions, et cetera, of the environment. It is clear that, while these attributes could be measured in monetary terms (using non-market valuation methods), it may be too costly or difficult to do so (hence the term 'intangibles'). However, they can be measured in other ways that include both quantity indicators that employ numeric and non-numeric scales and quality indicators such as 'good' and 'bad'. It is obvious that the EQ attributes need to be presented in a clear and concise fashion if they are to be of use in the decision-making framework.

Several principles govern the enumeration of items within the environmental quality account. Both an interdisciplinary approach and public input are required in this process, although the means for involving the public is left to the discretion of the planning agency. In all cases, however, the EQ attributes are to be displayed in a way that highlights the comparison between the 'with project' and 'without project' scenarios.

*Regional Economic Development and Employment: Indirect Benefits*

There is much confusion in cost-benefit analysis about the regional impacts of resource development projects and the use of multipliers to take into consideration so-called (but misleadingly labelled) 'indirect benefits' (including job creation).[8] Regional impacts are the purview of the RED account, and these have historically been addressed using input-output models, because such models can be used to develop activity and

[8] These are not indirect benefits (as discussed in section 3), because they are not a welfare measure. These might more appropriately be considered indirect impacts.

employment multipliers. Input-output models and similar regional accounting frameworks are only able to identify changes in value added throughout the regional economy (change in gross domestic product or GDP) brought about by the project or policy, but changes in value added are a measure of changes in economic activity and not a measure of economic surpluses (benefits or costs) per se. Rather, value-added represents an upper limit on the opportunity cost of the resources employed in the various activities that generate the value added (Stabler et al. 1988; Hamilton et al. 1991). The RED account recognizes that it is wrong to sum the regional and national economic benefits – increases in GDP cannot in and of themselves be considered a benefit measure because costs are neglected. Thus, simply because two items (efficiency and changes in GDP) can be measured in monetary terms does not imply that they are commensurable.

One possible approach to valuing the opportunity cost of a project is to compare the effects of the alternative use of the funds (as determined from an appropriate input-output model) with those generated by proposed spending on the project under consideration. The former might be thought of as project-specific opportunity costs and might be positive or negative, or inconsequential. These opportunity costs need to be included on the basis of the 'with-without' principle of project evaluation. Thus, it is necessary to subtract the 'benefits' of the alternative project from those of the proposed project, in which case the proposed project's net 'indirect benefits' might actually be negative.

The takeaway point is this: The economic efficiency of the resource development project is overstated if changes in value added are included while ignoring the potential value added generated by using the funds in an alternative endeavor (perhaps even leaving the funds with taxpayers). Use of an appropriate general equilibrium model would prevent this kind of confusion.

When labor resources are not fully employed, their shadow (true) value is not given by the observed wage rate. If there is persistent unemployment of resources, particularly labor, the opportunity cost of such resources (their shadow price) is essentially zero and an argument can then be made to include the value-added benefits of a project in the CBA. But there are a number of arguments against this view:

First, it needs to be determined if unemployment is indeed persistent, and, if it is, whether the cause is structural (e.g., a poorly trained labor force) or not. If it is structural, a publicly-funded regional development project aimed at job creation will not help local residents as it will attract workers from outside the region. From a national perspective job losses in other regions need to be counted as a negative impact of the project.

Suppose the reason why high unemployment exists is not structural. This does not imply, however, that a proposed resource development project is the best means for creating jobs. Macroeconomic policies may be much more effective in reducing unemployment. Indeed, there is a built in problem with capital intensive resource development projects. Several years to more than a decade is often needed to obtain authorization for proceeding with a resource development project, and this is also true for many other projects (e.g., replacing an old bridge, building a sewage treatment plant). The macroeconomic situation might change dramatically between the time of project conception and construction. Unemployment may no longer be a problem and, as construction begins, the project may simply bid up labor costs, making it more expensive to implement and perhaps making the project uneconomic. Relying on large projects to deal with unemployment could turn out to be wrongheaded.

Finally, if the shadow price of labor is zero, the opportunity cost of capital must also be higher than is evident from the observed rate of return to capital. The reason is that returns from capital must be diverted to support unemployed labor. Therefore, since the discount rate is determined by the opportunity cost of funds used in the project, the discount rate to be employed in the analysis must be higher than would otherwise be the case. The higher discount rate militates against resource development projects, and offsets the supposed benefits due to secondary or regional impacts.

If a public project is funded by an increase in local taxes, an interesting question that arises is whether or not the same multiplier is used to measure the contractionary impacts of those taxes as is used to measure the expansionary impacts due to the project itself. Use of the same multiplier leads to offsetting impacts, although the overall impact would likely be negative as a result of leakages – the revenue required to fund the project will be greater than the project costs because of transaction costs and inefficiencies inherent in tax collection and government bureaucracies. Likewise, spending public funds on projects to create jobs, while popular with politicians, ignores the jobs lost elsewhere due to the contractionary impact of higher taxes.

The RED account recognizes that, despite being valued in monetary terms, regional impacts (changes in economic activity) are not the same as economic efficiency or national economic development. Benefits to a region may be costs to the nation as a whole. The existence of a separate RED account simply recognizes that regional income transfers are important (just as the OSE account recognizes that income transfers among various groups in society might be important). By separating the NED and RED accounts, the incompatibility between national economic development and income distribution among regions is explicitly recognized.

*Other Social Effects*

The OSE account includes items that are not included in the other three accounts but are important for planning. While the P&G provide no procedures for evaluating other social effects, it does indicate that such effects include "urban and community impacts; life, health, and safety factors; displacement; long-term productivity; and energy requirements and energy conservation". The guidelines also call for the inclusion of the effects that a project has on income distribution, employment, the fiscal impacts on state and local governments, quality of community life, and so on. While some of these effects can be measured in monetary terms and are to be included in the economic efficiency (NED) account, others need to be displayed using guidelines similar to those of the EQ account. It appears that public agencies have substantial freedom within the planning process to include whatever items they wish in the OSE account and how they are to be displayed.

*Concluding Observations about Multiple Accounts*

A problem occurs with the multiple accounts approach when all of the accounts are given equal status – when no account is given precedence over any other account. In that case, proponents of any one account are not required to seek compromise, conceding to trade off one benefit for another, but they tend to become entrenched in their position. The WRC's P&G are clear that environmental quality, regional economic development and other social effects need to be compared against or in terms of the economic efficiency account. That is, tradeoffs between non-monetized effects (or 'intangibles') and economic efficiency must be made clear. This implies that social CBA takes precedence over other considerations, or that, at the very least, the cost of any deviation from an economically optimal decision must be identified in terms of its welfare loss.

It is important to recognize that project appraisal must always compare the situation 'with and without' the project, program or policy in place. Thus, a proper cost-benefit analysis will take into account all opportunity costs, including indirect costs associated with market failure (e.g., monopoly, unpriced environmental impacts), whose measurement was discussed in the previous section. Social CBA will ignore items that cannot be measured in monetary terms, not because these items are unimportant to the analysis but because they cannot be integrated into the money metric of applied welfare economics. They are an aside, addressed in descriptive terms if at all. The multiple accounts framework, on the other hand, requires first off that a proper social CBA be completed, but then that 'intangibles' be explicitly considered, with changes in such intangibles explicitly traded off against changes in economic efficiency.

Although the difference between cost-benefit analysis and the multiple accounts approach is a subtle one, it is nonetheless important enough to warrant the adoption of a multiple accounts approach for the evaluation of public projects, programs and policies. This recommendation comes with a warning, however: Application of a multiple accounts approach to evaluation should never become an excuse for neglecting a proper social cost-benefit analysis. The reason is that, outside of the surplus and rent measures employed in cost-benefit analysis, there is no other consistent, theoretically appropriate means of judging projects. The alternative is that one ends up trying to compare apples and oranges, in which case any decision can be justified.[9]

## Alternative Methods for Evaluating Projects

There exist many alternatives to social cost-benefit analysis. Some of these are quite sophisticated and address some of the weaknesses associated with the use of money metrics. While there is nothing wrong with many of the alternatives examined below, since project evaluation refers, after all, to any consistent set of scientific criteria for analyzing decisions, our view is that the cost-benefit criterion based on economic surpluses is the most theoretically sound and consistent. Nonetheless, this does not mean that information available from some of these alternatives could not inform the decision process.

### *Cost effectiveness analysis*

Where an objective can be realized by alternative means but the objective itself cannot be valued in monetary terms, cost-effectiveness analysis (CEA) can be used to determine the least-cost means of achieving the objective. CEA is often used for evaluating health, education, environmental and defense programs and policies, because program/policy benefits are generally not easily or accurately measured in monetary terms. CEA aims at identifying the least-cost strategy for achieving a non-economic objective and involves comparing the costs of various mutually exclusive, technically feasible project options and selecting the one with the lowest costs – the most cost-effective one.

Most of the CEA literature is in the context of the health sector, where stakeholders are reluctant to measure health impacts and human lives saved (or bettered) in monetary terms. Nonetheless, CEA can be applied in other sectors just as easily.

Recommendations for the use of CEA generally warn that the conclusions of CEA

[9] As an example, suppose you rank the potential purchase of an automobile by examining characteristics and rating each. Cost, fuel efficiency, color, power and other attributes are rated on a scale of 1 to 10. Cars are ranked according to the sum of the scores each attribute receives. Would a person really choose the car with the highest score? Perhaps, but it is unlikely as the ordinal ratings are not comparable unless they are converted to a common, cardinal metric.

must be weighed against a variety of political and distributional considerations. The information that CEA contributes is often summarized by the cost effectiveness (CE) ratio, which is the cost per unit health effect achieved by using a particular health intervention. The CE ratio ranks health interventions so that health resources are deployed in the most 'efficient' manner. CEA starts by identifying the proposed intervention and its alternatives, including the alternative of 'doing nothing'. Alternatives are then compared using the CE ratio:

$$\text{(2.5)} \qquad \text{CE ratio} = \frac{C_0 - C_k}{E_0 - E_k},$$

where subscripts 0 and $k$ describe the intervention under consideration and the alternative to which it is compared; $C_0$ and $C_k$ are associated present values of costs; and $E_0$ and $E_k$ are the respective health outcomes (measured in some fashion). When performing a cost-effectiveness analysis, the CE ratio of the studied intervention is compared to the CE ratios of other commonly used forms of medical care. If it is relatively low, the intervention under study is considered to be a good value.

The art of CEA is proper accounting of costs and health outcomes. Typical measures of health outcomes are years of life saved or quality-adjusted life years saved. These values are obtained from statistical medical experience. When dealing with environmental issues, the denominator from the CE ratio would contain the relevant variable for the environmental problem of concern. For example, it could be emissions, concentration of pollutants, energy savings or nuclear waste produced.

One challenge in using CEA is the choice of a CE ratio cutoff for decision making. Further, CEA may not be welfare enhancing because it often ignores all possible options (as seen in the formula where binary rather than multiple comparisons are made) and mixed strategies. Nonetheless, it is a rigorous method for bringing economic considerations into decisions regarding health care, and it has the advantage of being accepted by different stakeholders. However, our view is that, for taking into account intangibles (items that cannot be measured in monetary terms), both multiple-criteria decision making (next subsection) and multiple accounts analysis are preferred over cost-effectiveness analysis.

*Multiple criteria decision making*

Another alternative is to employ multiple-criteria decision making, or MCDM (e.g., Krcmar et al. 2005). This tool provides decision makers with the tradeoffs among all of the different objectives, so that the explicit effects on other accounts can be clearly identified when a choice is made. These are the opportunity costs as expressed in both monetary (foregone economic efficiency) and non-monetary terms. This is both the major advantage of MCDM and its weakness. As long as tradeoffs are made with respect to the money metric of cost-benefit analysis or economic efficiency, MCDM adheres to the multiple accounts criteria we considered above. If tradeoffs are made relative to other metrics (e.g., jobs versus carbon uptake without regard to efficiency), consistency in the evaluation of energy projects will flounder as society may end up not pursuing the 'best' suite of energy projects available.

Nonetheless, MCDM can serve a very important purpose in the multiple accounts framework of analysis. The reason why we favor the use of multiple accounts analysis is because not all possible spillovers can be measured in monetary terms – some are truly intangible in this regard. MCDM can deal with objectives that are not commensurable in a consistent and scientifically sound fashion. It enables the analyst to identify positions that are sub-optimal in the sense that two or more objectives can be improved simultaneously. For example, MCDM might suggest an alternative energy project to the one under investigation, one that generates more jobs and more carbon benefits while retaining the same levels of biodiversity, economic efficiency, and so on. The advantage is that, in making comparisons with the money metric, MCDM yields shadow prices (i.e., monetary values) for the intangibles, which could not be done in another framework of analysis.

One area of increasing interest in the development of MCDM is the use of fuzzy logic. The reason for this is the advantage that fuzzy logic has in quantifying language (as noted earlier in the context of non-market valuation). This approach recognizes that many of the concepts involved in decision making are far from clear or precise, in essence they are fuzzy. Fuzzy sets provide an explicit way of representing vagueness about what objectives are and how one might quantify them. However, it has proved difficult to implement fuzzy MCDM in practice, as demonstrated by Krcmar et al. (2001).

*Life-cycle assessment*

Life-cycle assessment (LCA) evaluates the effects that a product has on the environment over its entire life (hence it is sometimes referred to as ‘cradle-to-grave analysis). The objective is to trace the product after it usefulness has ended and it has been discarded; thus, it has the potential for increasing resource efficiency and, more importantly for private owners, decreasing liability. It can be used to study the environmental impact of either a product or the function the product is designed to perform. As LCA is a continuous process, companies can begin an LCA at any point in the product/function cycle.

LCA can be used to develop business purchasing strategies, improve product and process design, set eco-labeling criteria, and otherwise communicate about the environmental aspects of products. The key elements of LCA are to identify and quantify the environmental loads involved throughout the product cycle (e.g., energy and raw materials consumed, emissions and wastes generated) and to evaluate the potential environmental impacts of these loads.

Over the last ten years there has been a rapid expansion in the demand for and use of LCA, fuelled by both industry and government. For industry, a major use is in characterizing current operating practices with a view towards how industry stands in relation to current and proposed legislative measures. A series of LCA performed by any company over consecutive years will fully determine that company’s operating practices as well as establishing manufacturing trends. LCA can be used to identify potential resource savings and/or savings related to compliance with government regulations. Governments, on the other hand, can use LCA to heighten awareness of the implications of proposed legislation, especially in cases where the effects of legislation run counter to original intentions, so that legislation can be amended before it is adopted. An example of this has occurred in the setting of realistic recycling targets, with some countries having tempered recycling requirements so that they were more effective in achieving ultimate as opposed to proximate objectives. Companies in both the developed and developing world have used LCA to meet international ISO 14000 series environmental standards.

How does life-cycle analysis relate to cost-benefit analysis? Clearly, LCA could be useful in identifying (external) costs that are often ignored in standard social CBA, not because they are unimportant but because they are not recognized. For example, when personal computers and many other sorts of home electronics became readily available, their disposable was never on the radar screen of most analysts, regardless of the evaluation method they employed. Nonetheless, a LCA would have identified this as an environmental problem that only now is being addressed.[10] Thus, the EU has passed legislation requiring that automobiles must be made of environmentally friendly materials that are either entirely recyclable or capable of completely deteriorating and becoming benign to the environment.

However, LCA might fail to estimate the real value of externalities when dealing with non-uniform pollutants. LCA sums emissions independently in the place where there are released. This works fine with greenhouse gases like $CO_2$, because the marginal damage of 1 ton of $CO_2$ emissions is the same regardless of where it has been released. But for pollutants such as $SO_2$, $NO_x$, lead and particulates, the marginal damage from pollution is highly dependent on location. For instance, 1 ton of lead released in the center of a city results in greater damage to the society than 1 ton of lead released in a sparsely populated area. Since LCA gives the same value to emissions regardless the place they are released, it could provide misleading information when non-uniform pollutants are released in different locations.

*Cumulative effects analysis*

Economists have long considered the problem of cumulative effects in an

[10] Many discarded electronic products end up in China, because the Chinese government is willing to receive these wastes for a fee. This does not solve the environmental problem, but only shifts it from one jurisdiction to another.

externality context. For example, many municipalities have waste treatment plants that have a limited capacity. Efficient pricing requires that residents pay the marginal cost of waste treatment, and this is usually done. However, as more residents are connected to the system, the capacity is eventually exceeded. The dilemma for efficient pricing is that, since it is the last person/firm that is added to the system, that marginal individual or firm should pay the entire cost of building the new plant. This would be blatantly unfair. But how then does a new treatment plant with greater capacity get funded? One way is to charge a system development fee whenever a new residence or building is connected to the system, in the eventuality that the plant's capacity is exceeded.

The forgoing case is reasonably straightforward to analyze because measurement of cumulative effects is possible (although municipalities often fail to implement system development charges). From the perspective of energy development projects and environmental impacts, cumulative effects analysis seeks to measure the point at which the 'stream of wastes' or environmental damage becomes sufficiently great that investments in conservation and environmental improvements is warranted. Determining cumulative effects is beneficial (and can inform a cost-benefit analysis), but a cumulative effects analysis cannot say anything about policy design.

**Extreme Events and Irreversibility**

There are three means for addressing extreme events and the possibility of irreversibility resulting from a decision either 'to do something' or 'not to do something'.

(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 cost-benefit framework of analysis. If the probability of the event, its cost or some combination of the two is sufficiently high, the expected cost may be sufficiently great that avoiding the extreme event or irreversibility will be the optimal decision. In other cases, the cost will be small and the cost-benefit criterion will indicate 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.[11] This is a consistent approach (as argued below).

(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. Begin by ignoring the probability of the occurrence of any event 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 very small 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 large loss simply because the alternative is a project (which might be to do nothing) with extremely low probability of a loss that might only be slightly greater.

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 beyond routine tradeoffs, although the SMS 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.

[11] 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.

(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”.[12] While the EU 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) demonstrate the logical inconsistency of the precautionary principle. For example, a decision based on the precautionary 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 mining coal, and emissions of $CO_2$ that contribute to climate change. “Taken seriously, [the precautionary principle] can be paralyzing, providing no direction at all. In contrast, balancing costs against benefits can offer the foundation of a principled approach for making difficult decisions” (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 only when the costs of avoiding irreversibility are tolerable. In the case of the precautionary principle, no other criteria are employed unless there is no risk whatsoever of damage to human health or the environment. The chances of that in the case of energy projects is small – wind turbines endanger birds, fossil fuels lead to global warming, hydro dams endanger fish, biomass energy encourages destruction of wildlife habitat because marginal lands are brought into crop production, there is a risk of nuclear meltdown if nuclear energy is used, and so on.

Again, the proper way for dealing with extreme events and irreversibility is to estimate all of the costs and benefits of a project, taking into account all possible spillovers. Risks and people’s perceptions of risk, and expert judgments of health and environmental risks and the ranges of costs associated with spillovers, can be employed

[12] Statement adopted by 32 individuals at the Wingspread Conference, Racine, Wisconsin, 23-25 January 1998. Viewed April 7, 2011 at: <http://www.gdrc.org/u-gov/precaution-3.html>.

in Monte Carlo simulation to determine the probability that an energy 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’.

## CHAPTER 3. DISCOUNTING AND CHOICE OF DISCOUNT RATE

Because costs are incurred and benefits accrue at different points in time, cost-benefit analysis relies on discounting monetary 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 years or a thousand years from now. Clearly, it would be foolish to spend money today so as to obtain a benefit in one thousand years or even two hundred years from now. Discounting is required so that rational decisions can be made concerning how society spends and invests 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. The discount rate weights future costs and benefits. 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 into 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 evaluating 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).

**How to Discount the Future when Considering Future Generations**

A particular controversy about the discount rate relates to how different generations are weighted – how much importance we attach to the wellbeing of future generations compared to the current one. 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 today's investments that could lock them into a technology that is inappropriate to their circumstances. 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 the time horizon increases. This is referred to as 'hyperbolic discounting' in contrast to exponential discounting that uses a constant rate of discount (see Weitzman 1998, 1999; Dasgupta 2002). 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. This criterion is used 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 one or two percent – 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 $\beta$ 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

$$(3.1) \quad \int_0^\infty U(C(t))e^{-\beta t}dt \,,$$

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):

(3.2) $r = \beta + \varepsilon(t)\, C'(t)$.

In equation (2.2), $\varepsilon(t) = -C(t)U''/U' > 0$ 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 equation (2.2) is a 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.

**What Discount Rate?**

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 a real discount rate.

It also makes sense as a principle for choosing a discount rate to focus on consumption. Then, the consequences of a government program or 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, 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 that might be considered a safe haven during times of financial crisis (Prasad 2014).

Second, 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. In the latter case, borrowed funds 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 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% (= 0.40×10% + 0.60×4%). The main difficulty in deriving the opportunity cost rate is that it is not easy to determine where the *marginal* funds originate. Further, not all government revenues come from income taxes and/or domestic borrowing, as governments earn income through charges, tariffs on imported goods, and so on.

Finally, ethical issues arise when one discounts across generations – it is ethically indefensible to discount the utility (as opposed to consumption) of future generations. As future generations have always been richer, a zero discount rate on the utility of future people does not imply that their consumption cannot be discounted, because the marginal utility of an increase in their consumption is lower than that of current generations.

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. Further, 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 really face such a 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 1). 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".

**Table 1: Value Today of $100 Received in 200 and 400 Years: Comparison of Constant vs. Random Walk Discounting, Selected Discount Rates**

| Discount Rate | Constant discounting | | Nonmean-reverting random walk | |
|---|---|---|---|---|
| | 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).

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.

## Further Issues Related to Discounting

### *Zero discount rate*

Based on the above arguments, one might think that a zero (or very near zero) discount rate might be appropriate for any project that involves intergenerational transfers of resources. This argument is often used in the context of climate change to justify large current investments in mitigation because these are costly to begin with (high up-front costs), but provide high benefits far into the future. If rates of return in the private sector are high, then an optimal strategy might be for the government not to incur costs today but, rather, invest funds earmarked for mitigation and invest them in the private sector. The future returns from such investment could then be used to compensate those adversely impacted by climate change and/or to subsidize adaptation to climate change. This is just as true for other government programs or projects that are aimed at future generations. Thus, the use of an arbitrarily low or even zero rate of discount is not the panacea for justifying high current expenditures. Indeed, a proper accounting of opportunity costs (what else can be done with the funds?) might lead to a different conclusion.

### *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 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 tC 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/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. If damages rise slower than atmospheric $CO_2$, a positive discount rate on physical carbon is appropriate. A zero discount rate on physical carbon implies that marginal damages of atmospheric $CO_2$ are increasing over time at exactly the 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 (see van Kooten et al. 2014 for an application).

*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 about the outcome.

There are ways to account for risk in investment projects. A commonly applied method is the use of risk-adjusted discount rates 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:

(3.3) $r_i = r_f + \beta(r_m - r_f)$,

where $r_i$ is the required return for risky asset $i$, $r_f$ is the risk-free rate of return (say, the rate on Treasury bills), $r_m$ is the market rate of return, and $\beta$ measures the investment's contribution to risk relative to the market. Returns are assumed to be normally distributed, so $\beta$ is estimated as the ratio of the covariance of the asset and market returns to the variance of the market return:

(3.4) $\beta = \frac{\text{cov}(r_i, r_m)}{\text{var}(r_m)}$.

βs 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 an electric generating 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.

# CHAPTER 4. EXTERNALITIES AND NON-MARKET VALUATION

Indirect costs and benefits occur when projects have 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 loss 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.[13] Choice-based models employ information about a related activity (as opposed to

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[13] 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.

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 not directly related to other goods and services (or is separable) in individuals' utility functions. 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 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.

**Cost Function Approach**

The cost function approach to the measurement of environmental values relies on the estimation of a relationship between output of some market traded commodity and the level of the environmental amenity. For example, the output of an energy crop, such as corn for ethanol or switchgrass 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 per unit price of the energy crop, it is possible to estimate the costs that different levels of soil salinity impose. If salinity is related to certain land use practices then 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 Figure 4.1. 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 $y_2$ 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 Chapter 7, we attempt to replace soil depth with temperature and crop yield with a variety of goods or services that are traded in markets.

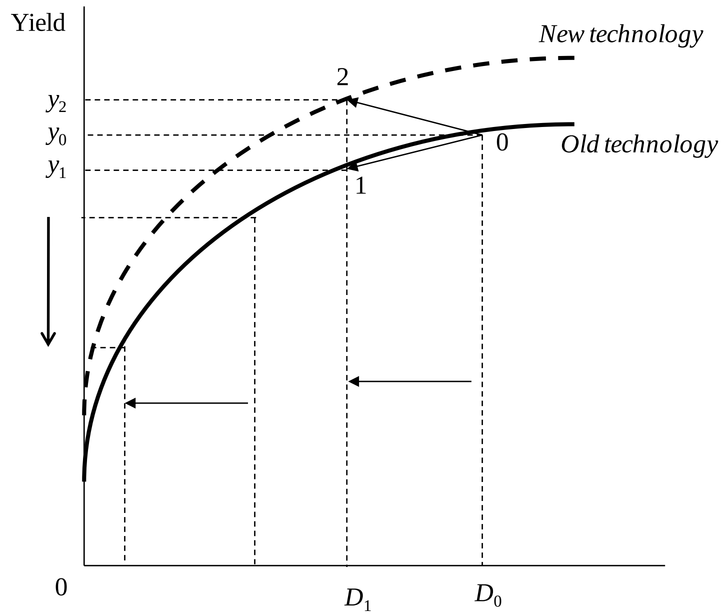


*Figure 4.1: Damage Function between Soil Depth and Crop Yield*

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.

## Expenditure Function

*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:

- Do environmental variables systematically affect land prices?
- Is knowledge of this relationship sufficient to predict changes in land prices from changes in air pollution levels, say?
- 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 to 2.0% lower, while traffic noise reduced house prices by 0.1-0.7% per decibel (Lesser et al. 1997, p.281).

*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

- individuals are observed to incur costs so as to consume commodities related to the environmental amenity of interest, and
- 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.

**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 (Figure 2.5), which relate to the unpriced benefits that environmental amenities provide in the production or consumption of some other good or service. For instance, a forest provides ecosystem services 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 values, 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 Figure 2.5). 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.

*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.[14]

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 Figure 4.2(a), 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.

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

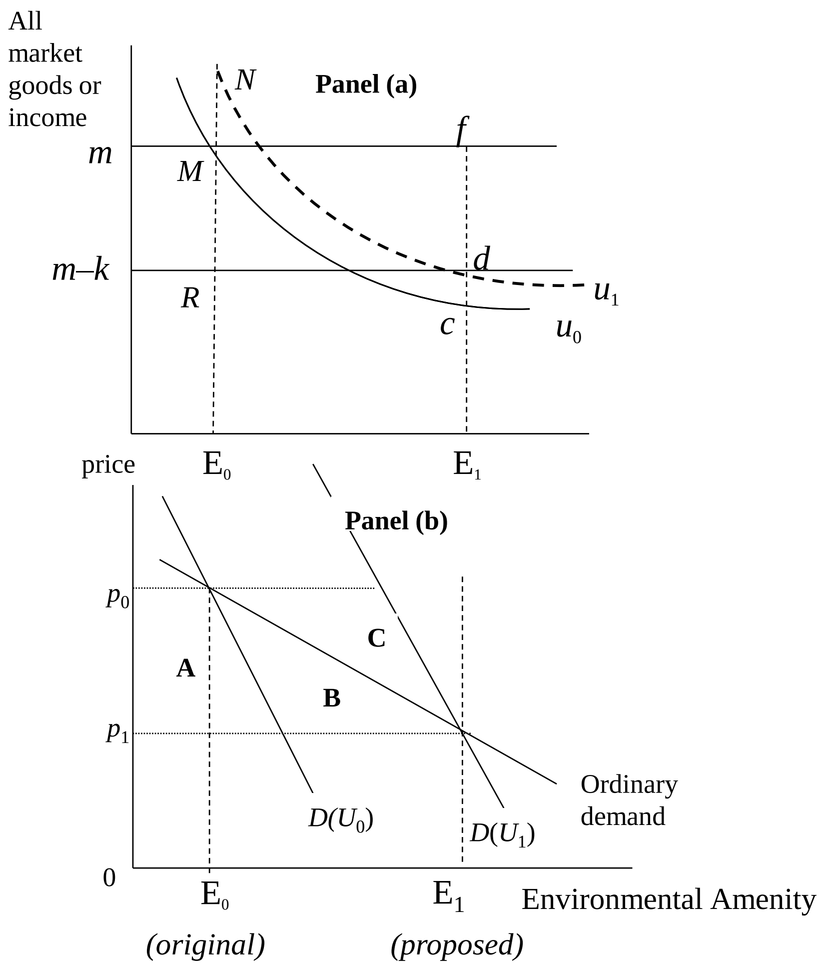


*Figure 4.2: Willingness to Pay and Willingness to Accept Compensation (Compensation Demanded) as Surplus Measures*

Despite the fact that environmental amenities are not traded in a market, we draw three demand curves in Figure 4.2(b). 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 Figure 4.2. 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 Figure 4.2(b) 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).[15]

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.

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[15] We could just as well examine the case where the 'original' level of the environmental amenity in Figure 8 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.

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. 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.

*Choice Experiments/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 (from the value of the one 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 also argued that choice experiments 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 (see Shaikh, Sun and van Kooten 2007).

Another advantage of CE over CVM 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 WTP and WTA compensation.

CE differs from conjoint analysis because, with the latter, respondents are asked 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 to apply this technique to the valuation of non-market commodities in ways different from CE continue (Smith 1997).

*Constructed Preferences/Stakeholder Method*

Gregory et al. (1993) propose a multiple attribute, utility-theory contingent valuation, or MAUT–CV, approach to address the inability of respondents in standard CVM to make holistic assessments about environmental resources. Individuals do not know the value of the resources they are asked to value, but "are constructing them, with whatever help or clues the circumstances provide" (p.181). Thus, rather than attempting to uncover environmental values, Gregory et al. (1993) argue that the analyst's task is to help individuals discover those values by helping them work towards "a defensible expression of value" (p.179). In essence, their approach is to work with stakeholder groups of less than 100 people, having them develop comprehensive, hierarchical attribute trees and then having them rank attributes on a 0 to 100 scale.

The MAUT–CV method also has the advantage that it is able to address uncertainty as components with probabilities can be built into the model, so that the final calculation is an expected value. It is unlikely that it can address disparity between WTP and WTA (between the value placed on gains versus that on losses) as the results are path dependent, varying by the 'path' used to help people discover their 'values'. Since the approach is designed primarily to enable groups of stakeholders come to a decision about a preferred course of action, as opposed to seeking to estimate a measure of well being (or surplus measure), it provides little in the way of useful information for social CBA, but does provide information about how a group of disparate stakeholders would rank projects/programs/policies.

*Fuzzy and ad hoc Methods for Determining Non-Market Values*

Given the difficulty that people have in valuing environmental amenities or public goods like wildlife, several researchers have employed a number of ad hoc methods for incorporating such difficulty or uncertainty into the valuation process (see Shaikh et al. 2007 for a review and comparison). As a consequence, some have suggested that verbal language be used in the CVM framework (Evans et al. 2003). Conversion of verbally-relayed preferences to monetary value is difficult and can, in our view, only be done using fuzzy set theory. Research along these lines has made some progress (van Kooten et al. 2002; Sun and van Kooten 2009), but no one has yet employed only verbal language to derive values for non-market amenities. The fuzzy methods used to date have found values similar to those found by approaches more solidly grounded in economic theory rather than the ad hoc alternatives. However, there remains the feeling that, while a fuzzy method can lead to the mitigation of many of the problems encountered with CVM, the link between economic theory and the values derived using the fuzzy approach is too weak for such values to be taken seriously.

*Concluding discussion*

The use of surveys to obtain information about environmental and other non-market values remains controversial. In his book, the *New Holy Wars: Economic Religion Versus Environmental Religion in Contemporary America*, Robert Nelson (2010) argues that, by developing the contingent valuation method and other approaches to non-market valuation, economists were able to avoid becoming irrelevant in debates about the environment, and indeed usurp the upper ground from biologists and other environmental scientists. Indeed, some ecologists have even adopted non-market values to make the case that the world's ecosystems are so valuable that they should be protected regardless of the cost (Costanza et al. 1997, 2014). Unfortunately, the authors confuse total and marginal benefits (as discussed in Chapter 2), and fail to realize that there are income constraints that prevent stated benefits from exceeding GDP.

In their latest study, Costanza et al. (2014) estimated that, in 2011, the globe's ecosystems provided services valued at between $125 trillion and $145 trillion (measured in 2007 U.S. dollars). In 2007, all of the economies in the world produced goods and services (a gross domestic product or GDP) worth $56.7 trillion, which had increased to $74.9 trillion in 2013 (measured in nominal U.S. dollars). Incredibly, these authors estimate that the value of the ecosystem services exceeded the value of all the goods and services produced globally. This is similar to arguing that the value of the labor used to produce something is greater than the thing produced, which is impossible!

Suppose instead that the Earth's ecosystems also provided goods and services that were not traded in markets. Given that the estimated value of the ecosystems is more than double the value of global GDP, it is clear that the income constraint of those indicating a willingness to pay for these unpriced services, or even their compensation demanded, would violate the global budget constraint. In other words, the estimates provided by Costanza et al. (2014) are completely meaningless. Their study might best be likened to an attempt to value the Earth's atmosphere: What is the benefit of the atmosphere? That is, what would be the cost (foregone benefit) of removing the Earth's atmosphere?

Finally, there is a problem with the use of surveys. Regardless of how well a survey is structured, respondents are required to value a contingency. The Noble Laureate Daniel Kahneman (2011) distinguishes between two systems that determine the way we think. System 1 is fast, intuitive and emotional, while system 2 is slow, deliberate and logical. System 1 dominates because we tend to be lazy and avoid engaging system 2 to the largest extent possible. In responding to the types of surveys economists use to elicit monetary values for ecosystem services, protection of wildlife, et cetera, respondents will rarely if ever engage their system 2. Research shows, for example, that respondents are then easily 'primed' – their response to any hypothetical question is determined by what engaged them previously. Researchers can easily prime respondents to give answers that favour what the researcher desires, but respondents can also be primed to give answers that will differ significantly from one occasion to another (pp.52-55). In each case, the values elicited are not helpful and certainly not representative of the true value of the non-traded goods or services in question.[16]

Can questionnaires be structured to provide the real value that people place on ecosystem services and the environment? Some economists argue that the state of the art has reached a point where, with adequate pre-testing, surveys can obtain reasonable monetary estimates of non-market goods and/or services. However, Kahneman (2011), McFadden and Leonard (1993) and others are sceptical, arguing that, despite many efforts, proponents on non-market surveys have not been able to overcome problems associated with priming, anchoring, framing and other problems, most notably the 'endowment effect' (Knetsch 2000; Kahneman and Tversky 1979, 1984). The endowment effect implies that people value something more when they own it than if they have to purchase it; thus, in the jargon of economics, there is a discontinuity in the indifference curve at the endowment. This violates the underlying theory of cost-benefit

[16] In addition to priming, Kahneman (2011) identifies anchoring (pp.126-127), joint versus single valuation (p.359) and framing (pp.366-369) as problems.

analysis, leading economists to conclude that nonmarket valuation methods are at odds with neoclassical economic theory and cost-benefit analysis (Hausman 2012).

**Benefit Transfer**[17]

Use of non-market valuation techniques to obtain surplus data for use in social cost-benefit analysis can be quite expensive and time consuming. The decision maker needs to determine whether the expense is warranted. A 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. The drawback is that values are not precise, although, in many instances, simple knowledge of a range of values is sufficient to take 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.

While debate over existing techniques for monetary valuation continues, the search for new and simpler approaches remains. Benefit transfer methods are still fairly new and this is an area of research that continues to develop.[18] Benefit or value transfer involves 'borrowing' monetary environmental values estimated at one site (the study site) and applying them to another (the policy site). The attraction of benefit transfer is that it avoids the cost of conducting 'primary' studies whereby the benefits of natural or environmental assets or the damages associated with degradation are measured with one or more of the techniques described above.

There are two main approaches to benefit transfer – unit value transfer and function transfer. Unit value transfer is the easiest as one simply transfers the environmental values from a study at one site to the policy site. The valuation estimates may be left

[17] This section is largely based on van der Heide et al. (2010)
[18] For example, a special issue of *Ecological Economics* examined the state-of-the-art and science of benefit transfer (Wilson and Hoehn 2006).

unadjusted or may be adjusted in some way. Although transferring unadjusted estimates is undesirable, since the values experienced at the study site may not be the same as those at the policy site, it is a widely practised approach (OECD 2001). For example, in her study of the value of natural capital in settled regions of Canada, Olewiler (2004) transferred environmental values from a variety of sources and jurisdictions as an approximation of the value of natural capital.

A more sophisticated approach is to transfer the entire benefit function. In this case, instead of transferring only the benefit estimates, the researcher transfers an estimated benefit function, substituting information about the independent variables at the policy site into the regression equation.

Meta analyses can also be used to adapt direct values and even value functions from multiple studies so they can be used at the policy site. Meta-regression analysis can be used to take the results from a number of studies, synthesise research findings and analyse them in such a way that the variations in unit values or value functions found in those studies can be explained (Navrud 2001; Dalhuisen et al. 2003; van Kooten et al. 2009).

The advantage of benefit transfer is that it is both pragmatic and cost-effective and, therefore, the method is an attractive alternative to expensive and time consuming original research. Benefit transfer enables the analyst to quickly inform decision makers about the environmental costs or benefits of projects and policies (Garrod and Willis 1999). In some policy contexts, however, the benefit transfer method remains controversial. The major reason for this relates to the accuracy of transferred estimates as validity tests show that the uncertainty could be quite large, both spatially and inter-temporally. This is especially the case for complex goods, such as biodiversity related to agricultural and landscape values. Nonetheless, the benefit transfer approach is recognized as a valid technique for valuation of agricultural and forest ecosystem biodiversity, but only if the circumstances at the study site are ‘close’ to those at the policy site, which is often unlikely. This does not necessarily imply that the application of benefit transfer should be restricted to use within the same region. There are many issues that must be addressed when conducting benefit transfers between different regions, and even between countries (which is controversial), especially as these concern landscapr3e values (Navrud and Ready 2007).

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.[19] An example of the types of values available is provided for the case of wetland services in Table 2.

**Table 2: 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: http://dare.colostate.edu/tools/benefittransfer.aspx

[19] Information about the Colorado State University benefit transfer project and a toolkit can be found at: http://dare.colostate.edu/tools/benefittransfer.aspx (viewed 12 February 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 12 February 2011).

# CHAPTER 5. WELFARE ANALYSIS AND INTERNATIONAL TRADE

Economic theory can fruitfully be applied to the problems of trade in agriculture and forestry. In this chapter, therefore, a qualitative assessment of the impact of government policies regarding trade in agricultural and forestry products is provided. Applied welfare analysis is used to identify and measure the economic costs and benefits of projects and/or public policies, as well as the income changes that government projects or policies bring about – the income (re)distributional effects (Just et al. 2004). Because of the richness of the various agricultural policies that have been implemented by the United States, the European Union and other countries over nearly a half-century of intervention (single-desk selling, non-recourse loans, target prices, quotas, payments-in-kind, etc.), the agricultural literature offers an excellent place to look for insights into policy (see Schmitz et al. 2010). Quantitative assessments of various policies depend on the development of an appropriate theoretical framework for conducting the analysis. In this chapter, such a framework is developed and some examples of how this approach can be used to analyze trade policies are provided.

## Spatial Price Equilibrium Trade Modelling

Trade in any product can be analyzed using a spatial price equilibrium (SPE) model of international trade. Because this is a partial equilibrium model, changes in countries' policies regarding the commodity in question will affect only the prices of that product, but have very little impact on relative prices elsewhere in the global economy. Spatial price equilibrium models are partial equilibrium trade models that assume any differences in prices between regions are the result of shipping and handling (transaction) costs, which include costs associated with transporting goods (e.g., freight, insurance, exchange rate conversion fees), plus tariffs and other non-tariff barriers. Thus, in the absence of trade barriers and transaction costs, prices would be the same in every region as a result of spatial arbitrage. That is, it is assumed that the law of one price (LOP) holds (Vercammen 2011, Chapter 2).

The development of a spatial price-equilibrium trade model for durum wheat is explained with the aid of Figures 5.1 and 5.2. Canada is a major producer and exporter of durum wheat, which is a high-protein content wheat used in the production of pasta. For the five-year period 2006-2010, Canada accounted for 11% of world durum production and 47% of global exports, so changes in Canadian exports will impact world prices. The derivation of the excess demand (ED) and excess supply (ES) functions for durum for any given region is illustrated in Figure 5.1. In the absence of trade (also referred to as autarky), domestic consumption, production and price of durum are determined by the intersection of the domestic demand (D) and supply (S) schedules. In the figure, the autarkic equilibrium quantity and price are $Q^*$ and $P^*$, respectively. A country will generally engage in trade if the world price of durum is greater or less than the domestic price (ignoring shipping and handling costs). If the world price is higher than the domestic price, the country will export durum (as is the case for Canada); if the world price is lower, it will import the good even if it produces more than the amount produced in the exporting country. How much will it supply or how much it will demand?

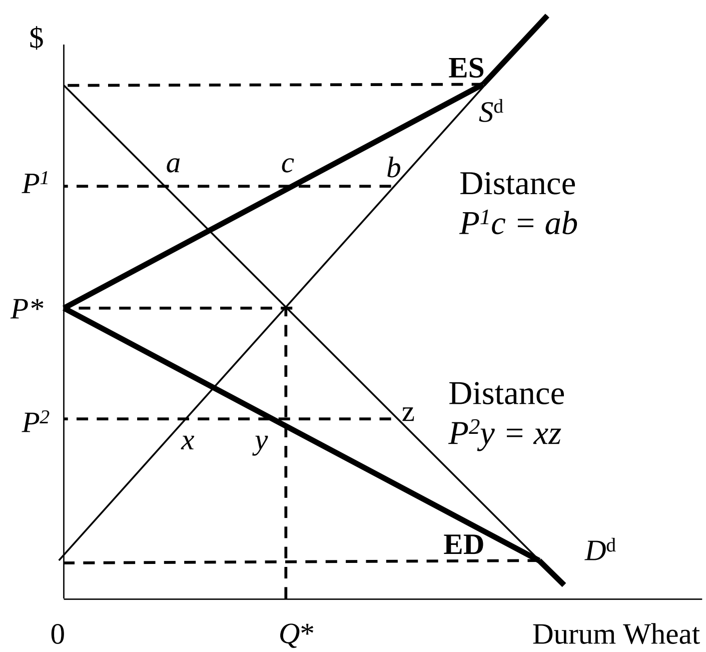


*Figure 5.1: Determining excess supply and excess demand for durum wheat*

Suppose that the world price, or what firms in the country can get by selling abroad (after shipping and handling costs), is $P^1$ (Figure 5.1). The amount the country will supply to the world market is equal to the difference between what domestic producers are willing to supply at $P^1$ (given by point *b* on the domestic supply curve $S^d$) and what domestic consumers will buy at that price (point *a* on $D^d$). The difference between what producers are willing to supply and what domestic consumers are willing to buy at each price above $P^*$ constitutes excess supply, with the ES function tracing out this excess supply at various prices. Thus, ES at $P^1$ (= distance $P^1c$) equals distance *ab*. Likewise, if world price is below $P^*$, it is the difference between what consumers are willing to buy and what producers are willing to sell that constitutes excess demand; it is these differences at various prices that trace out the ED schedule. At $P^2$, ED = $xz$ = $P^2y$. Both ES and ED are shown in Figure 5.1.

The ES and ED schedules can be derived mathematically. Suppose the (inverse) demand and supply curves in Figure 5.1 are linear:

(5.1) $P^D = \alpha - \beta q, \quad \alpha, \beta \geq 0$, and

(5.2) $P^S = a + bq, \quad a, b \geq 0.$

The excess demand and supply curves in the figure are then given by:

(5.3) $\text{ED} = \gamma - \delta q, \quad \text{with } \gamma = \frac{a\beta + b\alpha}{\beta + b} \geq 0 \text{ and } \delta = \frac{b\beta}{\beta + b} \geq 0.$

(5.4) $\text{ES} = \gamma + mq, \quad \text{with } \gamma = \frac{a\beta + b\alpha}{\beta + b} \geq 0 \text{ and } m = \frac{b\beta}{\beta + b} \geq 0.$

Notice that $\gamma$ (=$P^*$) is the equilibrium domestic price, so that, in the absence of shipping and handling (and other transaction) costs, the excess supply and demand curves start at the same point on the vertical (price) axis. Further, the absolute slopes of the ED and ES curves are identical (although ED slopes down and ES slopes up).

Now consider durum trade between Canada and the Rest of the World (ROW). The problem with this simplification is that Canada exports durum to a wide variety of countries, so a trade model should really take into account bilateral trade among various countries or regions, such as Canada and China, the U.S. and Indonesia, the EU and Africa, Argentina and China, and so on. There is also market fragmentation so that some countries in the EU might export durum wheat outside the EU (say France to China), while others import durum (say from Russia or Ukraine). Nonetheless, the Canada-ROW example offers an excellent way to illustrate how spatial, price-equilibrium trade models can be used to analyze policy. Further, the principles used in the case of two trading partners can be extended to include multiple countries engaging in bilateral wheat trade, although a numerical trade model is generally required in that case (see Paris et al. 2011; van Kooten and Johnston 2014).

A spatial price equilibrium durum wheat trade model for Canada and the rest of the world is illustrated in Figure 5.2. In the figure, the domestic demand functions for durum in Canada and the ROW are given by $D_{\mathrm{C}}$ and $D_{\mathrm{R}}$, respectively, while respective supply functions are given by $S_{\mathrm{C}}$ and $S_{\mathrm{R}}$. Under autarky (no trade), an amount $q_c^*$ of durum wheat will be consumed in Canada at a domestic price of $P_{\mathrm{c}}$ in panel (a); in the ROW, autarkic consumption will be $q_R^*$ at a price $P_{\mathrm{R}}$ in panel (c). Note that for trade to take place the difference between the autarkic prices must exceed the cost of transporting the good from one market to another (i.e., $P_{\mathrm{R}} > P_{\mathrm{c}} + t$, where $t$ refers to the shipping and handling cost). The wellbeing of citizens in each country is determined by the sum of the benefits they receive as consumers (consumer surplus) and as producers (producer surplus). As demonstrated by Just et al. (2004), economic wellbeing or welfare is always determined as the sum of surpluses (e.g., net revenues rather than gross sales).[20] In the absence of trade, the consumer surplus associated with durum production is given by area $a+b+c$ in Figure 5.2(a) for Canada and area $\alpha$ in Figure 5.2(c) for the ROW. The producer surplus is measured, in the absence of trade, by area $e+d$ for Canada and by area $\beta+\gamma$ for the ROW. Total welfare is the sum of producer and consumer surpluses, and is simply given by the area between the demand and supply curves. For Canada, total

[20] According to economic theory, the area between the demand and supply functions up to the point where they intersect provides the greatest welfare; further, perfect competition will always lead to the maximization of welfare because the perfectly-competitive equilibrium occurs where demand intersects supply from above (see Harberger 1971, 1972).

surplus in the absence of trade is given by area *a*+*b*+*c*+*d*+*e*, while it is area α+β+γ for the rest of the world.

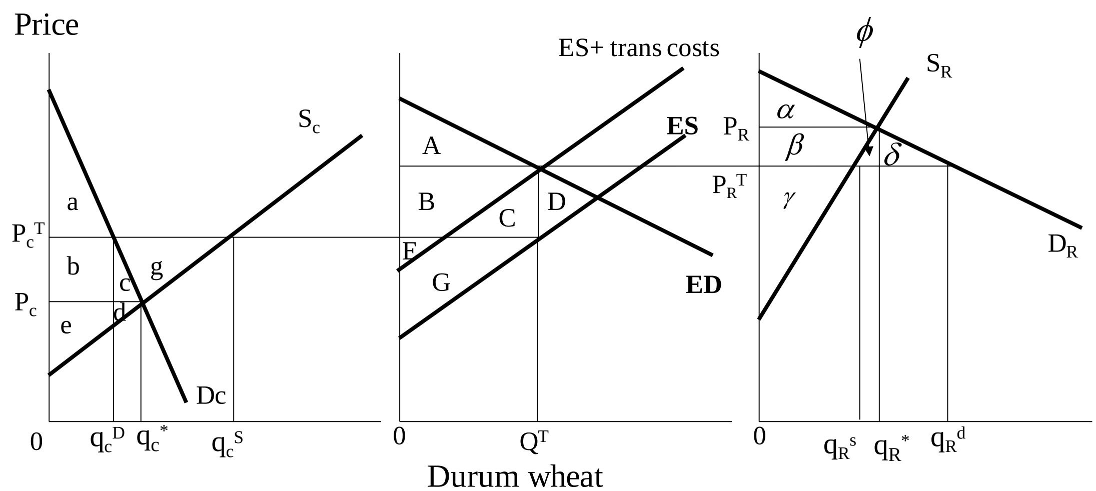


*Figure 5.2: Model of international trade in durum wheat*

**Unrestricted Free Trade**

To demonstrate that trade improves the welfare of citizens in each country, it is necessary to show that total surplus in each country increases. This is done using Figure 5.2. Since in the absence of trade the price in the ROW is greater than that in Canada, durum wheat will flow from Canada to the ROW as long as the difference in price between the two regions exceeds the transportation/transaction costs.

With trade, the price in Canada rises from $P_c$ to $P_c^T$, while ROW price falls from $P_R$ to $P_R^T$. Canadian durum processors (consumers of durum wheat) lose as a result of the price increase, processing less durum; consumption in Canada falls from $q_c^*$ to $q_c^D$ and consumer surplus falls from area *a*+*b*+*c* to only area *a*. However, Canadian farmers face a higher price ($P_c^T > P_c$ in panel (a)), causing them to increase production from $q_c^*$ to $q_c^S$. An amount $q_c^S - q_c^D$ (=$Q^T$) is sold to the ROW, while producer surplus increases from *d*+*e* to *b*+*c*+*d*+*e*+*g*. The wellbeing of Canadians as a whole increases by area *g*, with durum farmers the main beneficiaries from trade.

The situation in the ROW mirrors that of Canada. The fall in ROW prices causes the food industry (consumers) to purchase more wheat (from $q_R^*$ to $q_R^D$) and increase their overall surplus by an amount given by $\beta+\phi+\delta$. Durum wheat growers in the ROW now face a lower price and curtail output to $q_R^S$, giving up a producer surplus of $\beta$ in the process. However, the gain to consumers is greater than $\beta$, with the net gain to citizens in other countries given by $\phi+\delta$.

The main results can be summarized in the international market of Figure 5.2(b). The amount traded between Canada and the ROW is $Q^T = q_c^S - q_c^D = q_R^D - q_R^S$. The net gain to the ROW is area *A*, which is equal to area $\phi+\delta$ in panel (c); this net gain accrues to ROW consumers and therefore is measured under the excess demand curve ED. The gain to Canada equals the area above the excess supply curve ES below the demand price, or area *B*+*C*+*E*+*G*, but shipping and handling costs of *B*+*C* are incurred. Hence, the net gain from trade is *E*+*G*, which is equal to area *g* in panel (a). Note that both Canada and the rest of the world are better off with trade in durum wheat than without trade.

For the purposes of analyzing policy, a back-to-back representation of the trade model in the previous figure (Figure 5.2) can also be used. This is done in Figure 5.3, where $q_c$* and $q_R$* again refer to the autarkic quantities in Canada and the rest of the world, respectively, while $P_c$* and $P_R$* are the associated autarkic prices. Canada's excess supply curve can be represented in the ROW diagram (right-side panel in Fig 5.3). With trade in this case, the ES adjusted for shipping and handling costs of \$*t* per unit of lumber (ES+*t*) is added horizontally to the domestic ROW supply to find the relevant total market supply $S^T$ in the ROW market. The market clearing price in the ROW market is then $P_R^T$, while the price in Canada is $P_c^T$ ($=P_R^T-t$). Canada exports $Q_c^E$ ($=q_c^S-q_c^D$) amount of lumber to the ROW.

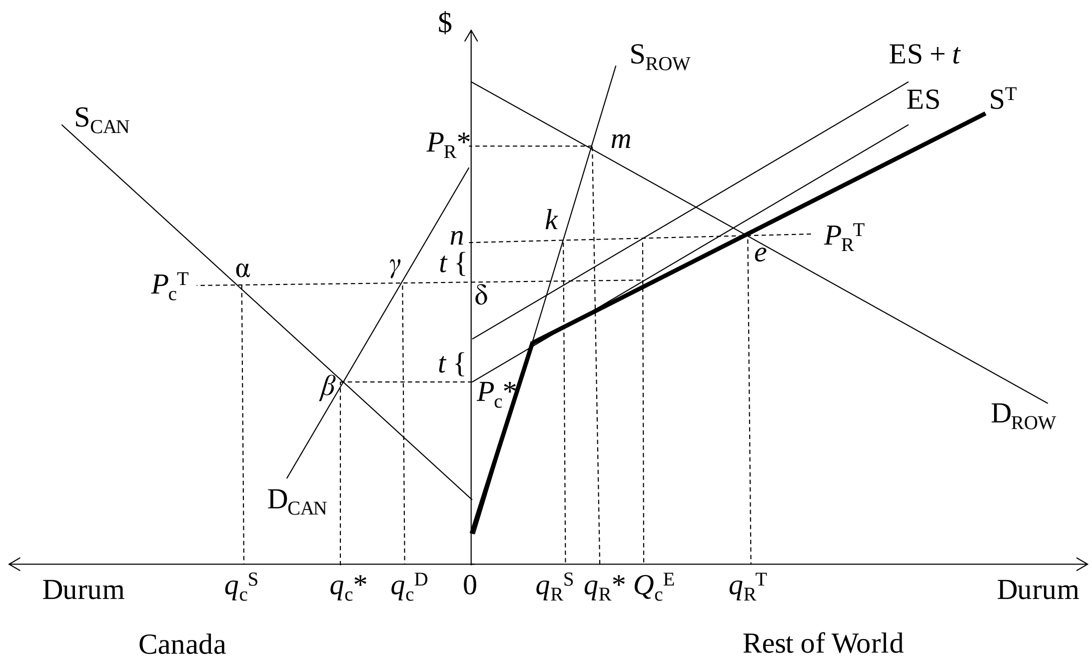


*Figure 5.3: Back-to-back representation of the durum wheat trade model*

The gains from trade and the gainers and losers in each of the two regions can be readily identified. In Canada, consumers lose a surplus equal to the area bounded by $P_c^* \delta \gamma \beta$ in the left panel of Figure 5.3, while durum farmers gain a surplus given by area $P_c^* \delta \alpha \beta$; the net welfare gain to Canada thus equals area $\beta \alpha \gamma$. There are gainers and losers in the rest of the world as well. The losers in this case are foreign wheat farmers whose producer surplus falls by the area bounded by points $P_R^* nkm$; durum consumers gain the surplus area bounded by $P_R^* men$. Summing the loss in producer surplus and the gain in consumer surplus leads to an overall gain in welfare in the ROW equal to the area bounded by *mke*. The global increase in welfare from trade in lumber is given by the area bounded by points $\beta \alpha \gamma$ in the left-side panel and the area bounded by points *mke* in the right-hand panel, minus the shipping and handling costs which equal $t \times Q_c^E$. The overall gain must, however, be positive because trade would not otherwise take place.

The approach in Figure 5.3 is somewhat richer than that in Figure 5.2, and it is usually used to analyze policies affecting trade, particularly in agriculture and forestry (e.g., Just et al., 2004; Schmitz et al. 2010). We use a similar diagrammatical analysis to investigate the (qualitative) impacts of various restrictions that governments use to favor domestic farmers, processors, manufacturers or consumers, et cetera.

**Trade and the Measurement of Wellbeing in Multiple Markets**

In the forgoing discussion, we focused on a single-commodity trade model. Many trade models include multiple commodities. It is not always clear how welfare measurement occurs when links among commodities are either in a vertical chain or horizontally related. In conducting welfare measurement in this case, it is important that we work with equilibrium demand and supply functions that take into account how price changes in one market reverberate through related markets back to the original market (see Just et al. 1982, pp.177-199).

In this section, we employ equilibrium demand and supply functions to examine the measures needed to analyze policy in an international context. In doing so, we distinguish between net welfare changes and changes in welfare surpluses that are considered to be income transfers. Net welfare changes are calculated along the lines discussed in Chapter 2, equation (2.1), following Boadway and Bruce (1984, p.254); that is, the direct costs measured in the market immediately impacted by the policy plus the indirect costs in all affected markets where price exceeds marginal cost.

*Vertical Chains*

Consider the case of the vertical chain provided in Figure 5.4, where wheat and flour markets are vertically integrated. It is assumed that the supply functions in the upstream *n*-1 markets that supply wheat producers (e.g., fuel, fertilizer, seed, tractor services, labor) are horizontal or perfectly elastic ($\varepsilon_S=\infty$); likewise, it is assumed that the demands for the downstream markets for bread and pasta (the n+1 market) are perfectly elastic ($\varepsilon_D=\infty$). These two assumptions imply that changes in the demand for inputs into wheat production do not affect the prices (denoted $r_{n-1}$) of inputs, or that changes in the supply of flour affect the prices (denoted $P_{n+1}$) of downstream bread and pasta. These are realistic assumptions since, for example, the cost of flour in the production of bread is a very small portion of the total cost of producing bread. Given these assumptions, the consumer surplus in the wheat market can be measured by the producer surplus in the flour market.

Now consider the change in consumer surplus in the upstream wheat market in panel (b). As a result of the government policy that reduced the production of flour from $F^0$ to $F^1$ in panel (c), derived demand for wheat shifts downward from $D_{wheat}(P^0)$ to $D_{wheat}(P^1)$. Due to this lower demand for wheat, the price falls from $r^0$ to $r^1$, causing a change in consumer surplus equal to (*u*–*v*) – surplus *u* is lost because of the inward shift of the demand function but *v* is gained because of the lower price. Since it is assumed that all wheat is used to produce flour, the change in consumer surplus in the wheat market is equal to the change in quasi-rent in the downstream flour market. Thus, the change in consumer surplus in the wheat market equals the loss (*c*+*d*) in Figure 5.4(c). Notice that the general equilibrium, competitive supply curve for flour $S^*_{flour}$ takes into consideration the effect of the new wheat price, $r^1$ , on flour supply; thus, it is not necessary to have $S^*_{flour}$ shift as a result of this price change as it is inherently incorporated through its derivation (Just et al. 1982, 2004).

There remain two additional surplus measures that need to be taken into account. First, in the wheat market (Fig 5.4b), the loss in quasi-rent to farmers is equal to area (*v*+*w*), which is equivalent to the change in consumer surplus of area *z* in the upstream market for fertilizer and feed, labor, fuel, equipment rentals, et cetera (Fig 4a). Again, this area must only be measured once, either in the wheat market or the equivalent measure in the upstream market; double counting must be avoided. In applied work, the upstream *n*-1 markets (Fig 5.4a) are not modeled, and therefore it is only the quasi-rent in the wheat market that is measured.

Finally, in the flour market (Fig 5.4c), a scarcity rent is created equal to area (*a*+c), as supply is constrained to be lower than demand as the result of policy intervention. Producers of flour may capture the scarcity rent if it were created through a quota on production, while, if it arose due to an ad valorem tax, the government captures it as tax revenue.

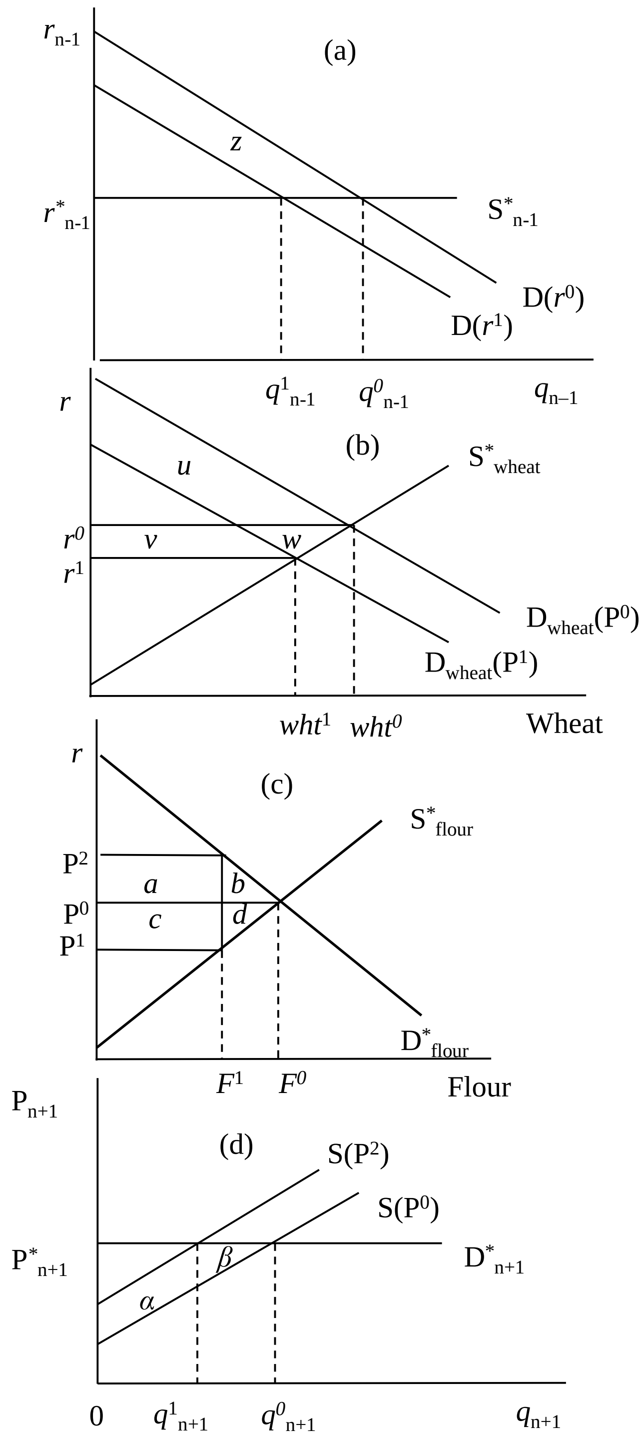


*Figure 5.4: Welfare measurement in a vertical chain*

The point of the above analysis is this: the welfare measures appropriate for a vertically integrated chain are the consumer surplus, producer surplus (quasi-rent) and scarcity rent. This result hinges on the assumption that remaining upstream and downstream markets are characterized by perfectly elastic output demand and input supply, respectively. It is also predicated on the assumption that markets for bread and pasta, which are horizontal markets to each other, are characterized as a single market and that this market is the only user of wheat. If, for example, beer producers require wheat as an input, it is then necessary to assume that the demand function for beer is also perfectly elastic. We now consider what happens if this is not the case.

*Vertical and Horizontal Chains*

Now suppose that there are other markets that compete with flour for wheat. Assume that wheat is purchased only by breweries that produce wheat beer and by mills that grind wheat into flour. The demand for wheat in this case is the sum of the separate derived demands for wheat by flour and beer producers. In essence, the demand for wheat is the horizontal sum of the value of the marginal product (VMP) of wheat in making beer and its value in producing flour. This is illustrated in Figure 5.5.

Recall again that a * denotes a general equilibrium demand or supply function, but only in a restricted sense. In Figure 5.5(b), we again assume a policy is implemented that restricts the amount of flour produced (this figure is equivalent to Figure 5.4c). The change in the price of flour will reduce the price of wheat, which in turn will increase the supply of flour; yet this feedback is not explicitly shown because it is already taken into account in the construction of the general equilibrium supply function $S^*_{flour}$. The same is true of $S^*_{beer}$; if there is an exogenous shift in supply or demand in the beer market that results in a change in its price, the price of wheat is impacted but the feedback from this price change on the supply of beer is already taken into account in the general equilibrium supply function. However, the general equilibrium supply function for beer does not take into account the feedback resulting from a lower price of wheat ($r^1 < r^0$ in Fig 5.5a) caused by the reduced production of flour. Therefore, the policy affecting the flour market will impact the beer market through changes in the price of wheat.

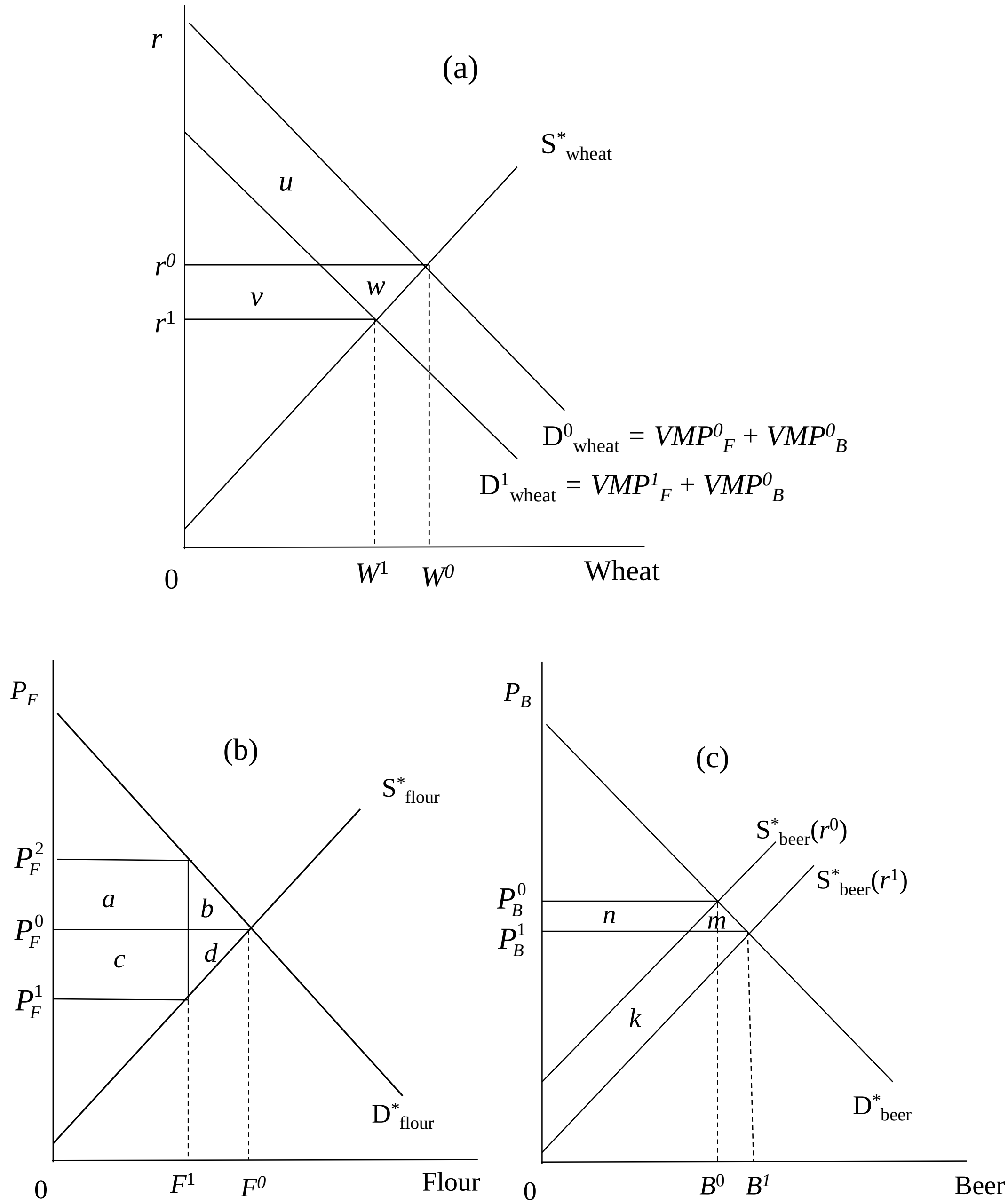


*Figure 5.5: Combining the vertical and horizontal welfare chains*

What is the welfare impact of a policy-induced increase in the demand price of flour but a reduction in the supply price? The welfare impacts on the downstream bread and other markets remains the same, as does the welfare impact in the upstream wheat market, at least as drawn. However, there is an additional welfare consideration to consider as a result of the horizontally-related beer market. Assume the beer market is also a final consumer market, so that, unlike the case of flour, there is no further downstream market to consider. The decrease in the price that producers receive for flour reduces the VMP of wheat used to produce flour (=$P_F \times MP_{wheat\ in\ flour}$) from $VMP^0_F$ to $VMP^1_F$, thus shifting the demand for wheat inwards as indicated in Figure 5.5(a). The price of wheat falls, thereby causing the supply function for beer to shift from $S^*(r^0)$ to $S^*(r^1)$. Suppliers of beer lose a producer surplus equal to area *n*, but they gain *k*, while consumers of beer benefit by area (*n*+*m*). Therefore, the net welfare change in the beer market is given by area (*k*+*m*).

What is the overall change in wellbeing? Upon applying the rule set out by Boadway and Bruce (1984, p.254), and provided in equation (2.1), the overall change in welfare is given by area (*b*+*d*) in Figure 5.5(b). All of the other welfare measures are income transfers. That is, once one sums up all of the welfare measures in the forgoing analysis, and assuming all markets are perfectly competitive, the only welfare change resulting from a policy that restricts the production of flour is given by area (*b*+*d*) in Figures 5.4(c) and 5.5(b). Yet, the income transfers that result from the policy are an important consideration.

Vertical and horizontal chains are central to spatial price equilibrium trade models. Further discussion of how welfare is measured in applied trade models and the structure of such models, including a method of calibrating components of a bilateral trade model, is provided in Johnston and van Kooten (2014). In the remainder of this chapter our focus is on the application of welfare economics to examine policy in the context of international trade.

## Economic Policy and Trade: Examples

In this section, two examples of how to use trade models to analyze economic policy are examined. In the first, European restrictions on Canadian imports of durum wheat are explored, followed by an illustration of the use of partial equilibrium trade models to examine the impacts of log export restrictions from British Columbia.

*EU Import Restrictions on Canadian Durum Wheat*

Consider again the case of trade in durum wheat between Canada and the European Union. The situation was initially considered more broadly in Figure 5.3, while the focus in this section is on Canada-Europe trade in durum wheat. Suppose the EU first imposes an ad valorem import duty on Canadian wheat and then replaces it with an import quota. The situations are illustrated in Figures 5.6 and 5.7, respectively, for the import duty and quota. The demand for wheat in both regions is a derived demand by flour and pasta producers. Since the autarkic price for durum is lower in Canada than in the EU, under free trade the EU would import Canadian durum wheat.

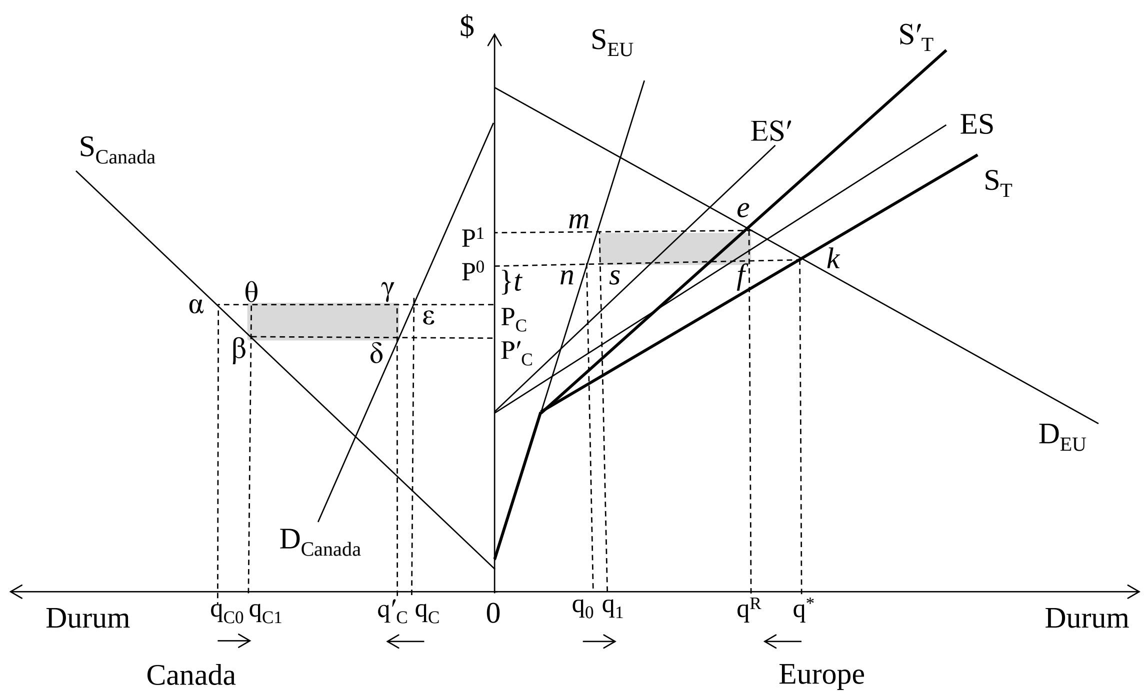


*Figure 5.6: Durum wheat trade: Imposition of an import duty on Canadian durum exports to Europe*

In the right-side panel of Figure 5.6, the European domestic supply function is denoted $S_{EU}$, while ES represents the Canadian excess supply function which includes the shipping and handling costs $t$. $S_T$ then denotes the horizontal sum of $S_{EU}$ and ES, with equilibrium occurring at point $k$ where European demand $D_{EU}$ intersects $S_T$. Under free trade, quantity $q^*$ would be consumed in the EU and the European price would be $P^0$; $q^0$ would be produced domestically, with $q^*–q^0$ imported from Canada. In Canada, the free trade price would be $P_C$, $q_{C0}$ is produced, $q_C$ is consumed and the difference exported to the EU.

An ad valorem duty by the EU on imports of Canadian wheat causes the excess supply curve to pivot from ES to ES′. The horizontal sum of ES′ and $S_T$ is now $S'_T$, so the intersection of the effective European supply and demand functions occurs at point *e*, where an amount $q^R$ is now consumed. This is less than the $q^*$ consumed under free trade. European farmers increase durum wheat production from $q_0$ to $q_1$, while Canadian exports fall from $q^*–q^0$ ($=q_C–q_{C0}$) to $q^R–q^1$ ($=q'_C–q_{C1}$). Canadian production declines and consumption increases as indicated because price falls from $P_C$ to $P'_C$. The European price, on the other hand, rise from $P^0$ to $P^1$.

The tax revenue accruing to the EU is given by sum of two shaded areas. Notice that the burden of this transfer falls on European consumers and Canadian farmers. Further, there is a deadweight loss due to inefficiency from not producing durum wheat in optimal fashion that is given by four small triangles – $\alpha\beta\theta$ plus $\varepsilon\delta\gamma$ in Canada, and *efk* and *mns* in Europe.

Now consider the case where the EU employs a quota on Canadian imports of durum wheat. This is illustrated with the aid of Figure 5.7. Here the quota is set so that the excess supply curve is given by ES′. The supply function facing Europeans is now given by $S'_T$ in Figure 5.7 so that the price difference between Europe and Canada is given by $P^1–P'_C$ rather than $P^0–P_C$ as under free trade. The results are similar to those in the previous figure (Fig 5.6), but the diagram illustrates (despite the use of similar labelling) a quota restriction that leads to lower imports from Canada than under the ad valorem tax. The quota rent equals the sum of the light shaded areas in Figure 5.7; area *A* representing the burden paid by Canadian farmers and area *B* the loss to European consumers. The quota rent is 'up for grabs' – it might accrue to European wheat importers (who are granted a license to import durum), Canadian exporters, or some other agent able to collect this rent. Whether the quota rent is greater than the tax revenue in

Figure 5.6 depends on the elasticities of supply and demand. As the deadweight losses (dark areas in Fig 5.7) increase, this causes the income transfers (light shaded areas) actually to fall.

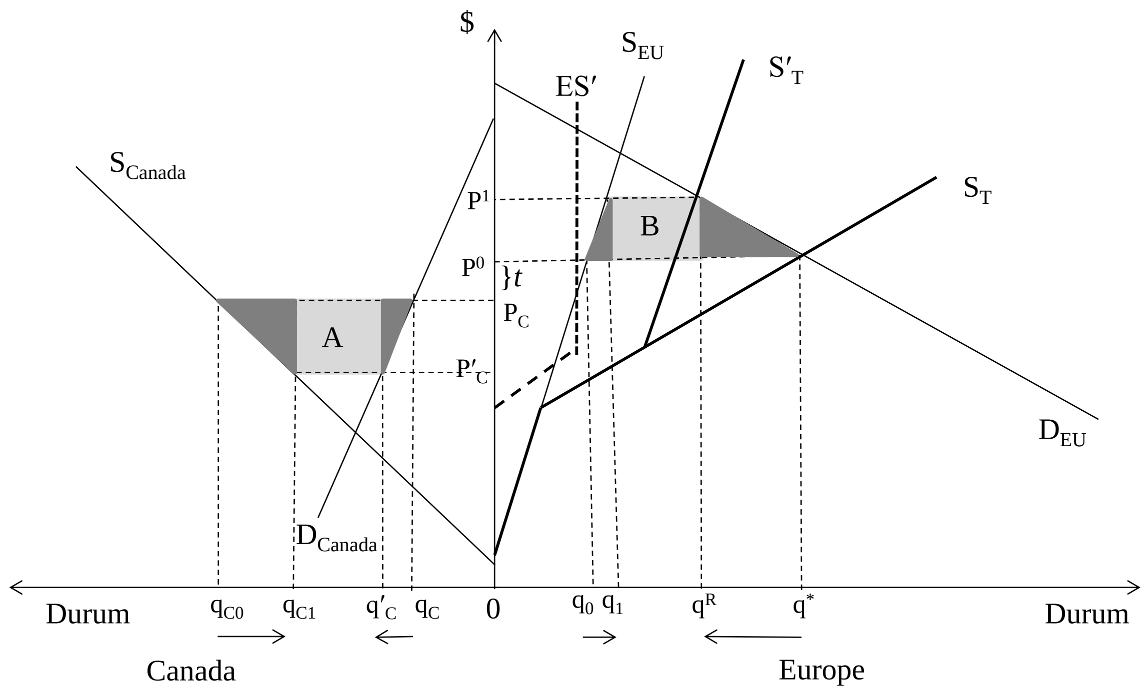


*Figure 5.7: Durum wheat trade: Reduction in quota on Canadian durum exports to Europe*

*Incentivizing Anti-Dumping and Countervail Duty Complaints: The Byrd Amendment*

As a trade measure aimed at foreign suppliers of agricultural commodities and other products, the U.S. Congress passed an amendment to the Agriculture, Rural Development, Food and Drug Administration, and Related Agencies Appropriation Act (2001). The amendment was the Continued Dumping and Subsidy Offset Act of 2000, commonly referred to as the Byrd Amendment. The Byrd Amendment allowed any "manufacturer, producer, farmer, rancher, or worker representative" to have been party to an antidumping or countervailing duty investigation to qualify for the disbursement of funds collected as a result of that investigation (WTO 2002). The funds would then be disbursed as compensation for expenditures in any of the following areas: manufacturing facilities, equipment, R&D, personnel training, acquisition of new technology, health care benefits to employees, pension benefits, environmental expenses, raw materials and inputs acquisition and working capital (WTO 2002). Because the affected party can claim expenditures in such a large variety of areas, there is a clear incentive for any U.S. agent to bring trade cases before the U.S. Department of Commerce.

The Byrd Amendment thereby incentivized U.S. agricultural producers, lumber manufacturers and others to initiate countervail (CV) duty actions against countries exporting to the U.S. Potentially, a successful trade complaint leading to the imposition of countervail duties on a foreign supplier results in higher domestic U.S. prices that benefit the complainant (increasing producer surplus and perhaps other rents) and potential CV duty payouts. Thus, the Byrd Amendment provided a 'double jeopardy' that encouraged U.S. producers to continue trade action against foreign sellers. For example, trade actions were subsequently directed at Canadian suppliers of wheat and lumber.

The Byrd Amendment prompted a series of dispute resolution panels at the WTO level, initially called for by Australia, Brazil, Chile, the EU, India, Indonesia, Japan, Korea and Thailand, and later supported by Canada and other countries. A WTO panel ruled in September 2002 that the Byrd Amendment violated at least nine WTO articles covering a host of fair trade practices, and this ruling was subsequently upheld on appeal in January 2003 with the U.S. directed to make changes accordingly (WTO 2002, 2003). Due to lack of timely U.S. action, the WTO authorized Canada to impose 15% ad valorem duties on certain U.S. products in retaliation for CVDs imposed on softwood lumber until it recouped $11.16 million USD in the first year (WTO 2005).

Although the Byrd Amendment was repealed in 2006, its provisions remained in effect until October 1, 2007. What we examine here, however, is the economic welfare distortions that result from a policy such as the Byrd Amendment.

Because companies that successfully petitioned the U.S. government to impose anti-dumping (AD) or countervail (CV) duties on imports could keep the revenue that previously went to the U.S. government, we follow Schmitz and Schmitz (2012) and examine the case of a barley processor that produces livestock feed and petitions to capture rents created when AD/CV duties are imposed on foreign barley inputs. The situation is discussed with the aid of Figure 5.8. We begin in panel (a) by showing the domestic supply of barley $S_D$ as a marginal outlay (MO) function facing the U.S. feed producer (right side of the diagram), which is assumed to have monopolistic power – otherwise the processor could not influence the price of barley. $D_{Feed}$ is the demand for the processor's output and $D_d$ is the derived demand for barley input; inputs of barley are assumed to be converted into feed output on a one-for-one basis (of course, units of output could be adjusted to facilitate this). On the left side of the figure, ES is the excess supply of inputs by the exporting country. The world price is given by $P_W$ and $Q^*$ is domestic consumption under free trade in barley, with $Q^* = q_I + q_D$, where $q_I$ refers to the amount imported and $q_D$ to consumption of domestic production. The price of feed is given by $P^*$.

Now consider panel (b) in Figure 5.8. To take advantage of the Byrd Amendment, the processor sets marginal outlay cost to the MR associated with the U.S.'s ED function for barley (as in the case of an optimal revenue tariff). Notice that the excess demand function for barley is shown in both the exporter and importer markets to illustrate the symmetry of the situation. The result is an after AD/CV duty price of $P_t$ and producer price $P_p$; the tariff or duty equals $P_t - P_p$. The new equilibrium consumption is then $Q^{**} = q_x + q'_D$, where $q_x$ is imported and $q'_D$ is the new domestic production. Note that $q_x = q'$.

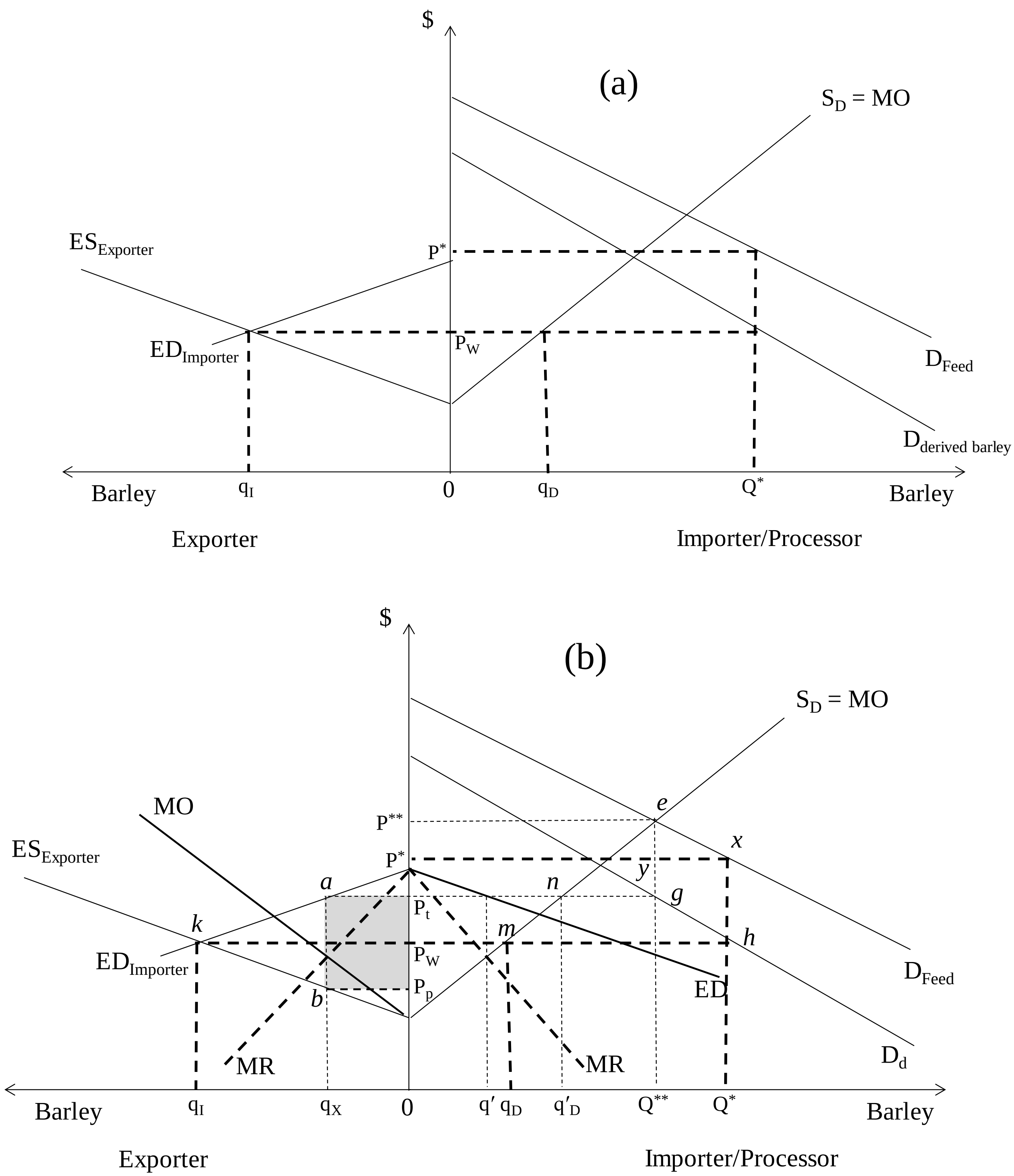


*Figure 5.8: Welfare economics of the Byrd Amendment*

The Byrd Amendment revenue is given by the shaded area $aP_tP_pb$ in Figure 5.8(b). The change in the processor's expenditures on domestic barley inputs equals $P_wq_d – P_pq_x$ and the processor's change in expenditures on foreign inputs equals $P_wq_I – P_tq_X$. In summary,

1. Exporters lose area $kbP_pP_w$;
2. Domestic producers gain area $P_tnmP_w$;
3. Importer consumers lose $P_tghP_w$; and
4. Processors gain the shaded area.

The change in the processor's profits is given by $\Delta\pi = \Delta TR – \Delta TC$ + Byrd Revenue, where

- $\Delta TR = P^*Q^* – P^{**}Q^{**}$ = – area $(yQ^{**}Q^*x)$ + area$(P^*yeP^{**})$
- $\Delta TC$ = area $(yQ^{**}Q^*x)$ – area$(P^*yeP^{**})$

Finally, since $\Delta TR = \Delta TC$, the change in the processor's profits ($\Delta\pi$) exactly equals the Byrd revenue.

*Restricting Log Exports*

Forest companies in British Columbia can only export logs from federal or private lands if logs are declared 'surplus' to domestic requirements; this implies that no domestic buyer is forthcoming or an offer to purchase 'surplus' logs is deemed inadequate. In cases where there is a large disparity between offers to sell logs and bids to purchase them, a provincial Timber Export Advisory Committee determines whether the seller of logs will be permitted to export them. Not surprisingly, log exports from the province have historically risen when lumber markets were weak, falling again as demand picked up. Naturally, lumber manufacturers and other log processors have opposed exports since they result in higher domestic prices.

Many economists have argued against log export restrictions, arguing that free trade in logs yields the greatest welfare benefits to the provincial economy (e.g., Fooks et al.

2013; Margolick and Uhler 1992). This may not be the case, however, because export restrictions may well be preferable to either total restrictions on log exports or complete free trade. For example, van Kooten (2002) argued that Canada should voluntarily restrict lumber exports to the United States in order to capture the policy-induced scarcity rents that would be created. In a more recent paper, van Kooten (2014) argued that British Columbia's log export policy is likely optimal from the perspective of maximizing welfare to the province, and that a movement away from that policy would lead to a loss in wellbeing. The discussion that follows relies almost entirely on this analysis.

Log exports from BC are an important part of the province's external trade. In 1987, log exports amounted to somewhat less than 4 million cubic meters ($m^3$), but a decade later they were less than ½ million $m^3$. Log exports rose dramatically after 1997; by 2005, they reached nearly 5 million $m^3$, falling to about 3 million $m^3$ by 2009 as a result of the global financial crisis, and then rising rapidly to well over 6 million $m^3$ in 2013. Given that global log trade amounts to about 35 million $m^3$, it is clear that changes in BC exports have an impact on world log prices.

Log trade between British Columbia and the rest of the world can be analyzed with the aid of Figure 5.9. In the left-hand panel of Figure 5.9, British Columbia's supply and demand functions are denoted $S_{BC}$ and $D_{BC}$, respectively. The price and quantity under autarky are then given by $P^A$ and $q_A$, respectively. With trade, the province faces an excess demand for logs from the rest of the world given by ED, while ES is BC's excess supply. However, $ES' = ES + T$ is the relevant excess supply as it includes shipping and handling costs of $\$T/m^3$. If BC restricts log exports to the amount $Q^R$ (= $q_1$-$q_0$ = quota level log exports), this shifts the ES to $ES^R$ in the right-hand panel representing the international market. Logs are sold internationally at price $P^1$, but domestically they are sold at the lower price $P^0$ as a result of shipping and handling costs.

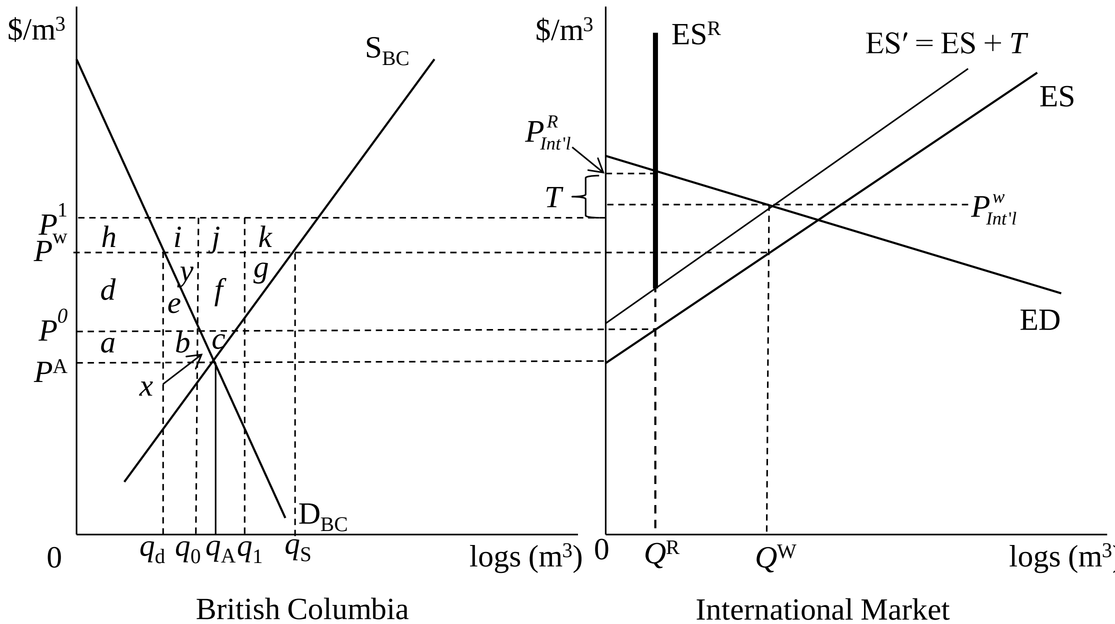


*Figure 5.9: British Columbia's log trade: Analysis of log export restrictions*

Compared to autarky (no exports), British Columbia's consumers lose (*a*+*b*+*x*) but producers gain (*a*+*b*+*x*+*c*) for a net gain of +*c*. In addition, area (*j*+*f*) is a surplus created by the policy-induced scarcity (i.e., not allowing free trade in logs) and could be wasted through the export process or captured by the log exporter or the (public) landowner. If log exports are now freely permitted, the world price $P^W$ becomes relevant and BC would export $Q^W$ logs (= $q_s$ - $q_d$ = free trade level of log exports). Compared to the restricted log export situation, BC consumers lose (*d*+*e*) and producers gain (*d*+*e*+*y*+*g*–*j*), assuming areas *f* and *j* accrued to the producers to begin with. The net gain to BC is thus (*y*+*g*–*j*) with *j* lost because of the price decline in the international market. This is the correct area that can easily be measured if the elasticities of supply and demand in each of the markets are known – that is, if there is information to construct the equations for the demand and supply functions.

As van Kooten (2014) demonstrates, British Columbia's log export policy has resulted in a level of exports that led to higher provincial wellbeing than would be the case if free trade in logs were allowed. (It also led to higher wellbeing compared to autarky.) Indeed, the level of permitted log exports might even be somewhat greater than the level that would result in the highest level of welfare.

The problem with the forgoing analysis is that it is static. It is based purely on welfare arguments identical to those used by Margolick and Uhler (1992) and Fooks et al. (2013). Suppose that the goal of government policy is to generate jobs or to create the largest possible wood processing sector in the world. Then, as argued by Smith (2012), it may be necessary to implement industrial policies that would prevent loss of manufacturing potential to other countries. Following the discussion in Chapter 2, the economist would then need to compare the impact of an industrial policy that restricts log exports to zero against the costs in terms of forgone wellbeing – to state explicitly the welfare costs of creating jobs. This would enable the policymaker to compare industrial strategies for creating manufacturing jobs across sectors. If the industrial policy is more concerned with retaining manufacturing ability (avoiding loss of manufacturing capacity to other countries) for strategic reasons, it might also be necessary to examine other economic strategies that create scarcity rents, such as import duties or export taxes. Again, the models discussed here could prove helpful in providing information on one of the aspects the decision maker must take into account – the aspect related to the economic efficiency of policy.

## Chapter 6

## The Welfare Economics of Climate Change

Perhaps the most difficult challenge facing applied welfare analysis comes in the arena of climate change. How do we conduct project analysis or cost-benefit cost analysis at this scale? Clearly, many of the assumptions underlying cost-benefit analysis are violated, most notably the assumption of small scale – that prices throughout the economy remain constant so that welfare can be measured across affected markets using equation (2.1). As a result, economists have developed integrated assessment models to address the welfare economics of global warming (see Tol 2014, pp.170-185; Nordhaus and Boyer 2000). Integrated assessment models (IAMs) constitute quite a different approach to applied economics than has been examined so far. They are also quite a bit different from computable equilibrium models that seek to account for changes in prices throughout the entire economy brought about by government policy. IAMs are preferred when it comes to issues such as climate change because computable general equilibrium models are not dynamic, lacking explicit links between one period and the next. The purpose in this chapter is to demonstrate how IAMs can be used to analyze economic policy. Since they have been applied primarily to address climate change policies, we consider IAMs in the context of climate change, although the main purpose is to examine how they are structured from an economic theory standpoint.

Integrated assessment models begin with the premise that global warming is unavoidable, and therefore that average global and regional temperatures rise in proportion to the rising concentration of greenhouse gases (GHGs) in the atmosphere. The most important GHG is carbon dioxide ($CO_2$), so much so that the impact of other GHGs is translated into $CO_2$ equivalence (sometimes denoted $CO_{2e}$). The damages of climate change are then assumed to be an increasing function of projected temperatures.

The problem is that there is a great deal of uncertainty not only about the relationship between damages and temperatures, but also about the relationship between rising atmospheric $CO_2$ concentrations and temperature, and whether and to what extent global warming is the result of human activities, principally fossil fuel burning and land-use change. Clearly, if natural forces play a more important role than human activities in bringing about climate change, or if the rate of increase in temperatures in response to higher concentrations of atmospheric $CO_2$ is much less than expected, or if damages from rising temperatures are small, or some combination of these, then the case for enacting policies to mitigate climate change is much weaker and that of adapting to change much enhanced.

There is also a great deal of uncertainty about the costs of climate change. It is often assumed that a carbon tax or carbon trading will reduce atmospheric concentrations of $CO_2$ to a socially desirable level through a combination of carbon capture and storage (CCS), which removes $CO_2$ from the atmosphere and stores it in underground sinks, enhanced energy conservation and improved energy efficiency, and substitution away from fossil fuel to renewable sources of energy that emit little if any $CO_2$. Surely, taxes and carbon trading incentivize the needed technological innovations, but there is no guarantee that this will come cheaply. Carbon trading is often characterized by corruption (van Kooten and de Vries 2014; Helm 2010), although taxes could result in an added benefit ('dividend') if the tax revenue is used to reduce distortionary taxes elsewhere in the economy, thereby leading to an overall efficiency gain over and above the environmental benefit from reducing $CO_2$ emissions. However, governments have a predilection to favor particular technologies over others through subsidies and/or employ regulations to reduce $CO_2$ emissions from certain sectors in the economy. Both carbon trading and government intervention can increase costs to the extent that adaptation may be the preferred option.

In this chapter, we examine the economics of climate change. Given uncertainty about the potential damages from climate change, we begin by briefly examining the science, the potential damages of greater concentrations of $CO_2$ in the atmosphere, which constitute the benefits from mitigating climate change, and the potential redistribution of welfare. Then we examine the structure of IAMs and how these are used to analyze policies for addressing climate change.

### Climate Change Science and Economics

The United Nations' Inter-governmental Panel on Climate Change (IPCC) is charged with understanding the risk underlying anthropogenic climate change from the perspective of the latest available science – to find the human footprint. Therefore, its priority is to discover the extent to which humans are responsible for climate change, and only secondarily the best means to mitigate humanity's role in causing climate change. Of course, the latter presupposes that climate change is both anthropogenic and to be avoided. In that case, a third task of climate research is to determine the cost of permitting climate change to continue unabated – that is, determining that the damages of potential global warming exceed the costs of mitigating it. Lastly, and only as an afterthought, does the IPCC examine possible strategies for adapting to climate change, even though the best strategy may well be to do nothing about climate change but rather to focus on reducing global poverty by encouraging economic growth, thus enabling people to adapt successfully. Economic growth can only occur if those living in developing countries have access to abundant and inexpensive energy (see Prins et al. 2010). Unfortunately, given the current mandate of the IPCC, natural causes of climate change are generally ignored, despite being the proverbial "elephant in the room."

#### *Finding Anthropogenic Climate Change*

Scientists have come to the conclusion that the correlation between rising $CO_2$ emissions from fossil fuel use and concentrations of atmospheric $CO_2$ constitutes evidence that rising global temperatures are the result of human activities, despite the fact that the increase in temperatures and the rise in atmospheric $CO_2$ concentration are weakly correlated at best; there is no straightforward causal relation between human fossil fuel use and climate.[21] It seems not to matter that empirical evidence fails to detect a statistically significant upward trend in global temperatures (McKitrick and Vogelsang

[21] This argument results in the causal fallacy *post hoc, ergo propter hoc* (after this, therefore because of this).

2014), that land-based temperature series are the result of an urban heat island effect (see van Kooten 2013, pp.15-47 for a review), that climate models are biased against natural explanations of climate change (Moncton et al. 2015), and that there has been no global warming for nearly two decades.

The first two IPCC reports (IPCC 1990, 1995) provided no empirical evidence for a link between human activities and global warming, speculating for the most part on the basis of climate models and the correlation between rising atmospheric $CO_2$ and the rise in global temperatures since the Little Ice Age (Lamb 1995). In contrast, the IPPC's Third Assessment Report (IPCC 2001) relied heavily on the 'hockey stick' graph to make the case that humans were responsible for global warming. That graph depicts global temperatures as remaining relatively constant over a period of 1,500 to 2,000 years (or even longer), followed by a rapid rise beginning in the $20^{th}$ century. The long period of constant temperatures constitutes the 'shaft,' and the recent temperature increase the 'blade' of the hockey stick. The hockey stick does away with the Medieval Warm Period (MWP) and Little Ice Age (LIA), explaining them as local phenomena despite anthropological and other evidence to the contrary. The hockey stick was a clever device for showing the supposed link between human activity and temperatures. The concentration of $CO_2$ in the atmosphere was flat until it began to rise at the time of the Industrial Revolution. If temperatures were shown to follow the same trend, then, presto, you apparently had found the human link to climate change. Unfortunately, the science underlying the hockey stick turns out to shoddy at best (van Kooten 2013, pp.71-95; see also Wegman et al. 2006; National Research Council 2006; McIntyre and McKitrick 2005).

The 2007 Fourth Assessment Report (AR4) no longer relied on the hockey stick to make the case that warming was the result of human activities. Rather, AR4 relied on the results of climate models themselves. The justification is provided on p. 684 of the Physical Science Basis volume. In Figure 9.5 of the report, two simulations are provided. The first consists of 19 temperature simulations from five climate models for the period 1900-2005 with only natural forcings included. The second consists of 58 simulations from 14 climate models for the same period, but now including both the natural and anthropogenic forcings. The ensemble of mean temperatures in the second case (which includes the anthropogenic forcings) tracks actual average global temperatures relatively closely, while modeled mean temperatures without anthropogenic forcings are below actual mean temperatures for 1900-2005. The IPCC concludes that this is clear evidence that human emissions of $CO_2$ are driving temperature increase. The same approach was subsequently used in the 2013 Fifth Assessment Report (AR5).

There are some problems with this approach. Outcomes from one set of model runs are compared to outcomes from another set of model runs. In my view, such a comparison is not valid. First, outcomes from two different sets of climate models are used in making the comparison. Further, by parameterizing (assigning ad hoc values to) enough variables it is always possible to get models to reproduce, fairly closely, a known, targeted set of data. What the modelers have not been able to show is that the ad hoc values they have assigned are accurate representations of the real world. This is problematic because models that track the past tolerably well are usually poor at predicting the future. This is evidenced in the case of climate change by the fact that models that have been parameterized to track past temperatures have not been able to forecast future temperatures with any degree of accuracy. This is shown by the large deviation between model projections of future temperatures and real-world observations for the period 1979 to 2014 (e.g., see Moncton et al. 2015). However, in the AR4 and AR5 reports, even the parameterized models used to illustrate the impact of anthropogenic forcings are different.

The use of models to demonstrate that humans are responsible for climate change is questionable from a scientific perspective. As noted by the Institute of Forecasters in a forensic audit of climate models, the climate models have never been validated and are simply unreliable (Moncton et al. 2015; van Kooten 2013, pp.140-142). Rather than recognizing the shortcomings of their models, climate modelers used the same approach to make claims about the increasing intensity of storms, rainfall events, etc., though empirical evidence indicates that storm events have been on the decline. Even the IPCC acknowledges this. In its 2012 special report on extreme weather events it said, “There is low confidence in any observed long-term (i.e., 40 years or more) increases in tropical cyclone activity (i.e., intensity, frequency, duration), after accounting for past changes in observing capabilities” (IPCC 2012, p.7). In AR5, the IPCC notes: “Current data sets indicate no significant observed trends in global tropical cyclone frequency over the past century and it remains uncertain whether any reported long-term increases in tropical cyclone frequency are robust, after accounting for past changes in observing capabilities …. Current data sets indicate no significant observed trends in global tropical cyclone frequency over the past century and it remains uncertain whether any reported long-term increases in tropical cyclone frequency are robust, after accounting for past changes in observing capabilities …. In summary, confidence in large scale changes in the intensity of extreme extratropical cyclones since 1900 is low” (IPCC 2013, pp. 216, 220).

The point here is simply this: You cannot base predictions on models that are not validated by *observational data*, even if they are validated *against each other*. While the models do indeed include a lot of well-known physical equations, they also contain a lot of ad hoc parameters (such as the climate sensitivity parameter) and information based on weak empirical foundations. Further, models are nonlinear, difficult to solve, and with no guarantee that any solution is anything more than a local optimum (or attractor). In other words, a numerical solution to a climate model could get trapped at a local point (as it often does), and an entirely different solution can be found simply by slightly changing one or more of the model parameters, or even one of the many starting values (e.g., initial concentration of water vapor in a certain region of the model) needed by the computer to start the algorithm for finding a solution. In many cases, the highly nonlinear equations in the models need to be linearized around some point near where the model builders expect the solution to lie, because the nonlinearities are too complex for even a high-powered computer to find a numerical solution.

*Climate Sensitivity*

One of the many parameters in the model that the modeler needs to set is the climate sensitivity. Climate sensitivity refers to the expected increase in temperature from a doubling of the atmospheric concentration of $CO_2$. In climate models it is the critical, climate sensitivity parameter that converts atmospheric $CO_2$ into temperature increases. Values of the climate sensitivity parameter used by the IPCC have ranged from a high of 4.5˚C to as low as 2.5˚C to 3.0˚C. While earlier IPCC reports were much more assertive about the size of the climate sensitivity parameter, stating a likely range of 2.0˚C to 4.5˚C with a best estimate of 3.0˚C, the more recent AR5 report is much less certain about climate sensitivity, reducing its lower likely bound to 1.5˚C and offering no best estimate. Yet, the IPCC expressed greater confidence that global warming is anthropogenic in nature than ever before; as of 2013, the IPCC is 95% certain that warming is caused by humans, up from 90% in 2007, 66% in 2001 and only 50% in 1996. These certainty values are frightening for the simple reason that they are mere speculation and not based on science. Probability ought to decline as a result of the material reported in AR5, not increase.

Recent studies by Schwartz (2007), Spencer et al. (2007), Spencer and Braswell (2008), Spencer (2008), and Lindzen and Choi (2009) point to a much, much lower value of the climate sensitivity parameter, more likely closer to 0.5˚C. The argument hinges on the role of feedbacks. If increases in atmospheric $CO_2$ increase water vapor in the atmosphere without increasing cloud formation, then there is a positive feedback that serves to amplify the initial warming. However, if increased water vapor leads to increased cloud cover, there is a negative feedback caused by the cloud albedo (reflectivity – reflecting solar radiation back into space before it can warm Earth's surface). This offsets the initial increase in warming caused by $CO_2$ rather than amplifying it. Thus the good news is that *empirical* evidence, as opposed to theoretical models, shows that climate sensitivity to $CO_2$ is much less than originally anticipated, with a "new observationally-based 'likely' range [of] … 1.25–3.0˚C, with a best estimate of 1.75˚C" (Lewis and Crok 2014).

*Natural Causes*

Cyclical changes in solar activities, cosmic rays originating in deep space, and ocean currents (Pacific Decadal Oscillation, Atlantic Multidecadal Oscillation, North

Atlantic Oscillation, etc.) are perhaps a better explanation of changing temperatures and possible global warming than $CO_2$ (see Monckton et al. 2015; van Kooten 2013, pp.158-165) While increased $CO_2$ in the atmosphere certainly warms the Earth, it needs to be amplified through water vapor before it leads to significant warming. However, there are serious questions regarding the role of water vapor, cloud formation, and so on. These issues remain to be resolved, and it is not clear whether and to what extent cloud feedbacks enhance or reduce the initial warming. Articles supporting both sides of this debate continue to appear in the refereed literature.

The reason climate modelers do not like the MWP is that humans were not a factor in causing it. It could not be explained by higher levels of atmospheric $CO_2$. Any climate model worth considering would not only need to predict observed temperatures over a long period, but also provide an explanation of the MWP. But the climate models do not appear capable of either. They do not provide an adequate explanation of the MWP, nor can they explain the current 17+ years with no temperature increase despite steadily rising $CO_2$ levels (Monckton 2014). The most common explanation – that the heat is hiding in the deep oceans (since sea surface temperatures have not risen) – is less persuasive given increasing evidence pointing to natural causes. Further, this line of reasoning leads to doubts about the state of climate science as it relates to AGW. The AGW story warns of an impending catastrophe if there is a rapid and large increase in the atmospheric temperature at the Earth's surface, but it says nothing of an impending catastrophe should there be an increase in the total energy content of the lithosphere / hydrosphere / cryosphere / atmosphere / biosphere. To argue that the temperature increase has not happened because the energy is hidden in the deep oceans is really to concede that there is something wrong with the way energy systems are modeled.

*Damages*

The benefits of mitigating climate change are the damages purportedly prevented. What are the expected damages from global warming? The list of potential damages that global warming proponents flag includes sea level rise, more frequent and more intense storms, increased risk of disease, heat waves and drought, loss of biodiversity, climate refugees and increased international tensions, and even psychological damage. Upon investigating the potential damage from each of these possible "effects," one is struck by two things. First, many are simply non-existent. There is no evidence that storm frequency or intensity is increasing. Rather, the available observational evidence suggests that the incidence and accumulated energy of storms have actually declined over the period of alleged anthropogenic global warming (Maue 2014). While damages from various storm events have increased over time, this cannot be attributed to more frequent or severe storms. Instead, storm damages have increased because more people and property are in harm's way (Pielke 2014) (Figure 4).

Nor is there evidence to indicate that climate change is causing sea levels to rise, although one might expect this if oceans expand as a result of warming. But without evidence, one is left to speculate, which is unscientific.

With regard to health concerns, these are best considered a red herring. The most frequently cited example concerns malaria, which hypothetically would spread as tropical temperatures shifted pole ward. But malaria (like dengue fever) is not a tropical disease but a disease of poverty (Reiter 1998, 2005). Indeed, it had appeared in Europe and North America as recently as the 1960s and was eradicated in these regions through mosquito control and public health efforts, and the greatest malaria outbreak in modern times occurred in Siberia – not noted for its tropical climate – in the 1920s and 1930s, infecting 9.5 million and killing over 600,000 (Manguin et al. 2008, p.244). Effective vector control and, as the recent *Ebola* outbreak indicated, the quality of health care are more important than climate in prevention of disease. The health of the globe's population would best be served by economic development that lifts people out of poverty.

The remaining categories are interesting but even more controversial. Increasing atmospheric $CO_2$ improves agricultural productivity, enabling crops to better utilize nutrients including water, thereby making them less susceptible to drought. While droughts might increase in some regions of the globe, overall a warmer atmosphere will hold more moisture leading to increased rainfall. However, some argue that, as temperatures continue to rise beyond an increase of 2˚C, the $CO_2$-fertilization effect will be offset by too much heat, while precipitation will evaporate before it hits the ground. These arguments are accepted with no empirical support. The only empirical evidence points to increased crop yields as atmospheric $CO_2$ increases and to declines in the incidence and prevalence of droughts as temperatures rise. Although using very crude methods to estimate benefits, one author estimated that the increases in atmospheric $CO_2$ since 1960 added $3.2 trillion in crop value, and projected rising $CO_2$ to add nearly $10 trillion more from 2014 to 2050 (Idso 2013, p.3). Likewise, mortality from cold weather exceeds that from hot weather so that, as global climate warms, deaths due to temperature extremes actually decline.

Biodiversity loss is difficult to measure, and its value more so (van Kooten and Bulte 2000, pp.270-307). Indeed, the methods used to determine nonmarket values, which play prominently in Nicolas Stern's (2007) evaluation of the costs and benefits of mitigating climate change, have recently come under severe criticism (see Chapter 4). Questions regarding the use of nonmarket valuation applies not only to biodiversity, but to environmental economics more broadly as the damages avoided by reducing pollution, for example, are estimated using the same techniques. Polar bears are the poster child of biologists – the harbinger apparently of climate change's negative impact on biodiversity. Yet, polar bear populations seem to be increasing, and not decreasing as a result of declining sea ice (Crockford 2013, 2014).

*Economic Evaluation*

There is a great deal of uncertainty regarding the extent of future climate change. If the climate sensitivity parameter is 0.5˚C to 1.5˚C rather than 2.5˚C to 4.5˚C, then the threat of climate change has essentially disappeared, and it would make little sense to implement expensive climate mitigation strategies. Likewise, if natural causes trump anthropogenic ones as the culprit behind global warming, then there is little that can be done to prevent warming. Again, no action should be taken beyond what might make sense for other reasons. Further, since climate models are highly unreliable and unable to predict with any accuracy, it makes sense that about all we have to deal with are speculative scenarios of future climate, some of which might even be plausible. There is not much to go on, so policy should proceed in small steps. Therefore, *if* we should do anything (and that is not certain), it makes sense to rely on a simple tax that might vary over time as more information becomes available, rather than change the structure of the economy through regulations and carbon trading that is open to corruption (Pindyck 2013; Prins et al. 2010).

From an economic standpoint, a carbon tax should be set equal to the social cost of carbon, which, in turn, is determined by the relationship between economic damages and atmospheric levels of $CO_2$ (not temperature!) – the social cost of carbon is the cost supposedly imposed on global society when one additional metric ton of $CO_2$ ($tCO_2$) is added to the atmosphere. There is no such relation; as noted earlier, temperatures are only weakly correlated with $CO_2$, but it is temperature that economists use to determine economic damages, which in turn are used in integrated assessment models to determine the social cost of carbon. For example, William Nordhaus' well-known and oft-used DICE model employs a simple functional relation between economic damage and global temperature (Nordhaus and Boyer 2000), but the damages are primarily nonmarket in nature. Given the work by Kahneman (2011) and Hausman's (2012) critique of nonmarket valuation, the very idea of a social cost of carbon is suspect. The policy maker is then left to muddle through. As part of this muddling through, the most rational policy that economists can agree upon is a carbon tax that raises funds for technological research and development, incentivizes greater energy conservation, but does the least harm to the economy, and picks no winners or losers among energy technologies.

## If We *Must* Try to Mitigate Global Warming, What Is the Best Policy?

Nordhaus has certainly not been afraid to make the case for a carbon tax, particularly advocating a tax that rises gradually as atmospheric concentrations of carbon dioxide increase. The tax is designed to increase in response to the supposed increase in damages from rising $CO_2$ levels.

### *The Case for a Carbon Tax*

Nordhaus (2010) argues that the "desirable features of any tax are that it raises revenues in a manner that has minimal distortionary effect on the economy and reinforces other objectives of national policy." A carbon tax is particularly relevant because it can be used to raise revenues to tackle the burgeoning U.S. debt. A carbon tax has the following advantages:

- It has the potential to raise substantial revenue.
- It is well understood.
- It increases economic efficiency as it tackles undesirable $CO_2$ emissions.
- It has potential health benefits, because reducing emissions of $CO_2$ will also reduce emissions of other harmful pollutants, assuming nothing else changes.
- It displaces regulatory inefficiencies associated with attempts to regulate greenhouse gas emissions, and useless subsidies to produce ethanol or protect standing forests, for example, when both these policies have been shown to have little or no impact on overall greenhouse gas emissions (due to release of other greenhouse gases and/or leakages).
- A carbon tax can be harmonized across countries, reducing overall distortions.
- A tax can enable the U.S. to meet international $CO_2$-emission reduction targets.
- A carbon tax is preferred to emissions trading because it captures the economic rents that are lost to government when a grandfathered cap-and-trade scheme, reduces transaction costs associated with emissions trading, and it leads to fewer opportunities for corruption.

Some of the claims that Nordhaus makes in favor of a carbon tax, such as "substantial public health benefits," are determined using the aforementioned nonmarket techniques. Nordhaus's calculations regarding the ideal tax ramp and budget implications are derived from his DICE model and are provided in Table 6.1 below. The present value of the tax revenues over the period to 2030 is 15% (discounted at 5%) of 2010 GDP, or 35% if discounted over the period to 2050. Therefore, the carbon tax can be expected to make a significant contribution to reducing the U.S. budget deficit and debt.

**Table 6.1: Ideal Carbon Tax Ramp and Budgetary Implications for the United States**

| Year | Tax rate ($/t $CO_2$) | Revenues (2010 $×$10^9$) | Year | Tax rate ($/t $CO_2$) | Revenues (2010 × $10^9$) |
|---|---|---|---|---|---|
| 2005 | 0.00 | 0 (0.0%) | 2025 | 63.00 | 282 (0.9%) |
| 2015 | 25.00 | 123 (0.6%) | 2030 | 89.80 | 386 (1.0%) |
| 2020 | 39.70 | 184 (0.7%) | 2035 | 128.10 | 528 (1.1%) |

Notes: Adapted from Nordhaus (2010). Results assume inflation and real GDP growth of 2.5%. Revenues as a proportion of GDP are provided in parentheses.

*The Adverse Aspects of a Carbon Tax*

Nordhaus also makes the case that the income re-distributional effects of a carbon tax are minimal, or at least no worse than those associated with a value-added tax or payroll tax for social security purposes. The average household in the U.S. consumes 12,000 kilowatt hours (kWh) of electricity annually and pays an average of 10¢ per kWh. If this power is generated solely by coal-fired plants, Nordhaus argues the annual cost to a household would rise in 2015 from $1200 to $1500, or by 25% ($300).

However, using Nordhaus's data and $CO_2$ release by fuel type, I calculate that a carbon tax of $25 per t$CO_2$ would increase the price that a household pays for electricity by 150%, or from $1200 to $3000 annually (assuming no reduction in use). The price of gasoline would rise by 15.1%, adding nearly 14¢ to a gallon of gasoline, not the 7¢ indicated by Nordhaus.

If governments are determined to try to mitigate global warming by reducing $CO_2$ emissions, a carbon tax is probably the best instrument that governments have in their policy arsenal. Yet, based on PEW surveys (Pew Research 2010) and a survey by *The Economist* (July 4, 2009, pp. 24-25) that indicated the majority of people would oppose climate change mitigation policies if these cost them $175 or more per year, it is unlikely that citizens would willingly accept a carbon tax. Rather, they would view it as another attempt on the part of politicians to pay for wrongheaded policies related to the 2008–2009 financial crisis, and perhaps financing of the Iraq and Afghanistan wars, which led to the growing U.S. debt.

In an effort to get serious about climate change, the leaders of the largest eight countries (G8) meeting in L'Aquila, Italy, agreed on July 8, 2009 to limit the increase in global average temperature to no more than 2°C above pre-industrial levels. To attain this, they set "the goal of achieving at least a 50% reduction of global emissions by 2050" with "developed countries reducing their aggregated domestic emissions by 80% or more" compared to 1990 (Schiermeir 2009). There is no way for the United States, Europe or any country to meet this target and retain anything remotely close to its present standard of living. Reductions in $CO_2$ on that scale are simply not achievable without severely impoverishing people. The last time the United States had $CO_2$ emissions that were 80% below 1990 levels was around 1905, when it had under a fifth as many people as it has now, and their average income was about 13% of what it is now (Goklany 2012, p.375).

Even emission reductions of as little as 25% would be difficult and costly to achieve. They would require huge investments in nuclear power generation, massive changes in transportation infrastructure, and impressive technical breakthroughs in everything from biofuels to battery technology. Yet, even if the developed countries are successful in reducing their emissions of greenhouse gases, the impact on climate change will be small. Growth in emissions by developing countries, especially China and India, will easily and quickly exceed any reduction in emissions by rich countries. Fossil fuels are abundant, ubiquitous and inexpensive relative to alternative energy sources; therefore, any country would be foolish to impair its economy by large-scale efforts to abandon them. It is evident that it does not matter what rich countries do to reduce their emissions of carbon dioxide. Their efforts will have no impact on climate change, but they will have an adverse impact on their own citizens. Whether AGW is real or not, whether the climate model projections are accurate or not, fossil fuels will continue to be the major driver of economic growth and wealth into the foreseeable future. But efforts to contain $CO_2$ emissions could curtail global poverty alleviation, perpetuating poverty and attendant high rates of disease and premature death and leading to a more unstable world.

**Integrated Assessment Models**

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