AFRICAN ECONOMIC RESEARCH CONSORTIUM (AERC)

COLLABORATIVE MASTERS DEGREE PROGRAMME (CMAP) IN ECONOMICS FOR SUB-SAHARAN AFRICA

JOINT FACILITY FOR ELECTIVES

Teaching Module Materials

ECON 537 - Environmental Economics II

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Facebook Twitter Website Email Website

Our mailing address is:
African Economic Research Consortium (AERC)
3rd Floor, Middle East Bank Towers, Jakaya Kikwete Road
P. O. Box 62882
00200 Nairobi
Kenya

Module 4.1. Framing the Environmental Problem: Pollution (4 hours)

Learning Outcomes

This Module addresses one of the major sources of environmental problem: pollution. After going through the module, the reader is expected to:

- ✓ identify the various categories of pollutants and the types of environmental problem associated with each
- ✓ understand how the policy response required to solve a pollution problem depends on the type of pollutant in view
- ✓ understand how economics defines the efficient level of pollution and how the efficient levels are derived for a flow and for stock pollutants
- ✓ have a good understanding of the depth of the pollution problem in Africa.

Outline

4.1 Categories of Pollutants and the Efficient level of Pollution

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- 4.1.3 Efficient level of Pollution

4.2 The Efficient Allocation of Pollution: Fund Pollutants vs. Stock Pollutant

- 4.2.1 The Efficient Allocation of Pollution: Fund Pollutants
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- 4.2.2 The Efficient Allocation of Pollution: Stock Pollutants
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Summary

Discussion/Review Questions and Exercises

Materials used for the Lecture

4.1 Categories of Pollutants and the Efficient level of Pollution

4.1.1 Introduction: The pollution problem

In our consideration of the interactions between the economic system and the environment, we saw that an environmental problem emerges when the rate of waste discharged into the environment exceeds its assimilative capacity (the case of pollution) and/or when a renewable resource is harvested beyond its regenerative capacity so that the ecosystem functions are affected negatively. We have examined in Module 3, the issues associated with the sustainable management of renewable resources. This Module provides a framework for conceptualizing environmental problems focusing mainly on pollution.

Pollution is not only a problem by itself, it impairs all the other estuarine functions of the environmental resource base (ERB). The damage caused by pollution can take many forms. At high enough exposures to certain pollutants, human health can be adversely impacted, possibly even leading to death. Other living organisms, such as trees or fish, can also be harmed by pollution. Inanimate objects, such as physical infrastructure like buildings and sculptures can also be affected (such as when acid rain causes sculptures to deteriorate or when particulates cause structures to discolor). This relationship between the amount of waste emitted into the environment, the absorptive capacity of the ERB and pollution damage is illustrated in Figure 4.1.

The amount of waste products emitted determines the load upon the environment. The damage done by this load depends on the absorptive capacity of the environment (its capacity to assimilate waste products). If emissions load exceeds the absorptive capacity, then the pollutant accumulates in the environment.

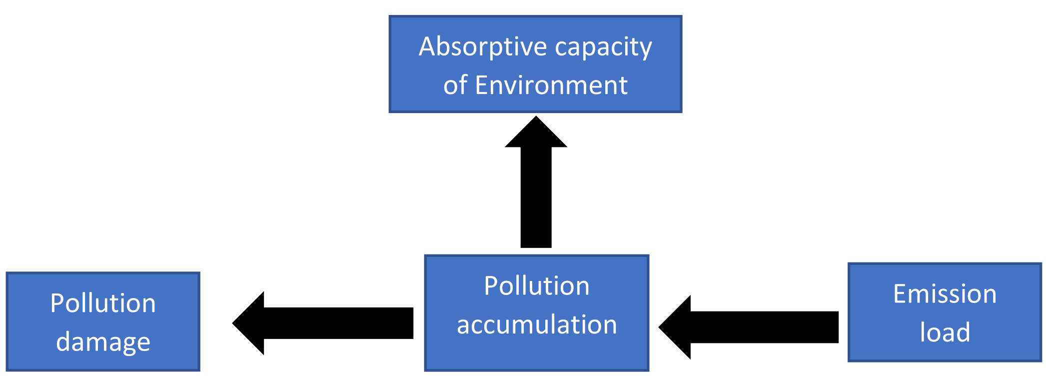

Fig. 4.1. Relationship between emissions and Pollution Damage. Source: Titenberg and Lewis, 2012.p360.

There are at least two questions that follow from the above.

- How much pollution abatement or control should society undertake? What is the appropriate level of pollution flow? How much pollution should society be willing to accept considering the benefits and costs of pollution control? and,
- How should the responsibility for pollution reduction be allocated among the various sources of pollution? Put differently, given that some target level of pollution has been chosen, what is the best method of achieving that level?

The second question has to do with pollution control policies and instruments. In that context, we will need a general framework for analyzing pollution control that allows us to define efficient and cost-effective allocations for a variety of pollutant types, compare these allocations to market allocations, and to demonstrate how efficiency and cost-effectiveness can be used to formulate desirable policy responses. This is the focus in Module 4.3. However, we need to first address the preceding questions.

4.1.2 What level of pollution is desirable?

From our consideration in Module 1, it is obvious that some level of waste discharge is required for the proper functioning of the ERB. In addition, it may not be possible to produce some goods and services that we do find useful and in the quantity in which they are needed without generating some pollution, even if only a small amount. To produce the goods and services we need in ways that are non-polluting may impose significant and unaffordable costs. The crucial question then is: what level of pollution should be considered desirable?

The answer to this question depends on what objective is being sought. If the objective is *economic optimality*, then the level of pollution chosen should be consistent with the maximization of social welfare. However, this criterion is not feasible in practice because the information required to establish the optimal pollution level is likely to be unobtainable[1]. In place of economic optimality, *economic efficiency* is often proposed as a more realistic goal for setting pollution targets. The use of efficiency criterion has aided the incorporation of natural resources into economic growth models. Pollution is then associated with resource extraction and use so that policies concerning pollution levels and natural resource uses are linked.

As we shall discover in Module 4.3, economic efficiency is not the only way of thinking about pollution targets. It may be necessary to adopt other considerations, such as sustainability, as the policy objective, or as a constraint that must be satisfied in pursuing other objectives. In this case, pollution levels (or their trajectories through time) would be assessed in terms of whether they

[1] This requires, among other things, knowledge of an appropriate social welfare function, and of production technologies and individual preferences throughout the whole economy and may also involve substantial redistributions of wealth.

are compatible with sustainable development. Efficiency and sustainability criteria do not usually lead to similar recommendations about pollution targets. However, pollution targets may be, and in practice often are, determined on grounds other than economic efficiency or sustainability. In some cases, policy may be based on what risk to health is deemed reasonable, or shaped by public opinion, or even pressure groups and sectional interests. In addition, political or political-economy considerations may in fact be hugely important in shaping the direction of policy goals. In addition, when the spatial influence of a pollution damage is transnational, policy makers may have to set targets within a network of obligations and pressures from various national governments and coalitions. In the final analysis, pollution targets are rarely, if ever, set entirely on purely economic grounds. Standards setting is usually a matter of trying to attain multiple objectives within a complex institutional environment. However, setting economic efficiency as the goal of pollution targets provides a useful framework for understanding environmental economics.

4.1.3. Efficient level of Pollution

What exactly constitutes an efficient allocation of pollution will depend on the nature of the pollutant and the associated damages. Different types of pollutants have different damage mechanism and hence differing impact on the absorptive capacity of the environment. They will therefore require different policy responses. Good public environmental policy requires an understanding of the nature of various pollutants, their effects on the environment, and their costs.

Pollution damages may arise from the flow of the pollutant (that is, the rate of emissions) or from the stock (or concentration rate) of pollution in the relevant environmental medium (see Figure 4. 2). **Flow-damage pollution** occurs when damage results only from the flow of waste discharge (the rate at which they are being discharged into the environmental system). This corresponds to the righthand side branch in Figure 4. 2. In this case, the damage will instantaneously drop to zero if the emissions flow becomes zero. This is exactly true when the pollutant exists in an energy form, such as noise or light, so that when the energy emission is terminated no residuals remain in existence. It may also be approximately true in a wider variety of cases, particularly when the residuals have very short lifespans before being transformed into benign forms.

The flow-damage pollution function can be represented as

$$D = D(M) \qquad (4.1)$$

Where M denotes the pollution flow, and D, pollution damage.

Stock-damage pollution: occurs when damage is a result of the stock of the pollutant in the relevant environmental system or environmental receptors (air, soils, biota and water systems) at any point in time. This corresponds to the central branch in Figure 4.2. For a stock of the pollutant to accumulate, it is necessary that the residuals have a positive lifespan and that emissions are being produced at a rate which exceeds the assimilative capacity of the environment. This can also happen in the case of waste discharges for which the ERB has zero assimilative capacity (e.g. some synthetic chemicals, such as polychlorinated biphenyls, PCBs DDT and dioxins, and a number of heavy metals, some rubbish that are not biodegradable, and strongly radioactive elements such as plutonium with extremely long radiation half-lives.). In this case, the left-hand branch in Figure 4.2 will not exist.

Stock-damage pollution can be expressed in the equation below

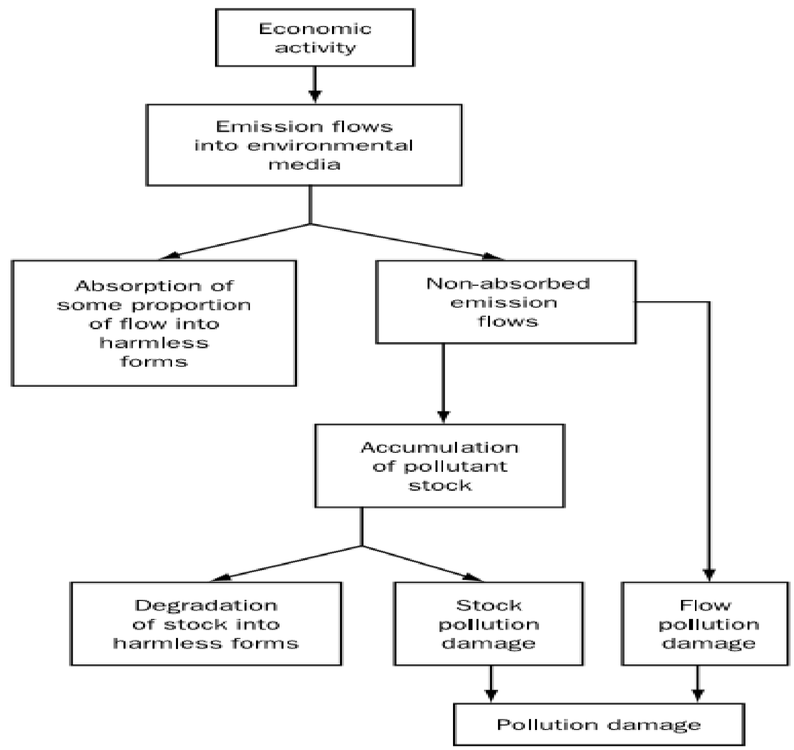

Fig. 4.2 Economic activity, residual flows and environmental damage. **Source**: Perman et al., 2003. p.199.

$$D = D(A) \qquad (4.2)$$

where A is the pollution stock, and D, is the pollution damage.

There could be *mixed cases*, where pollution damage arises from both flow and stock effects. Examples considered in this category include waste emissions into water systems and damages arising from the emissions of compounds of carbon, sulphur and nitrogen.

Some authors prefer to classify pollutants themselves based on the above damage mechanisms. In this respect, we can distinguish between stock and fund pollutants. **Stock pollutants** are pollutants for which the environment has little or no absorptive capacity. Such pollutants accumulate over time as emissions enter the environment. **Fund pollutants** are pollutants for which the environment has some absorptive capacity. These pollutants will generally not accumulate as long as the emissions rate does not exceed the absorptive capacity of the environment.

It is also possible to classify pollutants by their *zone of influence*. This describe the geographic area affected by any given environmental or natural resources management problem. **Horizontal dimension of influence** refers to the spatial domain over which damage from an emitted pollutant is experienced (local, regional, global), while the **vertical zone of influence** shows whether pollution damage is caused mainly by ground-level concentrations of an air pollutant (as in the case of lead or particulates) or by concentrations in the upper atmosphere (as in the case of ozone-depleting substances or greenhouse gases, GHGs). The local and regional categories are also not mutually exclusive; it is possible for a pollutant to be both. Nitrogen oxides released into the air, for example, or chemical discharges into rivers can be both local and regional pollutants.

This taxonomy is very useful in designing policy responses to various types of pollution problems. Policies addressing the damage caused by local pollutants near the source of emissions, for example, will differ from those for regional pollutants affecting wider areas. In addition, many organic pollutants injected into an oxygen-rich stream will be transformed by the resident bacteria into less harmful inorganic matter. For example, emission of carbon dioxide is absorbed by plant life and the oceans. However, most important pollution problems have some attribute of a stock-damage pollution effect. The most prominent are those which affect human health and life expectancy. Others affect built structures, such as buildings, works of art etc. and may adversely affect production potential, particularly in agriculture. Stock pollution levels influence plant and timber growth, and the size of marine animal populations. Less direct effects operate through damages to environmental resources and ecological systems. They can also impair other functions of the ERB. Table 7.1 lists some atmospheric pollutants while Figure 7.3 illustrates the primary linkages between pressures, state and impacts of atmospheric change that are associated with some of them.

4.2 The Efficient Allocation of Pollution: Fund Pollutants vs. Stock Pollutant

4.2.1 The Efficient Allocation of Pollution: Fund Pollutants

To the extent that emission exceeds the assimilative capacity of the environment, fund pollutants accumulate in the atmosphere and share some of the characteristics of stock pollutants. When the emissions rate is low enough, however, the discharges can be assimilated by the environment, with the result that the link between present emissions and future damage may be broken. When this happens, current emissions cause current damage and future emissions cause future damage, but the level of future damage is independent of current emissions. This independence of allocations among time periods allows us to explore the efficient allocation of fund pollutants using the concept of static, rather than dynamic, efficiency.

Within this framework, we can identify two different types of costs: damage costs and control or avoidance costs. In particular, we need to know something about how control costs vary with the degree of (pollution) control and how damages vary with the amount of pollution emitted. It is generally agreed that marginal damage caused by a unit of pollution increases with the amount emitted (that is, the damage cost function is upward sloping in the level of emission) and that the marginal control costs increases with the amount of pollution control (put differently, the marginal control cost function is downward-sloping in the level of emission, or upward-sloping in the level of abatement).

Table 4.1: Some atmospheric chemical components

BC	**black carbon**
CFCs	chlorofluorocarbons
CH4	Methane
CO	carbon monoxide
CO2	carbon dioxide
GHGs	greenhouse gases
HCFCs	hydrochlorofluorocarbons
HFCs	hydrofluorocarbons
Hg	Mercury
N2 O	nitrous oxide
NH3	ammonia
NMVOC	non-methane volatile organic compounds
NO	nitrogen oxide
NO2	nitrogen dioxide
NOX	nitrogen oxides
O3	ozone, tropospheric and stratospheric
OC	organic carbon
ODS	ozone-depleting substances
PAHs	polycyclic aromatic hydrocarbons
Pb lead	PBDE polybrominated diphenyl ethers
PBTs	persistent, bioaccumulative, toxic chemicals (includes POPs, metals)
PCB	polychlorinated biphenyl
PFAS	per- and polyfluoroalkyl substances PM particulate matter
PM10	PM less than 10 µm in diameter
PM2.5	PM less than 2.5 µm in diameter
POPs	persistent organic pollutants (as defined by international agreements)
SO2	sulphur dioxide

Source: UN (2019), p.109

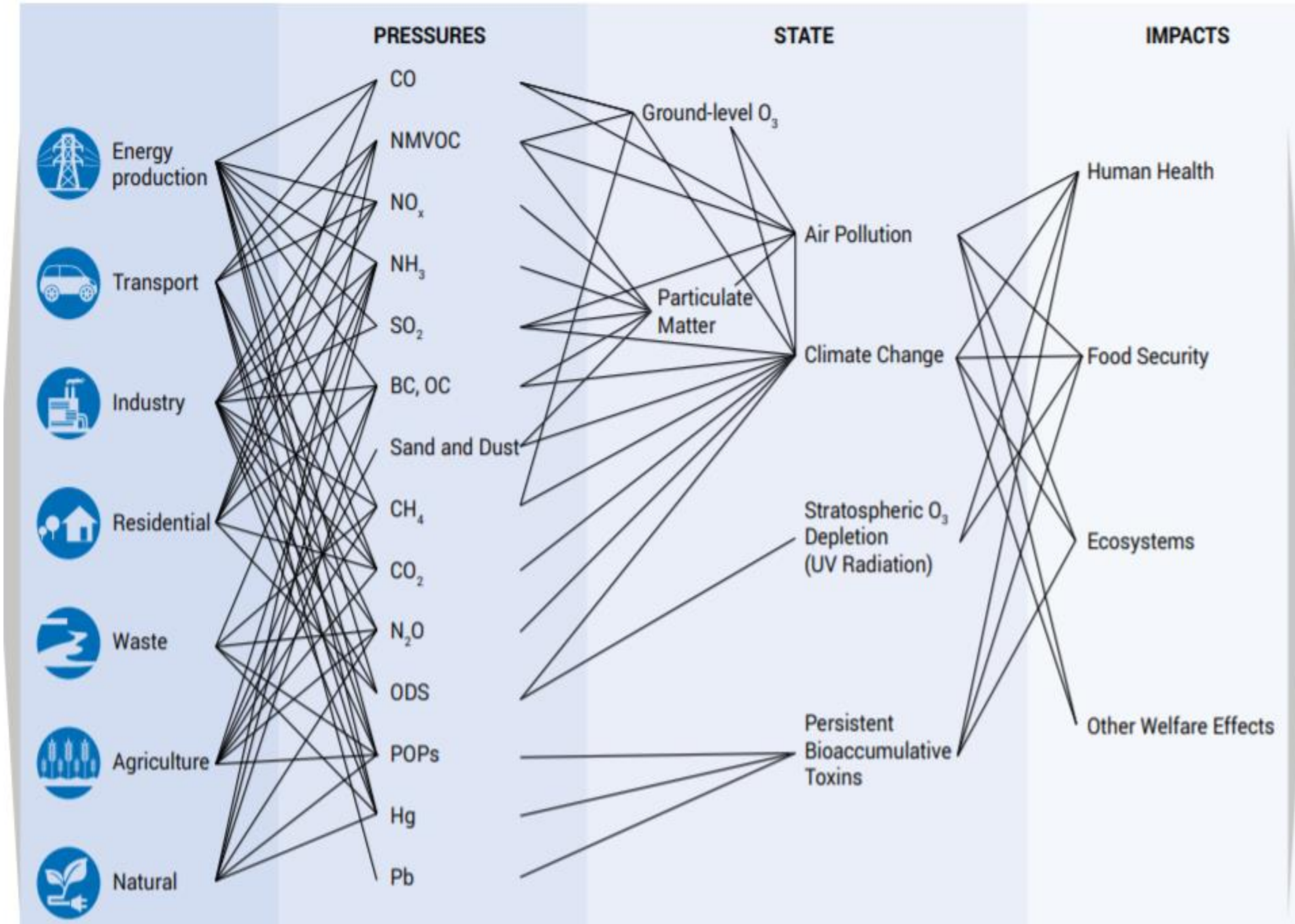

Fig. 4.3: Primary linkages between pressures, state and impacts of atmospheric change. **Source:** UN (2019), p.109

Intuitively, small amounts of pollution are easily diluted in the environment, and the body can tolerate small quantities of substances. However, as the amount in the atmosphere increases, dilution is less effective and the damage is more. Also, larger levels of pollution can lead to abrupt changes in ecosystems. An example is the present concern about climate change (Module 7.2). To understand the nature of the relationship between cost and pollution control, consider, for example, a firm that tries to reduce its particulate emission level by purchasing and installing electrostatic precipitator built to captures 80 percent of the particulates as they flow past in the stack. If it wants further reduction, it will have to install another precipitator and place it in the stack above the first one. But the additional precipitator will only capture 80 percent of the remaining 20 percent (or 16 percent of the uncontrolled emissions). Thus, the cost of additional unit of control increases as the level of control increases.

The efficient allocation for a fund pollution is at the point where the marginal damage cost is equal to the marginal control (abatement) cost (Figure 4.4). A movement from right to left on the horizontal axis refers to greater control and less pollution emitted. The marginal emission control cost can also be interpreted in terms of marginal benefit from pollution. Reducing emission control implies a reduction in control cost. This cost savings can be interpreted in terms of benefits from allowing more pollution. Thus, marginal abatement costs are equal to the marginal benefits that will be lost if emissions fall.

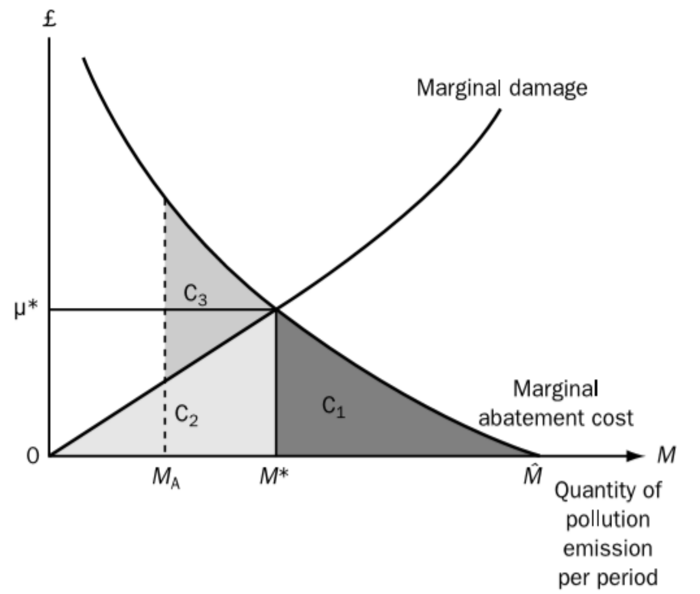

Fig. 4.4. Efficient allocation of a fund pollutant
Source: Perman et al.2003, p.173)

At the efficient allocation (M*), the damage caused by the marginal unit of pollution is exactly equal to the marginal cost of avoiding it. Put differently, the marginal benefit from pollution is equal to the marginal damage. The efficient level of pollution also minimizes the sum of total abatement costs plus total damage costs At M*, the sum of total damage costs (the area C_2) and total abatement costs (the area C_1) is C_2 + C_1.

Any other level of emissions will be inefficient because the further increase in avoidance costs would exceed the reduction in damages. For example, greater degrees of control or too little pollution (points to the left of M*, e.g., point M_A) implies a total cost of $C_1 + C_2 + C_3$, so that C_3 is the efficiency loss arising from the excessive abatement. Similarly, levels of control lower than M* (points to the right of M*) would result in a lower cost of control but the increase in damage costs would be even larger, yielding an increase in total cost.

The value of marginal damage and marginal benefit functions at their intersection is labelled μ* in Figure 4.4. We can think of this as the equilibrium 'price' of pollution. However, as there is no market for pollution, μ*is a hypothetical or shadow price rather than one which is actually revealed in market transactions. We could also describe μ* as the shadow price of the pollution externality. If a market were, somehow or other, to exist for the pollutant itself (thereby internalizing the externality) so that firms had to purchase rights to emit units of the pollutant, μ* would be the efficient market price.

As expected, the efficient level of pollution implies a positive amount of pollution. However, under certain conditions it is possible for the efficient level of pollution to be zero. In such cases, even a single unit of emission imposes a damage cost that exceeds the cost of control. This can be so for highly dangerous radioactive pollutants, such as plutonium, for example. This reality can be represented in Figure 4.4 by an upward shift of the damage cost curve of sufficient magnitude that its intersection with the vertical axis would lie above the point where the marginal cost curve intersects the vertical axis. In addition, the optimal level of pollution will generally not be the same for all parts of a country or region affected by the environmental pollution because of differences in ecological sensitivity, population concentration etc. For example, airports are mostly located outside cities or around the outer boundaries of cities.

In general, the optimal level of pollution will not be the same for all parts of a country (because of differences in ecological sensitivity). Areas that have higher population levels or are particularly sensitive to pollution would have a marginal damage cost curve that intersects the marginal control cost curve close to the vertical axis. Efficiency would imply lower levels of pollution for those areas. In contrast, areas that have lower population levels or are less sensitive should have higher efficient levels of pollution. For examples, some areas are less sensitive to acid rain than others because the local geological strata neutralize moderate amounts of the acid. Thus, the marginal damage caused by a unit of acid rain is lower in those regions than in other less tolerant regions. Also, pollutants affecting visibility are more damaging in national parks and other areas where visibility is an important part of the aesthetic experience than in other more industrial areas.

4.2.1.1 Modified efficiency targets

In some circumstances, society or policy makers may consider a particular effect or cost of pollution of primary importance, such as its effect on human health. In this case, pollution costs would be defined in terms of that effect alone. That leads to a revised or modified efficiency criterion in which the goal is to maximize the difference between all the benefits of pollution and this particular kind of pollution damage. Assume policy makers operate by making risks to human health the only damage that counts (in setting targets), how would this affect pollution targets? The answer depends on the relationship between emissions and health risks. One possible relationship is that illustrated by the vertical line in Figure 4.5a. It assumes strong discontinuity about human health risks associated with pollution. At levels of pollution below a threshold, M^H Total (and marginal) health damage is zero, but at M^H marginal damage becomes infinitely (intolerably) large. In this case, a modified efficiency criterion would require setting emissions target by the damage threshold alone.

It is also possible that marginal health damage is a rising and continuous function of emissions, as in Figure 4.5b. In this case, a trade-off exists in which lower health risks can be obtained at the cost of some loss of pollution benefits. With such a trade-off, both benefits and costs matter and a 'modified efficiency target' would correspond to emissions level M^{H^*}.

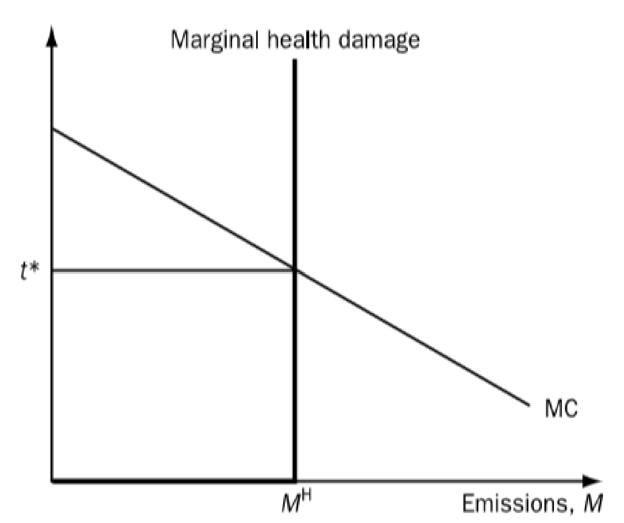

Fig. 4.5a Setting targets according to an absolute health criterion. Source: Perman et al., p.175

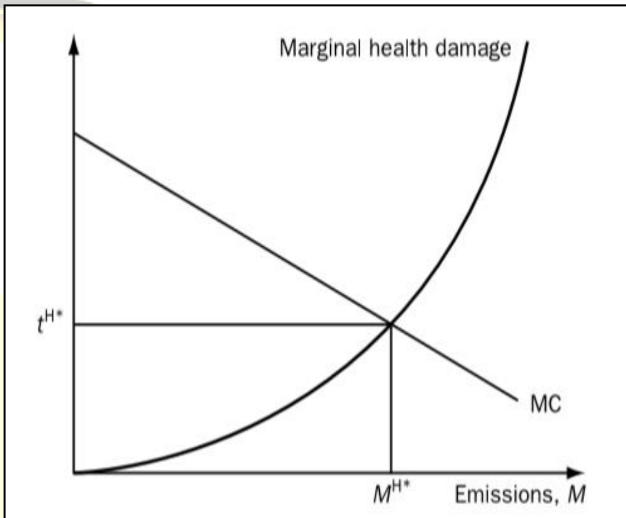

Fig. 4.5b A 'modified efficiency-based' health standard. **Source:** Perman et al.2003, p.175

4.2.1.2 No regrets and double dividends from environmental control

It may be possible sometimes to achieve environmental objectives at no cost or, better still, at 'negative' cost. Policies that allow this to be achieved has been labelled as **'no regrets' policies**. There are several reasons why these may arise:

- double dividends;
- elimination of technical and economic inefficiencies in the energy-using or energy-producing sectors;
- induced technical change;
- achievement of additional ancillary benefits, such as improved health or visual amenity.

The double dividend hypothesis posits that an environmental policy could produce double benefits by reducing environmental damages and also providing revenue that could be used to reduce other taxes thereby creating efficiency gains for the economy. For example, the revenues from an emissions tax (or a system of permits sold by auction) could be earmarked to reduce marginal rates of other taxes in the economy. If those other taxes have distortionary (i.e. inefficiency-generating) effects, then reducing their rate will create efficiency gains.

An environmental programme that requires firms to use new, less polluting techniques which they may not be aware of but which, nevertheless, are more efficient, or which provides incentives for them to do so, can generate a different kind of double benefit. Pollution is reduced and productive efficiency gains are made. One special case of this is dynamic efficiency gains, arising through induced technical change. It has long been recognized that some forms of regulatory constraint may induce firms to be more innovative (Porter's hypothesis, see Module 7.3). If a pollution control mechanism can be devised that accelerates the rate of technical change, then the mechanism may more than pay for itself over the long run.

4.2.2 The Efficient Allocation of Pollution: Stock Pollutants

For stock pollutants, pollution damage depends on the stock level of the pollutant. In the special (but highly unlikely) case where the pollutant stock in question degrades into a harmless form more-or-less instantaneously, the flow pollution model also provides correct answers to determining the efficient level of pollution. If the stock dimension is distinguishable from the flow only by some constant of proportionality, and so we can work just as before entirely in flow units. But in all other cases of stock pollutants, the flow pollution model is invalid.

This has implication for environmental policy. While the damage is associated with the pollution stock, that stock is outside the direct control of policy makers. Environmental protection agencies may, however, be able to control the rate of emission flows. Even where they cannot control such flows directly, the regulator may find it more convenient to target emissions rather than stocks. Given that what we seek to achieve depends on stocks but what is controlled or regulated are typically flows, it is necessary to understand the linkage between the two.

As indicated earlier, the analysis of stock pollution necessitates taking account of space (spatial dimension) and time (intertemporal dimension). We can distinguish between pollutants with a relatively short residence time (of the order of a day or so) and those with considerably longer lifetimes (years rather than days, let us say).

4.2.2.1 Spatial Implications of stock pollutants

Here we consider pollution control where damages depend on location of the emissions. The focus is on stock pollutants which have relatively short residence times in the environmental media into which they are dumped. Figure 4.6 provides a graphic illustration. There are two polluting *sources*, S1 and S2, that are located near four urban areas, R1, R2, R3 and R4 9 which we call *receptors*. These areas contain populations whose health is adversely affected by local ambient concentrations of the pollutant. We are interested in the amount of pollution the receptors receive from the emission sources. We assume that there is no long-term accumulation effect. Atmospheric processes break up and degrade concentrations rather quickly, so that emissions from the two sources persist for at most a few days. Thus on any one day, pollutant concentrations are determined purely by emissions of the last few days.

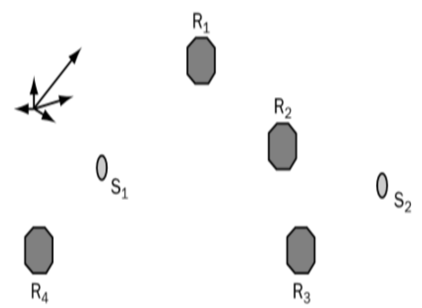

Fig. 7.6. A spatially differentiated airshed. Source: Perman et al., p.178

We need to know how the pollutant mixes across the regions. Mixing of a pollutant refers to the extent to which physical processes cause the pollutant to be dispersed or spread out. One possibility is that emissions are '**uniformly mixing**' (UM). A pollutant is uniformly mixing if physical processes operate so that the pollutant quickly becomes dispersed to the point where its spatial distribution is uniform. In other words, the measured concentration rate of the pollutant does not vary from place to place. This is the case with most greenhouse gases (GHGs).

4.2.2.2 Uniformly-mixing stock pollutants with short residence times

When pollutants are UM, the location of the emission source is irrelevant for the spatial concentration of pollution. Irrespective of the source location, pollutant stocks become evenly distributed across the whole spatial area. So, what matters as far as concentration rates at any receptor are concerned, is the total amount of those emissions. In this case, the simple flow pollution model can be used with minor modification to derive the efficient level of pollution. The modification relates to the relationship between the level of emissions of the pollutant (M) and the pollutant stock size (A). This relationship is now determined by a factor of proportionality, k, such that

$$A = kM \qquad (4.3)$$

with k fixed for any particular kind of pollution. Therefore, while damage is a function of the stock, and benefit is a function of flow, the damage function, (4.2), can be translated into an equivalent flow function using (4.3), that is

$$D = D(kM) \qquad (4.4)$$

When pollutants are not uniformly mixing or when they have relatively long lifespans, it will not be possible to use the flow pollution model to determine the efficient level of pollution. In the former case (where pollutants are not uniformly mixing), the location of pollution source will matter for the spatial concentration of the pollution and it will be impossible to have a single relationship between emissions and concentration over all space. A given total value of M will in general lead to differentiated values of A across receptors. Moreover, if M remained constant but its source distribution changed then the spatial configuration of A would also change. Most air, water and ground pollutants are not uniformly mixing. Examples of non-uniform mixing air pollution problems include ozone accumulation in the lower atmosphere, oxides of nitrogen and sulphur in urban airsheds, particulate pollutants from diesel engines and trace metal emissions.

For non-uniform mixing pollutants, it could be possible to regulate the environmental problem by controlling *ex ante* the location of pollution creators and victims. This approach, implemented primarily by zoning and other forms of planning control, forms a substantial part of the longer-term way of dealing with spatial aspects of pollution. However, where the location of polluters and people are already determined, and moving either is not a feasible option, the attention would focus on determining targets for emissions (the efficient level of pollution) from the various sources.

4.2.2.3 Non-uniformly-mixing stock pollutants with short residence times

Suppose that there are *J* distinct receptors, each being indexed by the subscript *j* (so j = 1, 2, . . ., *J*) and *N* distinct pollution sources, each being indexed by the subscript *i* (so *i* = 1, 2, . . ., N). Various physical and chemical processes determine the impact on pollutant concentration in any particular receptor from any particular source. For simplicity, we assume that the relationships are linear[2]. In that case, a set of constant 'transfer coefficients' d_{ji} can be defined. This describes the impact on pollutant concentration at receptor *j* attributable to source *i*. The total level, or concentration rate, of pollution at location *j*, A_j will be the sum of the contributions to pollution at that location from all N emission sources. This can be written as

$$A_j = \sum_{i=1}^{N} d_{ji} M_i \qquad (4.5)$$

where M_i denotes the total emissions from source i.

Assume as in Figure 4, there are N=2 sources and J=4 receptors, then we will have four equations corresponding to equation 4.5 which are given as

$$A_1 = d_{11}M_1 + d_{12}M_2 \qquad (4.6a)$$

$$A_2 = d_{21}M_1 + d_{22}M_2 \qquad (4.6b)$$

$$A_3 = d_{31}M_1 + d_{32}M_2 \qquad (4.6c)$$

$$A_4 = d_{41}M_1 + d_{42}M_2 \qquad (4.6d)$$

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[2] This is a very good approximation for most pollutants of interest but may not apply in a few cases, such as low-level ozone accumulation.

Using matrices, we can express this in compact from as

A = DM

$$\begin{bmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{bmatrix} = \begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \\ d_{31} & d_{32} \\ d_{41} & d_{42} \end{bmatrix} \begin{bmatrix} M_1 \\ M_2 \end{bmatrix} \quad (4.7)$$

Knowledge of the **M** vector and the **D** matrix then allows us to calculate ambient pollution levels, **A.** As in previous cases, the socially efficient level of emissions from each source is the set of emission levels that maximizes net benefits. This will consist of N values of M_i, one for each source. Efficiency in this case implies setting the emissions target (or standard) for each firm so that the private marginal benefit of its emissions is equal to the marginal damage of its emissions.

$$B_i{}'(M_i) = \sum_{j=1}^{J} D_j' \, (A_j) d_{ji} \qquad (4.8)$$

$$\text{for } \; i \; = 1 \ldots \text{N}$$

where $B_i'(M_i) = \frac{\partial B_i}{\partial M_i}$ and $D_j'(A_j) = \frac{\partial D_j}{\partial A_j}$

Note that because the i^{th} firm's emissions are transferred to some or all of the receptors, the marginal damage attributable to the firm is obtained by summing its contribution to damage over each of the *J* receptors.

An interesting property of the solution to equation set (4.8) is that not only will the efficient emission level differ from firm to firm, but also the efficient ambient pollution level will differ among receptors. All else being equal, firms located at sources with the highest pollution impact would be required to emit the least. At the same time, those receptors which would (in an unconstrained world) experience the highest pollution-stock level should have the highest efficient ambient pollution level. These two considerations have to be met jointly.

In practice, environmental regulators might deem that it is unethical for the pollution from firms to vary from place to place. So, they might impose an additional constraint on the problem to reflect this ethical position. One form of constraint is that the pollution level in no area should exceed some maximum level A^*(that is $A_j^* \leq A^*$ for all *j*). The imposition of an additional constraint will lead to a lower maximized net benefit from pollution (it will be associated with an efficiency loss). This efficiency loss is what is traded for the goal sought (in this case, greater equity in pollution level across firms).

4.2.2.4 Uniformly-mixing stock pollution with relatively long active lifespan

For these class of pollutants, the uniformly mixing assumption implies that pollutant concentrations will not differ from place to place, and so the spatial dimension of emissions control is no longer of direct relevance. Second, persistence of pollution stocks over time means that the temporal dimension is of central importance. Thus, an efficient pollution control programme will need to take account of the trajectory of emissions over time, rather than just at a single point in time. In other words, an efficient allocation of a stock pollutant **with relatively long active lifespan** must take into account the fact that the pollutant accumulates in the environment over time and that the damage caused by its presence increases and persists as the pollutant accumulates. By their very nature, the pollutants create an interdependency between the present and the future, since the damage imposed in the future depends on current actions. Hence analysis of efficient level of pollution must be cast within a dynamic framework. This is similar to what we learnt under efficient allocation of a depletable resource.

Assume a commodity, X, the production of which involves the generation of a proportional amount of a long-lived stock pollutant (that is, X is produced jointly with the stock pollutant; reducing the amount of pollution will require taking some resources away from the production of X). Assume further that the damage caused by the presence of the pollutant in the environment is proportional to the size of the accumulated stock. As long as the stock of pollutants remains in the environment, the damage persists. As usual, the dynamic efficient allocation maximizes the **present value** of the net benefit where the net benefit at any point in time, t, is equal to the benefit received from the consumption of X minus the cost of the damage caused by the presence of the stock pollutant in the environment. Both benefit and cost of damages increases as more X is produced.

As in the case of depletable resource, the efficient quantity of X (and therefore, the addition to the accumulation of the pollutant in the environment) would decline over time as the marginal cost of the damage rises (counterpart of declining extraction profile) while the price of X would rise over time, reflecting the rising social cost of production (counterpart of increasing price profile). As was the case with rising extraction cost in the case of depletable resources, technological progress could modify the efficient allocation, for example, by reducing the amount of pollutant generated per unit of X produced, or by creating ways to recycle the stock pollutant rather than injecting it into the environment; or by introducing ways of rendering the pollutant less harmful. Each and all of these would lower the marginal damage cost associated with a given level of production of X so that more of X could be produced for a given level of pollution.

As it is with depletable resources, stock pollutants with relatively long active lifespan also raise intergenerational equity concerns. Damages persist well after the benefits received from incurring the damages have been forgotten and these are passed on to future generations.

Given that damage at time t is determined by the contemporaneous stock size or concentration rate of the pollutant in a relevant environmental medium (A_t) and that gross benefits depend on the flow of emissions (M_t), we can represent the damage and (gross) benefit functions by

$$D_t = D(A_t) \qquad (4.9)$$

$$B_t = B(M_t) \qquad (4.10)$$

With relatively long-lived pollutants, emissions add to existing stocks and those stocks accumulate over time. In addition, except in the special case where pollutants are infinitely long-lived, part of the existing stock will decay or degrade into a harmless form over time, thereby having a negative impact on stock accumulation. This stock–flow relationship is often represented in a differential equation, such as

$$\acute{A}_t = \frac{dA}{dt} = M_t - \alpha A_t \qquad (4.11)$$

$$0 \leq \alpha \leq 1$$

Emission at time t, M_t, increases the stock of pollution, A_t. However, some of the existing sock are transformed into harmless substances by physical or chemical processes, or absorbed into oceans or other sinks where it has no damaging effect. The amount of pollution decay is captured by the term $-\alpha A_t$ where α is the *rate of decay or assimilation*. The net effect on A (and so whether A_t is positive or negative overall) depends on the magnitudes of the two terms on the right-hand side of equation 4.11.

- If α = 0, the pollutant exhibits no decay and the rate of stock accumulation ($\acute{A}_t$) is just equal to the flow of emission(M_t). Damages arising from current emissions will last indefinitely and the pollution stock and pollution damages will increase without bounds through time as long as M is positive. The stock at any time (which can be gotten from finding the integral of 7.11 is the sum of all previous emissions. Pollutants with this feature are known as a *perfectly persistent pollutant*. Approximate examples are some synthetic chemicals, such as heavy metal residuals, and toxins such as DDT and dioxin.

- If α = 1, we have instantaneous decay, which means the pollutant can be regarded as a flow rather than a stock pollutant.

- For the more general case of *imperfectly persistent pollutant*, we will expect to find 0 < α < 1. Here, the pollutant stock decays gradually over time, being converted into relatively harmless elements or compounds. An example, for which α is very low is Greenhouse gases (GHGs).

We have assumed that α is constant (that is a constant proportion of the pollution stock decays over any given interval of time). However, this may be invalid in practice, as we may have situations where the decay rate changes substantially over time, or varies with changes in either A or M.

Integrating equation 7.11 over time we obtain

$$A_t = \int_{\tau=t_0}^{\tau=t} (M_t - \alpha A_t) d\tau \qquad (4.12)$$

where t_0 denotes the first point in time at which the pollutant in question was emitted.

We can use this framework to address the problem at hand. Assume now that the policy maker aims to maximize discounted net benefits over some suitable time horizon (an infinite span, for example). Using t = 0 to denote the current period of time using the definition of gross benefits and damages in 4.8 and 4.9, the policy maker's objective is to select M_t for t = 0 to t = ∞ to maximize

$$\int_{t=0}^{t=\infty} (B(M_t) - D(A_t)) e^{rt} dt \qquad (4.13)$$

where r is the social (consumption) discount rate.

A complete description of efficient stock pollution will consist of a trajectory (or time path) of, emission levels through time. In general, this optimal trajectory will be one in which emission levels vary throughout time. However, in many circumstances, the trajectory will consist of two phases: *a steady state* in which emissions (and concentration levels) remain constant indefinitely at some level; and an *adjustment phase*; a path which shows how emissions (and concentrations) move from current levels to their efficient, steady-state levels. This adjustment process may be quick, or it may take place over a long period of time.

Obtaining the optimal trajectory of emission from (4.13) involves the application of the calculus of optimal control. This is outside the scope of this lecture material; hence we focus on describing one of the results: the efficient steady-state pollution level. In the steady state[3], the pollution flow and the pollution stock are each at a constant, unchanging level. Hence the time subscripts we have attached to variables become redundant and can be dropped. Moreover, with an unchanging stock A_t= 0 and so equation 4.11 simplifies to M = αA.

This result is intuitive. For a pollutant that accumulates over time, the pollution stock can only be constant if emission inflows to the stock (M) are equal to the amount of stock which decays each period (αA). Thus, in a steady state, the stock–flow relationship between A and M can be written as

[3] The term steady state is sometimes used to connote a state in which all variables of interest in some system are growing at a constant rate. This is not the idea here. Also, while we have assume the existence of a steady state, such may not always exist.

$$A = \frac{M}{\alpha} \qquad (4.14)$$

Equation (4.14) shows that in a steady state, the smaller is the value of α the larger will be the pollution stock for any given level of emissions. In general, an efficient steady-state level of pollution emissions requires that the following condition be satisfied:

$$\frac{dB}{dM} = \frac{dD}{dA}\left(\frac{1}{r+\alpha}\right) \qquad (4.15)$$

Equation 4.15 is a variant of the familiar marginal condition for efficiency requiring that the marginal benefit and the marginal cost of the chosen emissions level should be equal. More precisely, it can be read as an equality between the present value of the gross benefit of a marginal unit of pollution (the left-hand side of 4.15) and the present value of the damage that arises from the marginal unit of pollution (the right-hand side of 4.15).

Note that a marginal emission today has benefits only today, and so the present value of that marginal emission is identical to its current marginal benefit. In contrast, the damage arising from the marginal emission takes place today and in future periods. The 'discount factor' 1/(r +α) has the effect of transforming the single period damage into its present-value equivalent. At the level of M that satisfies equation 7.15, the value taken by the expression on each side of the equation is known as the *shadow price* of a unit of emission.

Two very important deductions can be gotten from (4.15)

- *Other things being equal, the faster is the decay rate, the higher will be the efficient level of steady-state emissions*: for any given value of dD/dA, a rise in α implies that the value of dB/dM would have to fall to satisfy the marginal equality. A lower value of dB/dM implies higher emissions. Intuitively, the greater the rate of decay, the larger the 'effective' discount rate applied to the marginal stock damage term and so the smaller its present value. A higher discount rate means we attach less weight to damages in the future, and so the emission level can be raised accordingly.

- *Other things being equal, the larger is the consumption discount rate, the higher will be the efficient level of steady-state emissions*: For any given value of dD/dA, a rise in r implies that the value of dB/dM would have to fall to satisfy the marginal equality. A lower value of dB/dM implies higher emissions. Intuitively, the greater is the consumption discount rate *r*, the larger is the discount rate applied to the stock damage term and so the smaller is its present value. A higher discount rate means we attach less weight to damages in the future, and so the emission level can be raised accordingly.

The second observation has significant implication for policy respecting long or infinitively lived stock pollution. Often there will be need to decide on the appropriate social discount rate to apply in determining efficient or desirable pollution targets. As it turns out, the choice of an appropriate discount rate can itself be controversial.

4.3 Pollution in Africa

Pollution includes water, air and land pollution. A major cause of water pollution in Africa is the throwing of general waste into local bodies of water. Communities in poverty do not usually have the funding to create proper waste-management systems so they pollute their water supplies instead. Once a water source suffers pollution, the contaminants can spread into the soil that supplies food and economic activity. For example, people have found metals from local waste in the soil of major agricultural plots of land.[4]

Air pollution is a major problem throughout the world with over 90 percent of people living in places that do not meet the World Health Organization's (WHO's) air quality guidelines[5]. It has also become the biggest environmental risk to Africa currently. The 2019 Global Environmental Outlook (UN, 2019) confirmed that both outdoor and indoor air quality is deteriorating rapidly in many areas in Africa due to various factors, such as the use of firewood and other biomass as sources of energy, increasing traffic volumes, importation of old second-hand vehicles, and increased use of the two-stroke engine motorcycles as alternative means of transport in both urban and rural areas.

Africa's air pollution problem differs from that found in many developed countries. For example, air pollution in cities, such as London, is mainly due to the burning of hydrocarbons for transport, but in African cities, such as Lagos, air pollution is due to the burning of rubbish, cooking indoors with inefficient fuel stoves, millions of steel diesel electricity generators, cars which have had the catalytic converters removed and petrochemical plants, all pushing pollutants into the air over the cities. In addition, compounds such as sulphur dioxide, benzene and carbon monoxide, that haven't been issues in western cities for decades, may be a significant problem in African cities[6].

Multinational companies and trade activities are continuing to add to the pollution in Africa. Governmental enforcement of laws requiring business and trading activities to be more environmentally friendly is low. Companies and trading activities cause the release of gas, oil spills, dangerous chemicals, and waste accumulating on the ground or in water thus increasing

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[4] https://www.washingtonpost.com/business/energy/air-pollution/2019/11/06/9487ebfe-007b-11ea-8341-cc3dce52e7de_story.html.

[6] https://www.theguardian.com/global-development/2016/oct/20/air-pollution-deadlier-africa-than-dirty-water-or-malnutrition-oecd

air and water pollution. Air pollution from coal releases dangerous gases that can poison plants, contaminate communities and produce acid rain. Unlike many other countries outdoor air pollution is growing at a fast pace in Africa. This is in spite of slow industrialization in many countries. And unless radically new approaches and technologies are put to use, the situation may be worse in future if many other countries pick up on industrialization. In addition, while many major environmental hazards have been improving with development gains and industrialization, outdoor (or "ambient particulate") air pollution from traffic, power generation and industries is increasing rapidly in Africa, especially in fast-developing countries such as Egypt, South Africa, Ethiopia and Nigeria.[7]

According to reports by the Organization for Economic Co-operation and Development, annual human and economic cost of tainted air runs to 712,000 lost lives and £364bn.[8] The Continent's air pollution is causing more premature deaths than unsafe water or childhood malnutrition, and could develop into a health and climate crisis.[9] For Africa as a whole, the estimated economic cost of premature air pollution deaths in 2013 was roughly $215bn (£175bn) a year for outdoor air pollution, and $232bn for household, or indoor, air pollution. Annual deaths from ambient (outdoor) particulate matter pollution across the continent increased by 36% from 1990 to 2013. Over the same period, deaths from household air pollution also continued to increase.[10]

One of the factors driving increasing pollution is urbanization and growth of urban slums. According to the World Health Organization (WHO), global urban air pollution levels increased by eight per cent between 2008 and 2013. This is expected to rise given the increasing level of migration to urban areas, which will likely lead to more human activities and more pollution. More than 80 per cent of people living in urban areas are exposed to air pollution levels that exceed WHO limits, threatening lives, productivity and economies. Indeed, Africa urbanizes at a very fast pace: today's 472 million urban dwellers will be around a billion in 2050. In Africa, the increasing level of urbanization coupled with poor urban planning leads to large

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[7] https://www.theguardian.com/global-development/2016/oct/20/air-pollution-deadlier-africa-than-dirty-water-or-malnutrition-oecd

[8] https://www.theguardian.com/global-development/2016/oct/20/air-pollution-deadlier-africa-than-dirty-water-or-malnutrition-oecd. Other sources suggest an estimated 600,000 deaths https://www.unenvironment.org/news-and-stories/story/air-pollution-africas-invisible-silent-killer-1; https://www.who.int/quantifying_ehimpacts/publications/PHE-prevention-diseases-infographic-EN.pdf?ua=1).

[9] Estimates suggest that dirty air could be killing 712,000 people a year prematurely, compared with approximately 542,000 from unsafe water, 275,000 from malnutrition and 391,000 from unsafe sanitation (https://www.dw.com/en/west-africa-struggles-with-rise-in-pollution/a-49965986; https://www.theguardian.com/global-development/2016/oct/20/air-pollution-deadlier-africa-than-dirty-water-or-malnutrition-oecd).

[10] Ibid.

numbers of people living in congested and poorly-serviced housing. This serves to exacerbate the problem of pollution. It is believed that the human and economic costs of air pollution in the continent might "explode" without bold policy changes in Africa's urbanization policies.[11] Figure 7.7 shows that urban vulnerability is already very high in many countries in Africa.

According to some authors, "the 'new' problem of outdoor air pollution in Africa is too large to be ignored or deferred to tomorrow's agenda. At the same time, Africa cannot afford to ignore the 'old' problem of household pollution or to consider it largely solved: it is only a few high-income countries – Algeria, Egypt, Libya, Mauritius, Morocco, Seychelles and Tunisia – that can afford to view the problem of air pollution as being a problem of outdoor particulate pollution alone." Overall, it is obvious that current means of transportation and energy generation in African cities are not sustainable. It is also not an easy choice. For example, whereas countries, such as China has reached a level of development that has allowed it to concentrate on solving air pollution, most African countries must grapple with several major environmental burdens (including unsafe water or unsafe sanitation or underweight children) at the same time.[12] In summary, among other things, African governments need to develop the political will to introduce and implement laws that limit pollution and also adopt medium and long term measures to acquire clean energy.[13]

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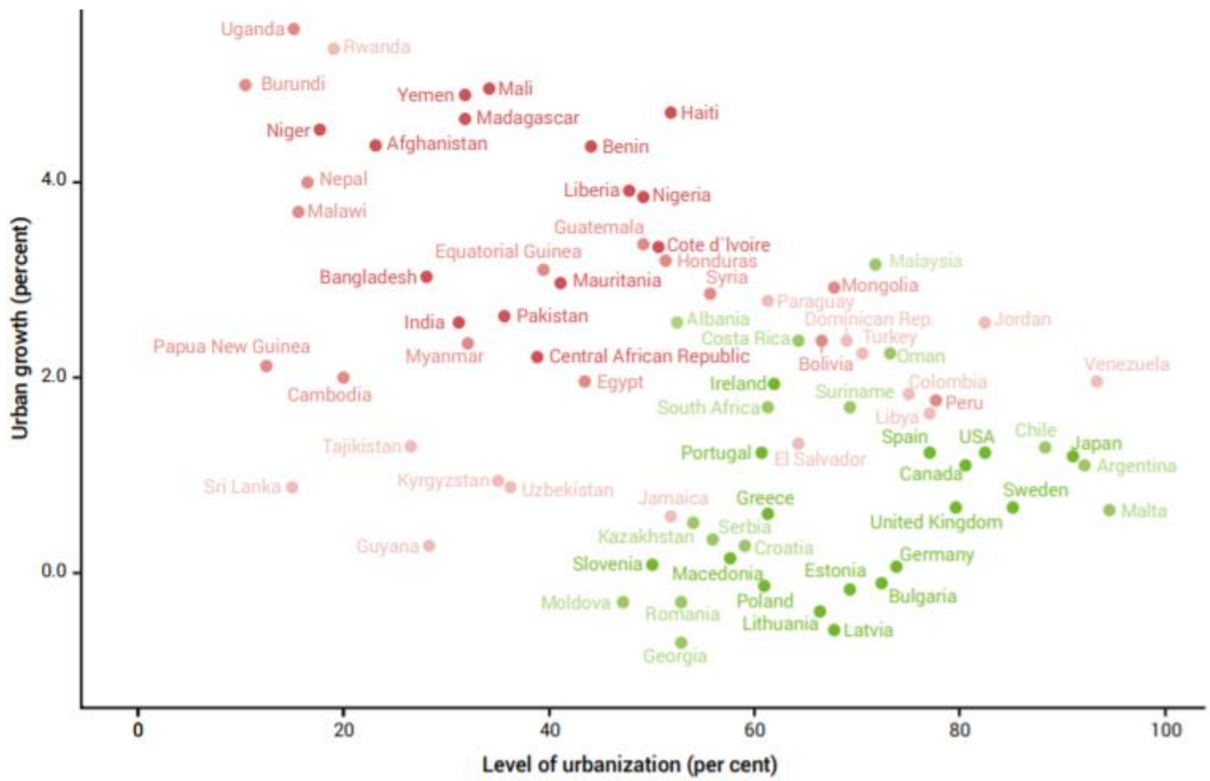
[11] https://www.theguardian.com/global-development/2016/oct/20/air-pollution-deadlier-africa-than-dirty-water-or-malnutrition-oecd; https://www.unenvironment.org/news-and-stories/story/air-pollution-africas-invisible-silent-killer-1

[12] Ibid.

[13] https://www.unenvironment.org/news-and-stories/story/air-pollution-africas-invisible-silent-killer-1



Classes of urban vulnerability	Level of urbanization	Growth rate 2000-2015
Very low	75.80	0.71
Low	69.19	0.92
Medium	56.07	2.36
High	43.51	2.89
Very high	38.59	3.71

Fig. 4.7 Urbanization and urban vulnerability. **Source:** Garschagen et al. (2014).in UN (2019), p.34.

Summary

- An environmental problem emerges when the rate of waste discharge into the environment exceeds its assimilative capacity (a pollution problem) and/or when a renewable resource is harvested beyond its regenerative capacity so that the ecosystem functions are affected negatively.

- Pollution is not only a problem by itself, it impairs all the other estuarine functions of the environmental resource base (ERB). Society needs to decide what pollution level should be accepted and how this should be allocated among the various sources.

- Economic efficiency is often proposed as a more realistic goal for setting pollution targets. What exactly is the efficient allocation of pollution will depend on the nature of the pollutant and the associated damages. Different types of pollutants have different damage mechanism and hence differing impact on the absorptive capacity of the environment. They will therefore require different policy responses. Good public environmental policy requires an understanding of the nature of various pollutants, their effects on the environment, and their costs.

- Stock pollutants are pollutants for which the environment has little or no absorptive capacity. Such pollutants accumulate over time as emissions enter the environment. Fund pollutants are pollutants for which the environment has some absorptive capacity. These pollutants will generally not accumulate as long as the emissions rate does not exceed the absorptive capacity of the environment.

- The zone of influence of a pollutant also matters. Horizontal dimension of influence refers to the spatial domain over which damage from an emitted pollutant is experienced (local, regional, global), while the vertical zone of influence shows whether pollution damage is caused mainly by ground-level concentrations of an air pollutant or by concentrations in the upper atmosphere.

- The efficient allocation for a fund pollution is at the point where the marginal damage cost is equal to the marginal control (abatement) cost.

- In some circumstances, society or policy makers may consider a particular effect or cost of pollution of primary importance, such as its effect on human health. In this case, pollution costs would be defined in terms of that effect alone. That leads to a revised or modified efficiency criterion in which the goal is to maximize the difference between all the benefits of pollution and this particular kind of pollution damage.

- The analysis of stock pollution necessitates taking account of space (spatial dimension) and time (intertemporal dimension). Also important is the active lifespan of the pollutant.

- For uniformly-mixing stock pollutants with relatively short active lifespan, the location of the emission source is irrelevant for the spatial concentration of pollution, so the simple flow pollution model can be used with minor modification to derive the efficient level of pollution. However, most air, water and ground pollutants are not uniformly mixing.

- For non-uniform mixing pollutants with relatively short active lifespan, it could be possible to regulate the environmental problem by controlling ex ante the location of pollution creators and victims. This approach, implemented primarily by zoning and other forms of planning control, forms a substantial part of the longer-term way of dealing with spatial aspects of pollution. However, where the location of polluters and people are already determined, and moving either is not a feasible option, the attention would focus on determining targets for emissions (the efficient level of pollution) from the various sources.

- In this case, the efficient emission level will differ from firm to firm, and the efficient ambient pollution level will also differ among receptors. All else being equal, firms located at sources with the highest pollution impact would be required to emit the least. At the same time, those receptors which would (in an unconstrained world) experience the highest pollution-stock level should have the highest efficient ambient pollution level.

- An efficient allocation of a stock pollutant with relatively long active lifespan must take into account the fact that the pollutant accumulates in the environment over time and that the damage caused by its presence increases and persists as the pollutant accumulates.

- In this case, the dynamic efficient allocation maximizes the present value of the flow of net benefits, where the net benefit at any point in time, t, is equal to the benefit received from pollution activity minus the cost of the damage caused by the presence of the stock pollutant in the environment.

- In this case, the choice of an appropriate discount rate can itself be controversial. In addition, stock pollutants with relatively long active lifespan raise intergenerational equity concerns.

- Air pollution is arguably the most serious environmental risk facing Africa today.

Discussion/Review Questions and Exercises

1. What is the significance of the distinction between stock and flow pollutants in the formulation of environmental policy? Provide an example each of a stock and a flow pollutant.

2. Explain the concept of the 'efficient level of pollution'. What information is required in order to identify such an efficient quantity?

3. What differences and considerations are relevant for determining the efficient level of pollution for a uniformly-mixing stock pollutant and a non-uniformly-mixing stock pollutant with relatively short active lifespan?

4. What considerations come into determining the efficient level of pollution for a stock pollutant with a relatively long active life span?

5. Discuss the following propositions

   (a) 'Only the highest standards of environmental purity will do.'
   (b) 'A clean environment is a public good whose benefits cannot be privately appropriated. Therefore, private industry which is run for private gain will always be the enemy of a clean environment.'

6. Using equation (7.15), deduce the effect of
   (i) a decrease in α and
   (ii) an increase in r (ceteris paribus) on

   (a) M^* (b) A^* (c) μ^*

7. What is the most important pollution problem in your country? What are the drivers and what do you think can be done to address it?

Materials used for this Module

1. Perman, R., Ma Y., McGilvray J. and Common M. (2003). **Natural Resource and Environmental Economics,** 3rd edition**.** Edinburgh, Longman.

2. Tietenberg, T. & Lewis, L. (2012). Environmental & Natural Resource Economics 9th Edition, The Pearson Series in Economics.

3. UN Environment (2019). Global Environment Outlook – GEO-6: Healthy Planet, Healthy People. Nairobi. DOI 10.1017/9781108627146.

Module 4.2: Environmental and Natural Resource Management Policy Instruments (4.5 hours)

Learning Outcome

This Module provides a discussion on Policy Instruments that are potentially available to governments to use to address environmental and natural resource problems. After going through this module, you should be able to

- ✓ Know the two broad divisions of policy instruments available for regulating environmental problems.
- ✓ Identify the main command and control instruments for environmental and natural resource management.
- ✓ Explain how command and control instrument(s) could be used to help solve environmental problems and the conditions under which they could be effective.
- ✓ Identify the three broad categories of economic instruments available for environmental control.
- ✓ Explain certain advantages of economic instruments and possible objectives that they could achieve.
- ✓ Explain the key features of price-based instruments and when they can be used
- ✓ Explain what property rights-based instruments are and when they can be used
- ✓ Explain the key features of legal, voluntary and information-based instruments for environmental and natural resource management and when they can be used.
- ✓ Understand public provision as an Environmental Policy tool and its limitations.
- ✓ Appreciate the relevance of second-best theory in environmental and natural resource policy, and especially in the context of Sub-Sharan Africa.

Content Outline

4.1.1 Introduction
4.1.2. Command-and control Instruments
    4.1.2.1 Regulation of Technology
    4.1.2.2 Regulation of Performance
4.1.3 Economic Instruments
    4.1.3.1 Price-Based Instruments
    4.1.3.2 Property Rights-based Instruments
    4.1.3.3 Legal, Voluntary and Information-Based Instruments
4.1.4 Direct Provision of Public Goods
4.1.5 Second-best mix of policies
Summary
Discussion/Review Questions and Exercises
Exercises
Materials used for the Lecture

4.1.1 Introduction

Where the government has the will, means and capacity to address environmental and natural resource management problems, it will still need to find and use appropriate policy tools to achieve the purpose. The policies available to redress environmental problems fit into two broad classes: command and control instruments and economic instruments.

Command and Control Instruments are the laws and regulation used by governments to directly control pollution and manage natural resources. In the application of these instruments, the government stipulates the technologies that must be used to curb pollution, determines the maximum amount of emissions that is permissible, and regulates the use of natural resources. Polluters have little or no flexibility in the application of command and control instruments as the laws and regulations must be observed uniformly as stipulated by all agents. To ensure compliance, the government is required to monitor enforcement and prosecute offenders in a court of law. This usually requires detailed information about regulated industries, since the government must understand the details of industrial technologies.

Economic instruments provide market and financial incentives for polluters and natural resource users to change their behaviour by making pollution and overuse of natural resources more costly. In economic terms, economic instruments internalize externalities (environmental costs) through increasing the prices that individuals and industries must pay to use resources or to emit pollutants. As pollution or the use of natural resources become more expensive, polluters and consumers have strong financial incentives to reduce such activities through conservation, substitution of materials, or rationalizing consumption.

Both command and control and economic instruments attempt to shift the costs and responsibilities associated with pollution or over exploitation back to the polluter or users (the Polluter Pays Principle, PPP). The differences between the two policy types, however, are significant in terms of cost and effectiveness. Economic instruments possess a number of inherent advantages over command and control instruments for many problems. They are generally more affordable, flexible, responsive, and encouraging to technology innovation. In addition, although economic instruments cannot overcome a corrupt or weak political structure, they can help make moderately functioning governance structures work more effectively. As such they try to minimize possible policy and institutional failures.

In practice, economic instruments are used together with command and control instruments to increase policy efficiency, and achieve environmental targets at a lower cost. Economic instruments can complement rather than fully replace command and control policies, offering many potential applications even in countries with substantial policy constraints. However, combining policy elements requires care since the elements can sometimes work at cross-purposes.

4.1.2. Command-and control Instruments

Command and control (CAC) policies for environmental regulation include those that regulate technology and those that regulate performance.

4.1.2.1 Regulation of Technology

The regulation of technology allows governments and their environmental agencies to ban or restrict specific technologies that cause pollution or deplete natural resources. Conversely, they may require the use of technologies that reduce emissions or prevent overuse of natural resources. The two policy options in this category are the designation (specification) of technology and zoning.

(i) Designating Technologies:

By designing a standard, the regulator (typically the government through its environmental protection agency) can prescribe the technology that firms and households have to use, prevent the use of some technology altogether, or prescribe the conditions under which a polluting technology can operate. For example, regulations may require the use of the "best available" or "state-of-the-art" technology to ensure that polluters adopt improvements as technology changes. As an illustration, consider the case where public service minibuses are emitting a lot of smoke yet simple observation may show that other minibuses do not emit as much smoke. The regulator can therefore require the polluting minibus to cut down on its smoke emissions using available cleaner technology.

(ii) Zoning

In some cases, governments or its environmental agencies may restrict the location of the use of technology. To do this they use zoning laws to regulate where firms may use certain technologies because they generate excess noise, odours, or potential exposure to hazardous materials in populated areas. On the other hand, these same technologies may be zoned for use in areas where the effects can be absorbed without excessive damage to the environment or natural resources.

Mandatory technology design standards are the most commonly used environmental control instruments because they have an intuitive simplicity and they appeal to the desire of policymakers to quickly address (if not solve) the problem at hand. Technology standards have been employed for a whole range of purposes, including automobile emission control (where mandatory installation of catalytic converters on new cars is now almost universal), regulation of nuclear power (where plants are regulated not only by being given maximum emission levels (zero in this case) but are also required to comply with more detailed and specific technology requirements, such as multiple control systems and specific kinds of hazardous material containment), and natural resource management (for example, in fishing where the use of cyanide and dynamite are banned, in agriculture and forestry, where certain pest control techniques are banned, and in some cases replanting of trees after harvest is mandatory).

The regulation of technology through design standards is particularly appropriate when

- Technical and ecological information about the environmental problem to be resolve is complex.
- Crucial knowledge is available at the government rather than at the firm level so that the overall impact of the regulation can be estimated but not the effect at the individual or firm level.
- Firms are unresponsive to price signals (e.g.,a firm could be operating in a non-competitive setting), or investments to improve environmental practices are large and have little benefit to the individual firm.
- Standardization of technology could hold some major advantages for both producers and the general public as in the case of catalytic converters.
- One design or technology is definitely superior to others available, making its mandated implementation the best alternative.
- Monitoring costs are high so that monitoring emissions is more difficult than monitoring technology

Where appropriate, the use of technology regulation can provide clarity of choice, economy of administration, effective control, and ease of monitoring. Design standards are also useful in circumstances, where considerations other than efficiency (e.g., ease of inspection and estimation of effects) may be of overriding concern. In many cases, both regulators and polluters often prefer the use of technology regulation because it is easier to understand and comply with than more indirect methods of pollution control or natural resource management. It also appears intuitively fair because everyone engaged in a certain activity is required to use (or is prohibited from using) the same technology.

However, a major drawback of technology regulation is its inflexibility. Since it is not possible for the regulator to have information about individual abatement levels or appropriate technologies for each firm, the government will designate a standard technology for all polluters (e.g., catalytic converters, filters or chimneys). This prevents a given firm or individual from using an alternative technology even though it may be more effective in a given circumstance. Consequently, firms have little incentive to develop better technology.

4.1.2.2 Regulation of Performance

Rather than requiring or prohibiting particular technologies, the regulation of performance targets individual levels of emissions or natural resource exploitation by imposing directly-enforced government limits on the quantity of emissions or harvest of a renewable resource for each individual or firm. Options in this category includes performance standards, tradable emissions permits, and zero emissions.

(i) Performance Standards

Under this approach, the regulating agency chooses the maximum allowable emissions or harvest for each firm or individual polluter. Thus, unlike in the case of technology regulation, firms have some flexibility in the choice of abatement method by which to meet the mandated goal. In addition, firms could choose between reducing output levels and increasing abatement level per unit of production and/or trade-off between polluting units within the organization.

Experience suggest that the regulation of performance can lead to increasingly effective solutions to environmental problems. For example, technology for removing effluent gases from motor vehicle exhausts as government emission performance standards have tightened over time.

(ii) Zero Emissions or total bans

This is a unique type of performance standard that imposes a total ban on particular emissions considered harmful to human health or to endangered species at any positive level. Total bans are most often used for radioactive materials, dangerous pesticides, heavy metals (cadmium, lead) and toxic chemicals as well as the trade in ivory and endangered species. The ease of monitoring may explain the popularity of the use of total bans, even in cases where some level of emission or harvest might be possible.

A potential problem with performance regulation is that controlling individual emissions rates (such as those set for new cars) do not imply full control on total levels of pollution or ambient pollution levels. This is because total pollution levels depend both on the output for each agent and the number of agents operating in the economy. Even if each polluter produces no more than the permitted amount of pollutant, the total pollutant load will exceed desirable levels when there are too many individual polluters. The same is true with natural resources management where the total harvest (e.g. grazing level, fish catch, tree cutting) can become unsustainable if there are too many harvesters, even though each harvester only extracts his or her permitted amount of the resource. In addition, regulation of individual performance can be costly because every individual polluter or user must have his or her emissions or usage inspected.

4.1.3 Economic Instruments

Economic instruments provide financial incentives for polluters and natural resource users to reduce output of pollutants and unsustainable use of natural resources. There are different ways to classify economic instruments (see Panayotou, 1998). A simple and convenient approach is to divide them into three basic types: price-based instruments, property rights-based Instruments, and legal, voluntary and information-based instruments.

4.1.3.1 Price-Based Instruments

These instruments include special government taxes, charges, or fees designed to raise the price of polluting the environment or exploiting natural resources. These policies attempt to set the price for users of environmental and natural resources 'right' to cover the excess social and environmental costs caused by the economic activities of polluters or natural resource users (externalities). Appropriate pricing of resources through price-based instruments sends a more accurate signal to users encouraging more appropriate resource consumption and conservation.

Common price-based instruments are direct taxation, input and output taxation, emission or access charges, refunded emissions payments, deposit refunds, subsidies and removal of perverse subsidies.

Direct taxation involves the use of Pigouvian taxes in the case of pollution. In natural resources management, governments use price-based instruments such as mining royalties, stumpage fees (a fee typically charged by the government to logging companies for the right to harvest lumber from public land), user fees (fees charged to users of goods or services provided by the government), and land taxes as variants of Pigouvian taxes. They impose fees and taxes as part of natural resource management policies to correct market failures (any externalities related to resource use) or institutional failure (the absence of property rights). As such, natural resource use fees help reduce and compensate for negative effects - loss of natural resources and inherent pollution caused by mining, forestry, and fishing - and impose a scarcity rent when there is no effective owner who can claim such a rent (as for fish stocks for instance). Fees charged for natural resources use are a considerable source of revenue in low-income countries

The use of Pigouvian taxes requires the regulating authority to be able to determine the marginal damage and the marginal abatement or control cost curves for each pollutant and then set the tax or charge equal to marginal damage at the optimal level of pollution. Such an ideal state of affairs would include having fully informed, honest, welfare-maximizing regulators and appropriate concepts of property rights. In reality, no government or private organization can have all the data needed to know exactly what an appropriate tax would be. So, one cannot find real world situations where the tool is applied as prescribed by the theory. In real world applications, governments adjust pollution taxes, charges, and fees by trial and error to obtain an approximate solution.[14] Further, earmarking environmental tax revenues for environmental

[14] In the practical policy development, medical practitioners, ecologists or environmental engineers (rather than economists) may recommend target levels of pollution or natural resource use without an economic analysis of the marginal costs of the environmental damage. The government then negotiates actual taxation among various interests and imposes them through the political process. In addition, the relatively complex legal process involved in passing and modifying tax laws makes them difficult to be adjusted to changing conditions. Further, when revenues go to the general treasury rather than to a specific trust fund, the effect of the tax instrument in addressing the specific problem is often lost. Local or industrial sector charges (over which polluters or resource users have some influence) are typically more readily acceptable since the money stays within the sector or the region.

purposes may be a controversial issue, especially in developing countries were public funds are often scarce. If the environmental tax itself gives enough incentive to reduce pollution or resource overuse sufficiently, the tax benefits may be diverted to the general treasury. If on the other hand the tax does not give enough incentive to fully solve the environmental problem (which is often the case) it may be argued that tax revenues should be earmarked for environmental purposes such as publicly-financed abatement (e.g. sewage treatment).

Input and Output taxes are levies on some input or output that can be easily monitored and that serves as a good indicator or proxy for the regulated pollution. They are often used in cases where the monitoring of emissions is impossible, difficult or costly, so that the government cannot directly tax the polluting activity. Gasoline taxes and vehicle weight charges are examples that are introduced based on the assumption that the ones paying will also be responsible for car emission and thus cause the environmental harm. The relationship between gasoline consumption and the environmental damage caused by vehicle emissions is far from simple and valuing and monitoring each vehicle is too complex to be practical. Therefore, regulators choose gasoline taxes as a proxy even though unused and contained gasoline itself is not a pollutant. Under differentiated vehicle weight charges, the amount of tax charged on a vehicle depends on its weight. The government bases such charges on the presumption that heavier vehicles are more damaging than the lighter ones. Several counties tax fertilizer rather than attempt to measure the amount of contamination of groundwater sources from each bag sold. Box 4.1 provides an illustration with the imposition of taxes on plastic bags to prevent littering.

Economists sometimes refer to input and output taxes as **presumptive taxes** because, in the absence of direct monitoring, the government presumes that the agent that uses a certain input or produces a certain output is polluting. Some researchers favour the use of presumptive taxes in developing countries where monitoring individual emissions is often impossible. However, while such charges are simpler to administer, it is important to keep in mind that they are not equivalent to emissions charges. Not every unit of the taxed product may have the same impact on the environment. For example, some purchased fertilizer may be used in sensitive areas (and therefore should be heavily taxed to reflect its high marginal damage), while others may be used in areas with lots of natural buffering (and therefore should not be taxed as heavily). Since the normal product charge would be the same per bag, it would not be able to make these kinds of distinctions. Product charges are most efficient when all purchased units of that product cause exactly the same marginal damage. Although full efficiency is probably rarely achieved by product charges, they may be better (even much better) than doing nothing.

Box 4.1 The Irish Bag Levy

Rapid economic growth in Ireland in the 1990s was marked by a significant increase in the amount of solid-waste per capita. The lack of adequate landfill sites resulted in escalating costs of waste disposal, which in turn led to more illegal dumping and littering. It was feared that tourism, one of Ireland's largest industries, would be negatively affected as a consequence of the degradation of the environment. The food industry, which based a significant amount of their marketing strategies on a healthy, wholesome reputation, also suffered as a result of the public perception of their role in the increased litter. The most visible element of litter was plastic bags, so in 2002 the government introduced the Plastic Bag Environmental Levy on all plastic shopping bags, with a few exceptions that were sanctioned for health and safety reasons. Retailers were charged a fee of 15¢ per plastic bag, which they were obliged, by the government, to pass on to the consumer. This levy was designed to alter consumer behavior by creating financial incentives for consumers to choose more environmentally friendly alternatives to plastic, such as "bags-for-life." (Bags-for-life are heavy-duty, reusable cloth or woven bags, which were made available in all supermarkets, at an average cost of €1.27.) Expectations that this levy would bring about a 50 percent reduction in the number of plastic bags used were exceeded when the estimated actual reduction turned out to be 95 percent! In a single year, Irish consumers reduced their consumption of plastic bags from 1.26 billion to 120,000, while concurrently raising approximately €10 million in revenue for the government. Placed in the Environmental Fund, this revenue finances environmental initiatives such as recycling, waste management, and, most importantly, antilitter campaigns. This levy has been viewed as a major success by the government and environmental groups alike. It has also been enthusiastically embraced by Irish consumers, thanks to an intensive environmental-awareness campaign that was launched in conjunction with the levy. Irish retailers, although skeptical in the beginning, have also recognized the huge benefits of this levy. Estimates suggest that their costs were offset by the savings from no longer providing disposable bags to customers free of charge, as well as the profit margin earned on the sale of "bags-for-life," whose sales have increased by 600–700 percent since the introduction of the levy. The amount of plastic being sent to Irish landfills has been dramatically reduced, bringing about a clear visual improvement. The success of this case has promoted the diffusion of this idea. For example, in 2008 China banned super thin plastic bags and imposed a fee on other plastic bags.

Source : Linda Dungan. "What Were the Effects of the Plastic Bag Environmental Levy on the Litter Problem in Ireland?" http://www.colby.edu/~thtieten/litter.htm/; **Source:** Titenberg & Lewis, 2012. p389.

In addition to input and output taxes, governments can use **subsidies** to raise the relative price for polluters compared to non-polluters, e.g. by *offering subsidies*, refunds and other positive payments for improved environmental practices, or by *removing perverse subsidies* (i.e. those that promote environmentally unsound practices). Government subsidies can compensate for the cost of environmentally friendly production and consumption behaviour, and thereby encourage such behaviour.

A subsidy can be either a direct repayment of abatement costs or a fixed payment per unit of emissions reduction. In the latter case, the subsidy serves as a kind of negative tax. If the polluting company is out of business, bankrupt or unidentifiable (as is the case with some historic cases of pollution, particularly in developing or formerly planned economies), then the public sector may have little choice but to finance cleanup with public funds or subsidize other companies to do the cleanup. As such, subsidies can be a practical alternative, particularly when other instruments or incentives to clean up the environment are not feasible. Situations where the polluter expressly owns the property rights to a certain resource that society wants (for example, oil discovered below a private property) can also warrant subsidies. Subsidies are also useful where the government wishes to protect privately owned environmental assets (e.g. land, forests, and waterways) without assuming full ownership or eliminating all private uses. The subsidy instrument does not fulfil the Polluter Pays Principle (PPP) and is, partly for that reason, popular with polluters and owners or potential buyers of polluted property whose activities did not cause the pollution.

The removal of perverse subsidies – i.e. subsidies that promote economic development and stimulate unsound environmental practices (for example, subsidies supporting industries such as fishing, forestry, etc.) – can also have a direct impact on environmental quality. Governments usually provide such subsidies in an effort to achieve some other desirable societal good such as economic development, job creation, protection of a way of life, or relief for the poor. From the environmental economics perspective, it is important to stress that any perverse subsidy distorts markets and hence creates inefficiencies. This leaves a society as a whole with fewer resources to address its problems, no matter which ones are the most pressing. Most perverse subsidies are maintained not because they are the only way to promote a certain policy goal, but rather because the benefiting stakeholders have strong vested interests and prevent changes.

Many observers see removal of such perverse incentives as a far more important issue than providing of subsidies to improve the environment. Such inappropriate subsidies promote rather than prevent wasteful and environmentally destructive behaviour. Combining subsidies with other price-based instruments can be quite effective for environmental and natural resources management. For instance, the government can combine quantity restrictions with a small subsidy for over-compliance or with high fees for pollution emitted above a certain level. Such combinations may serve as a safety valve if regulators are not sure of the optimal pollution pricing level. They may also provide a way to collect information on abatement costs. However, there are two primary problems associated with subsidies as an economic instrument. First, subsidies can be too expensive as a policy instrument especially in developing countries where the opportunity cost of public funds is high. Second, removal of perverse subsidies is often politically complicated because subsidies often go to powerful vested interests.

Under **deposit refund**, the government can exempt polluters that demonstrate abatement or clean technology from taxes or refund presumptive taxes to them. Deposit refund systems involve a charge on some particular item and a subsidy for its return. As such, they are combined instruments of charge and subsidy used to encourage environmentally appropriate recycling. Recycling beverage bottles and cans are the most well-known example but the principal applies to anything (automobiles, chemicals, fluids) that cause environmental damage if not recycled. Deposit refunds, and similar systems, operate on the assumption that the consumer or firm will pollute in the absence of the system; for instance, that people will not recycle bottles without financial incentive to do so. In cases where disposal harms the environment, the deposit refund becomes a tax expenditure on inappropriate disposal. The polluters (those who do not return the item) pay a charge, whereas those who return the item collect a refund and therefore pay nothing. Box 4.2 illustrates the use of deposit refund instrument in Korea, while Box 4,3 illustrates a successful use of refunded emission payments in Sweden.

Box 4.2. Sweden Offers Sulphur Tax Rebates for Abatement

In Sweden a substantial tax is levied on the sulphur content of fuels (over $4 per kg of sulphur) but this is rebated for large emitters who can prove how much sulphur emission they have abated. For large emitters, therefore, the effect of the sulphur tax is precisely the same as the emissions tax; for everybody else the tax on the sulphur content of fuels provides incentives to switch to low-sulphur fuels and to reduce energy use overall. The tax has been extremely effective as it is relatively simple to implement because it can be levied at wholesale level. The national target for sulphur emissions was met several years ahead of the schedule, and the revenue from the tax was actually lower than projected, as a result of the extensive fuel-switching and emission reductions that followed introduction of the tax.

Source: Panayotou T. (1998). Box 4-2, p. 53; UNEP, 2009.

Box 4.3 Korea Adopts a Massive Deposit Refund System

Korea uses an extensive waste disposal deposit refund system which covers food, beverages, liquor bottles and containers, batteries, tyres, lubricating oil, electric home appliances (and any other item that generates toxic waste), bulky or heavy commodities that require treatment, non-degradable materials and harmful household commodities that should not be mixed with the general waste stream. The manufacturer is required to deposit a certain amount for each unit sold, refundable upon collection and treatment.

Source: Panayotou, T. 1998, Box 4-2, p. 56; UNEP, 2009

The distinguishing feature of the deposit refund scheme is that it has a disclosure mechanism; the government or firm pays the refund when the potential polluter demonstrates compliance by returning the item that carries the refund, therefore reducing the need for monitoring of illegal disposal. Refund programmes have spread widely in both developing and developed countries in recent years. In the developed world, the system has very wide applications. For example, Sweden instituted a deposit refund scheme on scrap vehicles to prevent their abandonment in the woods to rust. It is conceivable that governments could use similar instruments to recover other polluting inputs, such as cadmium or mercury (UNEP, 2009). However, the setting up of the deposit refund fee, especially in developing countries where there is no information on the possible reactions of consumers or the environmental impact of some of the wastes, is an iterative process - you have to keep trying to get the deposit refund high enough to stimulate use of the system. This means that it is not possible to know in advance whether a particular fee structure would be successful or not.

Refunded Emissions Payments (REPs) combines charges and subsidies. An REP is a charge imposed on polluting firms, the revenues of which are returned to the same group of polluters, not in proportion to the payments made but in proportion to another measure such as output. The individual firm pays a tax on emissions and receives back a share of the total fees collected based on output. The net effect of the payment and refund is that firms with above average emissions make net payments to the firms that are cleaner than average. In the application of this instrument, the firms with high ratios compensate firms that have a low ratio of emissions to output.

It is believed that REFs can improve pollution control and provide incentives for the adoption of cleaner technology in situations where the government lacks adequate political authority to enforce compliance. Such systems make it easier for politically powerful polluters to comply with environmental regulations. However, they are effectively a market-distorting subsidy, and can even be a perverse subsidy. In the first instance, firms pay for the pollution they produce, which is a pollution charge or tax. In the Pigouvian sense, it corrects for negative externalities caused by the pollution. In the second instance, the raised money is returned to the industry, which is basically a general subsidy for this industry and gives it a comparative advantage with respect to other industries. The main policy advantage of REPs – and of tax-subsidy schemes in general - over taxes, relates to the distribution of cost. Because all firms will pay less and some firms even make money in a REP scheme, it will not create the same kind of resistance (and lobbying) from polluters as taxes often do. The use of refunded emission permits, however, is a relatively new concept and there is little empirical experience around the world.

4.1.3.2 Property Rights-based Instruments

These instruments define, adjust, or create property rights to ameliorate environmental damage by defining the basic enforceable law for ownership and use of both tangible (e.g. land) and intangible (e.g. permits) property. The purpose is to manage the environmental assets by creating, clarifying, and enforcing rights to specific property. Some property rights-based instruments define rights to ownership of existing property. Others create property in the form of tradable permits to use resources or emit pollutants. Both of these instruments give the authorized parties a direct financial stake in the renewable natural resources and environment in general. This, in turn creates self-interest for reducing pollution, for maintaining sustainable harvest rates, and for the direct monitoring and control of illegal activities. More specific instruments include tradable emission permits in pollution management, individual transferable quotas in fisheries management, transferable grazing rights in range management, and transferable development rights in property management.

Clearly defined and enforced property rights, which are established through legal regulations[15], are the foundation of all markets. They provide policy makers with two separate tools. First, their establishment gives the incentive to use existing resources sustainably and efficiently. Second, policy makers can decide how they want to distribute the rights. Taking use of the latter aspect can often help in getting support for suggested policies, for example by assigning property to the poor, to traditional users, or to important stakeholders. The pressure to establish or clarify property rights, generally, increases as the supply of a given type of property decreases due to resource depletion or increases in pollution even as the demand remains steady or grows. Conditions such as traditional but vaguely documented claims to ownership or free use of land, water, etc., or widespread absentee ownership of land with uncertain tenure for users of the land often lead to overuse of resources and uncontrolled environmental pollution. In addition, as pressure grows on the use of scarce resources the threat of violence among competing claimants, public corruption, and extreme poverty increase. Under these circumstances, clearly defined property rights provide incentives to control pollution impacting the property or to ensure a sustainable use of renewable resources.

The establishment (including definition, granting or allocation), and clarification of property rights include a variety of policies that facilitate improved stewardship of the environment, such as:

- The granting of communal tenure in the use of public property by local communities under conditions that promote sustainable use of natural resources and the reduction of pollution.
- Permanent transfer of tenure rights or ownership from large absentee owners or the government to those who actually farm the land or use the resources. These are sometimes called "*land to the tiller*" programmes.
- Transfer of public enterprises, which have weak incentives to maintain environmental quality, to private individuals or organizations to which strong incentives may be applied.

[15] We do not consider other means of establishing property rights, such as tradition or force of arms.

(Obviously, transfer from public to private ownership without economic or regulatory incentives does little to help the environment.)

For the purpose of this lecture, we examine property right-based instruments under two categories: common property resource management (CPR), and tradeable permits.

(i) Common property resource management (CPR)

In the context of natural resource management in developing economies, common property resource management (CPR) is particularly important. In developing economies, the right to use common property (grazing lands for example) is usually established by tradition, and the resource can be freely used by anyone. Such a system naturally encourages each user to maximize their amount of use. The very act of defining the right to use common property (who, when, how much, under what conditions) creates an economic instrument to manage the use of natural resources and control of the pollution of common property. Using this economic instrument, it becomes possible for the first time to overcome the tragedy of the commons and rationally manage the use of common property. The common property may still belong to everyone in society but the use of it is regulated to prevent abuse. CPR management is particularly relevant when the resources of an ecosystem are erratic, caused, for example, by unreliable rainfall), as well as when there are possible problems, such as the desire of each user to maximize their own use, which will eventually lead to the degradation of community property resources (see Sterner, 2003, Sterner and Coria, 2012 for a review of these conditions)

The literature recognizes three strategies associated with CPR management. These are (i) 'Perfect' government control, (ii) Privatization, and (iii). Cooperative management with local enforcement. The third is considered the superior alternative in many settings. Using such a strategy requires that

- Boundaries are clear and outsiders can be excluded,
- Rules are adapted to site-specific conditions,
- Decision-making is participatory (democratic),
- Locally designated agents monitor resources,
- A local court or other arena is available to resolve conflicts,
- Graduated sanctions are used to punish infringements,
- Outside government respects the CPR institutions

However, there are many potential problems associated with the definition and management of common property rights. For example, lack of trust among the actors can lead to poor results (e.g. when traditional users of grazing lands do not trust government representatives from the capital). In some cases, it may be impossible or difficult to create communal property rights (e.g., in the case of global warming or ozone layer depletion). Further, the creation of property rights may disenfranchise the poor and therefore contributes to worsening poverty (e.g. where, "squatters" or subsistence users lose traditional but informal rights to use property).

(ii) Tradable Permits

The second type of property right is the right to limited use of public assets such as the right to emit pollutants, to take fish from public waters, or graze livestock on public lands. As economic instruments, these property rights take the form of tradable permits.[16] To create a tradable permit system, the government first determines the total amount of a resource to be used or pollutant to be emitted. Thereafter, it issues individual permits to use some part of the total limit, and then, allow the permits to be traded by the holders. For the system to work the total number of permits should not exceed the estimated capacity to assimilate pollutant loads without deteriorating environmental quality, or, in the case of renewable resources, the yield or harvest that can be taken without a decline in the stock size.

The use of tradable permits regulates the total amount of resources that can be extracted or pollution emitted but leaves it to the market to determine who will extract the resources or emit the pollution and at what price. In using this instrument, the decision maker says in effect "in the next ten years, we will only allow a total of X tons of pollutant to be released into the atmosphere" or "for the next ten harvest seasons, the total amount of tilapia to be harvested from Lake Victoria is X tons per season" to be consistent with sustainable management of the environment or the resource base. The government has the option of auctioning the permits, or of distributing them for free ('gifting'). Auctioning will ensure that the market value of the permit is raised by governments. It is often applied when permits are to be given to larger, profit-oriented companies. If issues of poverty are a major concern, or if resistance among participating stakeholders against auctioning is insurmountable, permits can also be given out for free. In both cases, a permit allows its holder to emit a certain amount of pollutant or to harvest a certain amount of a resource in a specified period of time.

After the allocation of permits (through auctioning or free distribution) a firm wishing to emit or harvest beyond what their permits allow can only do so at the expense of another firm. This is possible since it is feasible for a firm to emit less pollutant or harvest less than the permits it holds allow. The permits that are not needed can then be sold to another firm. For example, a firm in a fishery can choose to harvest fewer fish than its allowable quota and sell the extra permits to another firm. For such a scheme to work efficiently, the allocated permits must be transferable

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[16] As an economic instrument, this differ from licenses – e.g. for hunting or fishing – which also seek to regulate the total take, in that the licenses cannot be traded and have little associated economic incentives other than the cost of the licenses, which is usually small.

to new as well as existing holders of permits. A permit holder must be able to sell his permits if he or she is making losses and wishes to exit from the market. A new firm that wants to enter the market can only do so by purchasing rights from a firm already operating in the market.

Tradable permits are issued under a number of names depending on the issue to be addressed including:

- Tradable Emission Permits in pollution management
- Individual Transferable Quotas in fisheries management
- Transferable Grazing Rights in range management
- Transferable Development Rights in property management.

The most successful permit-trading programmes have included

- **Emission Reduction Credit Programmes**: where a firm that reduces emissions more than required gets credit for the extra reduction, which the firm can either sell to firms whose emissions are above the statutory maximum, or can bank for its own later use.
- **Ambient Permit Trading**: A variant of tradable emission permits in which the value of emission reduction credits differs from region to region depending on the relative ambient concentrations so as to discourage development of 'hot spots'.
- **Output Based Allocation**: This is used for the initial allocation of pollution permits, based on relative output levels of existing firms.
- **Cap and Trade Programmes**

However, several conceptual and practical problems must be overcome in the application of tradable permits. First, for the permits or quotas to work, they must acquire the characteristics of other property rights, such as permanence and reliability. Permanency gives owners of property rights the confidence and incentive to make long term and costly productive investments in their properties. If permits or quotas are not seen as a real title for property, the market for them will not develop, and without a market their worth as an economic instrument is nil.

Second, the potential buyers of permits need to understand the market. This may require considerable public education. In the case of natural resource management, a lack of knowledge among users of the resource about the underlying ecosystems and lack of agreement about how they should be managed can create major difficulties. Policy makers need to ensure that all stakeholders have a common agreement about the essential facts and trust in the research that produced them.

Third, many features of permit systems (i.e. the definition, number, duration, and temporal and spatial validity of the permits and the proposed method of their allocation) cannot be decided using only ecological and technical calculations. At bottom, these become political decisions. These decisions are crucial for the performance of the programme but can entail immense political pressure because permits transfer valuable property rights and, potentially, substantial wealth.

Finally, there is the problem of *thin markets* and transaction costs. Thin market exists If a permit system is established but very few people are willing to trade in it. In this case, the market will not develop properly. The same will be true if traders of permits incur high transaction costs, for example, if the trading process is lengthy and complicated or involves fees. Designers of tradable permit systems need to make sure that the permit market is sufficiently big to allow for multiple trades, and they need to find ways to keep transaction costs low. In addition, for tradable permits to work properly, prescribed targets for total use of emissions must be responsive to changes as the operating environment changes, for example as abatement technology improves. For instance, if a standard abatement technology commonly used by all companies used to have 60 per cent efficiency in eliminating pollutants but now has 80 per cent efficiency. This means that most firms would have extra credits to sell or bank leaving few potential buyers and little incentive to reduce pollution. In such a situation, the total permitted pollutants would need to be reduced again creating the scarcity required for a market to work.

4.1.3.3 Legal, Voluntary and Information-Based Instruments

Legal instruments hold individuals and organizations liable for environmental damage they cause. They include criminal penalties, fines, civil liability statues, and performance bonds. Voluntary and information-based instruments include voluntary environmental agreements, information campaigns, eco-labelling, and other certification.

(i) Legal Instruments

Legal instruments are designed to ensure the enforcement of rules by increasing the economic cost of non-compliance. These economic penalties remove the competitive advantage that the firm would gain through non-compliance. Most enforcement relies on three types of legal instruments imposing economic penalties: fines, liability and performance bonds.

- **Fines:** fines are commonly imposed by the government when a firm has knowingly violated environmental or health laws to make a profit. Fines are relatively easy to impose and can often be assessed on the spot. In some cases, special administrative procedures and courts are established to allow more efficient use of fines as an economic instrument. The use of fines to ensure compliance, however, requires that the government has sufficient police or inspectors, appropriate legal staff, and a functioning legal system. From an economic perspective, the penalty imposed by fines must be large enough to actually deter undesirable behaviour. Small fines may be seen as merely a cost of doing business. Not only the amount of the fine itself is important, but also the probability of being caught when violating an environmental law. Companies will have an economic incentive if their expected cost from a violation, namely the probability of being caught multiplied with the level of the fine, is higher than the benefit they expect from bypassing the rules.

- **Liability:** Under liability sanctions, an accused violator may be taken to court – by either the government or private plaintiffs - to compensate for the cost of environmental damage. Liability sanctions are usually easier to enforce and much more costly to the violator than are fines. They do, however, require a fully functioning legal system and, even then, may involve prolonged litigation. Companies could be strictly or partially liable for damages caused and this may have important implications for their behaviour. Partial liability implies that the person injured has the right to compensation only if the party causing the injury has taken less than due precautions. Strict liability means a right to compensation irrespective of precautions. Suing a large firm or government agency is risky and expensive, and many individuals do not have the necessary resources to hire a lawyer and proceed with a lawsuit. The incentive to do this is further reduced in the case of partial liability. Strict liability gives more rights to the injured individuals and can be seen as the ultimate policy instrument that promotes the internalization of all environmental damages and risks.

- **Performance Bonds.** Governments often require that firms have special insurance, known as a performance bond, to ensure that they have the wherewithal to actually pay for the environmental damages they cause. An economic deterrent effect for potential violators is the increased cost for future performance bond insurance – or the inability to obtain such insurance at all - if the firm needs to use the insurance to cover environmental damage liabilities. In addition, firms will not be able to purchase performance bonds if bonding companies deem them likely to violate environmental regulations in the future.

  Performance bonds have the advantage that they make it relatively certain that governments or private plaintiffs can recover damages. The fact that insurers are assessing the risks of non-compliance increases the effectiveness of environmental policies. However, the use of performance bonds is usually restricted to industries with a greater than average risk of causing significant environmental damage – oil transport, forestry, mining, heavy industry – where the additional cost of the bond insurance is commensurate with the risk.

The empirical application of legal instruments may be difficult in those developing countries where the judicial systems are weak. Specific problems with the use of legal instruments include the very high costs of litigation, lack of information about liability, and poorly or incompletely defined property rights making responsibility for damages uncertain and the imposition of penalties impossible.

(ii) Voluntary Environmental Agreements

Voluntary environmental agreements are agreements among private firms, government agencies, and/or nongovernmental organizations designed to encourage voluntarily investment, clean-up, or other changes to reduce negative environmental impacts. The incentives for such agreements include subsidies, favours, positive publicity or good relationship with the government. In recent years, 'voluntary agreement' has become a popular catchphrase among environmental policy experts and are promoted as a useful instrument for policy making. For example, more than 13,000 US firms, nongovernmental organizations and local agencies were estimated to be involved in voluntary government initiatives in 2000 (US Government, 1998, see UNEP, 2009). To serve as an economic instrument, the agreement needs to produce a level of abatement beyond the one achieved without government involvement. For these reasons, voluntary agreements are often organized and facilitated by the government rather than arising from within the regulated industries.

Under voluntary agreements, firms agree to invest, clean up, or undergo changes to reduce negative environmental effects and receive, in exchange, subsidies or other benefits. The benefits may take the form of more lenient regulation, some official protection against civil liability lawsuits, good publicity, a good relationship with the government, and perhaps speedier and less formal treatment of other environmental controls. In developing agreements, the government agency may negotiate an agreement with a single firm (especially if it is a large firm with a major impact on the environment) or with multiple firms represented by a trade association or other intermediary organizations.

The relative benefit of voluntary agreements over command and control instruments or the more measurable benefits of most economic instruments may be as much a cultural or a psychological one as one of effect. It has been suggested that the 'covenanting process'—that is, the dialogue itself, rather than the formal agreement—has been touted as the main feature that makes voluntary agreements successful. Voluntary agreements allow firms to save face before their stockholders while accepting the fact that they must spend company funds to reduce emissions or curtail exploitation of natural resources. In the same way, voluntary agreements allow the government regulatory agency to improve its image with the public, elected officials and the general business community by presenting itself as open-minded and reasonable in its dealings with the private sector rather than inflexibly bureaucratic. They are also sure that firms are more likely to comply with the measures to which they agreed. Thus, the agency can get some savings in regulatory costs.

Voluntary agreements are popular in cases where firms are in some way rewarded for engaging in more abatement than would normally be required. They are most promising when the opportunity for technical abatement is good while imperfections (in the product or technology markets) make the use of conventional instruments, such as taxes, difficult. In addition, voluntary agreements are an alternative to taxes when emissions verification is problematic. From the government perspective, voluntary agreements may be most attractive in cases where the government does not have sufficient power to coerce the polluter. In contrast, firms may be more inclined to voluntary agreements when the state has sufficient power to enforce its will without an agreement, because then, firms will be motivated to negotiate the best conditions possible.

One potential problem with voluntary agreements is that they depend on other tougher instruments to function. Strong environmental lobbies that stimulate firms to acquire 'green' labels, and therefore enter into voluntary agreements, are often lacking in developing countries. Thus, the potential for voluntary agreements in such countries appears to be weak. The voluntary banning of chlorine from paper bleaching in Sweden illustrates the notion that voluntary agreements work best against a backdrop of tougher instruments. The companies stopped using chlorine, although their response was a reaction to plans to introduce an environmental tax on chlorine. Presumably, the demand for 'green' labels on paper products also contributed to this shift. As the Swedish government and parliament were drafting the laws, industry decided to be a 'first mover' and voluntarily ban chlorine. In this way, they avoided the tax payment, gained good publicity, and set a precedent for future battles concerning environmental legislation (See Sterner, 2003. pp 119-122 on and more on the potential and scope of voluntary agreements for enhanced environmental management).

(iii) Information-Based Instruments

All policy instruments require information to function, but public disclosure of information can be an economic instrument in its own right. As an economic instrument, public disclosure can change environmental behaviour of polluters and consumers by directly influencing the market. The instrument is used to publicize those firms or products that meet certain standards in the way they are produced or harvested.

Information-based instruments are becoming increasingly popular among theorists and in real world applications. Information provision has been referred to as the 'third wave' of environmental policy making (presumably after command and control instruments and economic instruments), and its popularity can be explained by the changing costs of providing, processing and disseminating relevant information. Information disclosure as an instrument for pollution management is particularly promising in situations where administrative costs of more traditional policies are excessive (see Sterner, 2003, pp 122-126, for applications in northern Europe). In addition, there is growing acceptance of public disclosure for natural resources management in both industrialized and less developed countries (e.g., organic farming, forest certification programmes).

Forms of information disclosure include:

- **Labelling:** where products are directly labelled as being environmentally friendly or meeting certain criteria (e.g. low energy usage, organic).
- **Public Disclosure:** in which comparative information about the environmental practices or violations of environmental law of different companies is made available to the public. Product by product comparison can also be provided.
- **Ratings** or **Rankings** : provide information about the environmental impact of a product or the environmental performance of a firm on the relative scale (e.g. Grade 1, 2, or 3). The advent of the internet has made such information easy to access and increasingly powerful.
- **Environmental certification of firms:** which use a fixed system of certification within some predetermined bounds such as ISO 14000 or EMAS standards[17]. These systems are usually oriented towards the management structures of firms, and not towards compliance with environmental standards or environmental performance per se.

Disclosure programmes may also be categorized by the item certified (the target): they can provide information about products, the firms themselves, or their processes and management procedures. Product labelling programmes have been around for decades and the number of product labelling programmes has been increasing rapidly. Examples include 'Organic' certification of food, which is widespread, and probably one of the oldest programmes; Type 1 'green' labelling of products, which has become popular in northern Europe; Certification programmes, such as the Canadian Environmental Choice, the US Green Seal, the Japanese ECO MARK, and the French NF Environment (UNEP, 2009).

Some potential problems with the use of Information-Based Instruments include the fact that low-income levels in developing countries may prevent the majority of people from being able to make consumer choices, which are necessary for information-based instruments to be effective. In addition, agents may use 'green' and 'eco' labels as mere mantras without necessarily adequately protecting the environment. One area where this seems to be prevalent is in 'eco-tourism'. Finally, there may be inadequate knowledge or concern about the advantages of green products.

[17] EMAS: Eco-Management and Audit Scheme of the European Union. ISO 14000: International Standards Organization rules for environmental practices (for more information see http://europa.eu.int/comm/environment/emas/index_en.htm and http://www.iso.org/iso/en/iso9000-14000/index. html.

4.1.4 Direct Provision of Public Goods

The purpose of the direct provision of public goods is to maintain environmental or natural resource quality through direct public expenditure. In this case, the government (through its environmental protection agency) takes direct responsibility for solving a particular environmental or natural resource management problem for which the market cannot successfully provide a universal solution. Examples include:

- Street cleaning
- Disease vector (e.g. mosquito) control (taking responsibility for major environmental threats and managing certain kinds of research and control functions typically undertaken by environmental protection agencies)
- Maintenance of urban water and sewer systems (although the state or municipality usually tries to cover costs by charging some kind of user fees. Such fees may be part of property taxes or other taxes, or, as is becoming increasingly common, they may be user fees tied more specifically to the service provided).
- Maintenance of natural parks and nature preserves

Under direct provision, a resource or environmental ministry applies its own personnel, know-how, and resources to solve a given problem. In the environmental arena, this mechanism is essentially the provision of public goods.[18] These activities, of course, can also be carried out by private companies but only at the behest of the government or quasi-government organization (e.g. a homeowners' association), which becomes the sole customer for the service.

For example, the creation of parks and protected areas that exclude livelihood activities is a common approach to protecting biodiversity. Protected areas have strictly defined borders that unauthorized people are not supposed to cross. Marine protected areas are a somewhat more recent addition to the plethora of land-based parks. In some cases, they are designed specifically to protect a stock. Certainly, this policy will work best if the area chosen truly does create services that are of value for other areas in the neighborhood that are still being fished.

However, direct government provision of environmental services is susceptible to the usual problems that confront the provision of public goods. In particular, because the government is providing a public good, it is likely to under supply, more so in countries with weak governance structures and low tax bases. Also, free provision of some public goods such as fresh water will result in overuse by consumers and can lead to exploitation of valuable resources. In addition, since provision of public goods is often done by political agents allocating public tax money to specific projects, politicians may seek to expand the definition of public goods to subsidize particular constituencies. In addition, political access and power influences which of the many

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[18] Some will argue that the phrase 'policy instrument' is not appropriate in this context and will rather reserve the word 'instruments' or policies that influence other agents (Coria and Sterner, 2011),

possible projects get funded, and how quickly. The projects of greatest need from a social or environmental point of view may differ markedly from those with the strongest political constituencies or greatest political return for the public official.

The role of the state can be broken down into several components: financing, administration, provision, and control. During the two to three decades, in most countries, the state has started to refrain from acting as direct producer of goods and services, focusing instead on financing. Several activities that were formerly thought of as natural state monopolies have been organized in such a way that the government agency merely retains a control function, and private entrepreneurs are hired to provide the services. One of the factors that have contributed to this change is the remarkably negative popular image of state enterprises as incompetent elephants beyond the control of the government. Nevertheless, state resource enterprises are still very common, partially due to the strategic nature of many natural resources and rent-seeking opportunities that permit government officials to gain the political support from key actors outside the government.

For exploitation rates to be sustainable and dynamically efficient, government must ensure that state enterprises are kept accountable for the quality of their resource management and the damages they cause. Governments must also ensure that directives to state resource enterprises call for appropriate rates and methods of resource exploitation. Unfortunately, this is not often the case. Instead, governments fail to keep state resource managers accountable, demand that state enterprises engage in over or under-exploitation of resources, make inappropriate investments within and outside the resource-exploitation process or set the prices of state-produced outputs too high or too low. Undercapitalization of state enterprises is also common, due to the government's unwillingness to approve adequate investment budgets, its excessive taxation of state operations or the failure to prevent that funds are diverted away from needed investments (Ascher 1999, see Coria and Sterner, 2011).

Table 4.2 helps to sum up our discussions on environmental and natural resource policies.

Table 4.2: A taxonomy of policy instruments

Policy Instrument	Some applications to natural resource management
I. Command-and-Control (Environmental Regulations)	
Detailed Regulation -Regulation of technology (designation of technology, zoning) -Regulation of performance Legal mechanisms, liability	Automobile emission control, regulation of nuclear power, zoning regulation of fishing (e.g., dates and equipment) Bans on ivory trade to protect biodiversity, bans on use of cyanide and dynamite in fishing, ban of certain pest control techniques in agriculture and forestry, Water quality standards Harvesting and replanting rules in forestry. Liability bonds for mining or hazardous wastes
II. Economic Instruments	
1. Price-based instruments (Using Markets) Taxes, fees, or charges Subsidies and subsidy reduction Deposit refund schemes	Mining royalties, Gasoline taxes, vehicle weight charges, user fees, land charges, Park fees Fishing licenses Stumpage fees Reduced agricultural subsidies Reforestation deposits or performance bonds in forestry
2. Property rights-based Instruments (Creating Markets) Creation of property rights Common Property Resources Tradable quotas or rights	Private national parks Property rights and deforestation CPR management Water trading, individually-tradable fishing quotas, Transferable rights for land development, forestry, or agriculture, rights to emit pollutants, to take fish from public waters, or graze livestock on public lands
3. Legal and Voluntary-based Instruments (**Engaging the public**) Information Provision, Labels Voluntary Agreements	fines, civil liability statues, and performance bonds green labeling of food, forest products, public disclosures, ratings and rankings, environmental certification (organic' certification of food,
III. **Direct provision**	Direct provision of parks

Source: Adapted from UNEP (2009) and Coria and Sterner (2011). p20.

4.1.5 Second-best mix of policies

In Module 2.4 we learnt that second-best policies are called for whenever there are cases of multiple market failures and that this is especially often the case in relation to environmental and natural resource problems. Several other daunting challenges come into play, including the need to

- consider not only efficiency but feasibility and in particular distributional concerns in policy selection
- deal with combinations of goals. Environmental problems are urgent but so are many other pressing goals such as dramatically urgent needs for poverty alleviation, employment creation, or conflict resolution;
- deal with policies that require action at the local, national, and international levels.

Sound realistic policy-making must deal with ways these policies interact. This will often require a form of second-best policy mix (Damon and Sterner, 2012).

There is a growing emphasis on political feasibility in the design of appropriate policy instruments to address environmental and natural resource problems. This is even more relevant in the context of developing countries, and in the case of Sub-Saharan Africa. Experience with market-based environmental policies has deepened over the past two-to-three decades, so has the ability to adapt policy instruments to complicated and heterogeneous contexts. However, not much progress has been made in meaningfully accounting for the importance of political feasibility (political realities and contextual nuances) in the choice, success or failure of environmental and natural resource management policies. Political feasibility often hinges on factors, such as risks to competitiveness and employment, or on the distribution of costs of certain policies rather than on considerations of pure efficiency alone (Damon and Sterner, 2012).

Expectedly, the central role of policy instruments goes beyond efficiency to achieving a just and sustainable development. The goal of green growth cannot be achieved without sound policies that are both effective and politically realistic. Many believe an emerging understanding of the interaction between policy instruments and the political landscapes in which they must be adopted, should be harnessed to drive the next stage of green development. As aptly stated, 'policy making does not happen in a vacuum' and the study of environmental policy choices must start to holistically incorporate the ways that instruments interact with other political goals—if there is hope of these instruments being adopted widely and designed effectively (Zivin and Damon, in Damon and Sterner, 2012). Honlonkou and Hassan (2014)[19], argues for example, that

[19] Honlonkou and Hassan (2014), Designing Environmental Instruments to Finance Agricultural Intensification Through the Clean Development Mechanism: Direct Cost Subsidy Versus Tax Cut Under Asymmetric Information, Springer International Publishing Switzerland, September 2014 DOI: 10.1007/978-3-319-09360-4_28

one of the most successful instruments so far to address climate change, the Clean Development Mechanism (CDM) is at pains to succeed in small, developing countries facing sustainable development problems like food security. Worse, while the CDM succeeded in financing agricultural projects, few are funded in small, developing countries. For many countries in Sub-Saharan, solving poverty problems may predominate over solving pollution problems if a choice exists between the two (Rowland, 1973).

Summary

- For the government to address a given natural resource management or environmental problem, it must find and use the appropriate policy tool. The policies available to redress environmental problems fit into two broad classes: command and control instruments and economic instruments.

- Command and Control Instruments are the laws and regulation used by governments to directly control pollution and manage natural resources. In the application of these instruments, the government stipulates the technologies that must be used to curb pollution, determines the maximum amount of emissions that is permissible, and regulates the use of natural resources.

- Economic instruments provide market and financial incentives for polluters and natural resource users to change their behaviour by making pollution and overuse of natural resources more costly.

- Both command and control and economic instruments attempt to shift the costs and responsibilities associated with pollution or over exploitation back to the polluter or user. The differences between the two policy types, however, are significant in terms of cost and effectiveness.

- Command and control (CAC) policies for environmental regulation include those that regulate technology and those that regulate performance

- Where appropriate, technology regulation can provide clarity of choice, economy of administration, effective control, and ease of monitoring. However, a major drawback of technology regulation is its inflexibility.

- Performance regulation targets individual levels of emissions or natural resource exploitation by imposing directly-enforced government limits on the quantity of emissions or harvest of a renewable resource for each individual or firm. Options in this category includes performance standards, tradable emissions permits, and zero emissions.

- A potential problem with performance regulation is that controlling individual emissions rates do not imply full control on total levels of pollution or ambient pollution levels since total pollution levels depend both on the output for each agent and the number of agents operating in the economy.

- Economic instruments provide financial incentives for polluters and natural resource users to reduce output of pollutants and unsustainable use of natural resources. They include price-based instruments, property rights-based Instruments, and legal, voluntary and information-based instruments.

- Price-Based Instruments include special government taxes, charges, or fees designed to raise the price of polluting the environment or exploiting natural resources. Common price-based instruments are direct taxation, input and output taxation, emission or access charges, refunded emissions payments, deposit refunds, subsidies and removal of perverse subsidies.

- Property Rights Based Instruments define, adjust, or create property rights to ameliorate environmental damage by defining the basic enforceable law for ownership and use of both tangible (e.g. land) and intangible (e.g. permits) property. The purpose is to manage the environmental assets by creating, clarifying, and enforcing rights to specific property. They include common property resource (CPR) management, and tradeable permits.

- Common property resource management CPR management schemes include 'Perfect' government control, Privatization, and Cooperative management with local enforcement. The third is considered the superior alternative in many settings.

- There are many potential problems associated with the definition and management of common property rights. For example, lack of trust among the actors can lead to poor results (e.g. when traditional users of grazing lands do not trust government representatives from the capital). In some cases, it may be impossible or difficult to create communal property rights (e.g., in the case of global warming or ozone layer depletion). Further, the creation of property rights may disenfranchise the poor and therefore contributes to worsening poverty (e.g. where, "squatters" or subsistence users lose traditional but informal rights to use property).

- Tradable Permits confers the right to limited use of public assets such as the right to emit pollutants, to take fish from public waters, or graze livestock on public lands. The use of tradable permits regulates the total amount of resources that can be extracted or pollution emitted but leaves it to the market to determine who will extract the resources or emit the pollution and at what price. However, several conceptual and practical problems must be overcome in the application of tradable permit, such as permanence and reliability, the need for potential buyer to understand the market, and political considerations.

- Legal instruments hold individuals and organizations liable for environmental damage they cause. They include criminal penalties, fines, civil liability statues, and performance bonds. Voluntary and information-based instruments include voluntary environmental agreements, information campaigns, eco-labelling, and other certification.

- Legal instruments are designed to ensure the enforcement of rules by increasing the economic cost of non-compliance. These economic penalties remove the competitive advantage that the firm would gain through non-compliance. Most enforcement relies on three types of legal instruments imposing economic penalties: fines, liability and performance bonds

- Voluntary environmental agreements are agreements among private firms, government agencies, and/or nongovernmental organizations designed to encourage voluntarily investment, clean-up, or other changes to reduce negative environmental impacts. The incentives for such agreements include subsidies, favours, positive publicity or good relationship with the government.

- There are many forms of information disclosure including labelling **(**where products are directly labelled as being environmentally friendly or meeting certain criteria, e.g. low energy usage, organic), Public Disclosure **(**in which comparative information about the environmental practices or violations of environmental law of different companies is made available to the public), Ratings or Rankings, which provide information about the environmental impact of a product or the environmental performance of a firm.

- Some potential problems with the use of Information-Based Instruments include the fact that low-income levels in developing countries may prevent the majority of people from being able to make consumer choices, which are necessary for information-based instruments to be effective. In addition, agents may use 'green' and 'eco' labels as mere mantras without necessarily adequately protecting the environment. One area where this seems to be prevalent is in 'eco-tourism'. There may also be inadequate knowledge or concern about the advantages of green products.

- The purpose of the direct provision of public goods as an instrument is to maintain environmental or natural resource quality through direct public expenditure. In this case, the government (through its environmental protection agency) takes direct responsibility for solving a particular environmental or natural resource management problem for which the market cannot successfully provide a universal solution.

- In general, economic instruments possess a number of inherent advantages over command and control instruments for many problems. They are generally more affordable, flexible, responsive, and encouraging to technology innovation. In addition, although economic instruments cannot overcome a corrupt or weak political structure, they can help make moderately functioning governance structures work more effectively. As such they try to minimize possible policy and institutional failures.

- In practice, economic instruments are used together with command and control instruments to increase policy efficiency, and achieve environmental targets at a lower cost.

Discussion Questions

1. Consider the following case studies

Case 1: Reforestation effort in Brazil

In an effort to encourage good reforestation practices, timber policies in Brazil charge a tax on wood consumption except when the harvesting is offset by equivalent reforestation. Recognizing that there are insufficient resources to oversee reforestation directly, Brazil has chosen to forego revenues from timber sales so long as the cuts are properly replanted. However, the programme has generally failed. The tax on wood consumption is set too low to make it worthwhile for the foresters to replant. In any event, the programme is poorly enforced so that foresters rarely pay the tax at all. Monitoring is difficult especially in frontier regions. Those forestry fees that were collected usually go to pay administrative costs rather than support the environmental purposes for which they had originally been intended (Source: UNEP, 2004. Also in UNEP, 2009).

Case 2: Soil conservation in Dominican Republic

In the El Naranjal watershed in the Dominican Republic, US AID funds provided subsidized credit to participating farmers adopting soil conservation measures. Initial adoption rates were quite high (90 per cent in 1985), yet by 1990, only half of the farms continued to practice the conservation measures, as the subsidies had stopped. As further subsidies were expected, farmers actually delayed rational conservation measures in order to wait for the payment. The follow-on project of US AID recognized that the farms were already receiving tremendous benefits in the form of subsidized irrigation water. This second project tied continued access to subsidized water to proper adoption of soil conservation measures. The result has been substantial use of conservation techniques without additional direct subsidies. (Source: UNEP, 2004; UNEP 2009).

For each of these cases, what can you identify as the problem and/or solution. What lessons can be learnt for effective formulation of environmental policies?

2. The case study below is used to illustrate, among other things, that 'no environmental programme - even when using highly effective economic instruments - is ever really finished'

(a) Read through and state whether you agree or disagree and why?

(b) What lessons can we learn on how property rights measures can be used to address difficult environmental issues.

Case 3- Tenure Reform: Mankote Mangrove, St. Lucia

A common property rights economic instrument proved ideal in the efficient management and sustainability of the Mankote mangrove forest ecosystem in the Caribbean nation of St. Lucia. The Mankote forest comprises the largest contiguous tract of mangrove in St. Lucia and 20 per cent of the total mangrove area in the country. The government had traditionally prohibited exploitation of the publicly owned forest but allowed open access. The prohibitions proved ineffective. Widespread and uncontrolled charcoal harvesting threatened to destroy the entire forest. The imminent destruction of the forest, in turn, greatly endangered the many ecosystem services the mangrove forest provides, including maintaining coastal stability, preserving water quality, serving as a fish breeding and nursery ground, trapping silt, and providing an important bird habitat.

Most of the charcoal was harvested by extremely poor subsistence harvesters who had no legal right to any use of the publicly owned mangrove resources. The harvesters had no ready alternative employment should their access to the mangroves be cut off due to either resource depletion or effective policing. To protect the mangrove as both an ecological and economic resource, the government organized the subsistence users into a collective and granted clearly defined communal tenure rights for charcoal extraction. For the first time, the harvesters had a direct stake in the sustainability of Mankote resources. Communal tenure also gave each individual harvester an incentive to monitor his peers and ensure mangrove cutting regimes were properly followed. Technical training on effective ways to manage cuts was provided, as well as periodic monitoring of the overall mangrove health (as measured by tree size and number of new stems). Longer-term efforts to reduce the economic pressure on the mangrove were implemented using job training programmes and the attempted development of a hardwood forest outside of the mangrove. (This last element has been of limited success). As part of the programme, Mankote was established as nature reserve. Thus, not only did the programme secure the tenure of the charcoal harvesters, it worked successfully to prevent threats to the Mangrove from large-scale development or fishing.

By modifying property rights, St. Lucia (in large part due to efforts of the Caribbean Natural Resources Institute, a regional NGO) has been able to protect the Mankote Forest and all its ecosystem services. Mangrove depletion has stopped and tree cover is now increasing, all without displacing jobs. Despite the overall success, the case does have some problems that should serve as a caution to users of this model: The process has taken more than 15 years. Many resources at risk elsewhere would not survive such a long policy gestation period. The harvesters' tenure may not be secure. The tenure is granted through a letter from the Deputy Chief Fisheries Officer; it is not clear how much legal protection such a letter provides. Threats from outside developers remain, and challenging the validity of the tenure rights would seem an obvious tactic. Intensive development at the borders of Mankote could fragment ecosystems sufficiently to reduce the viability of the area. Finally, there is little information on how the new tenure holders will constrain internal growth of their group to ensure harvest pressures remain sustainable. (**Source:** UNEP, 2009).

3. Read the following case study and discuss the questions below individually or in groups.

(a) What is/are the environmental problem(s) described in the case study?

(b) What are the baseline conditions in the country (legal, fiscal, government)?

(c) What is / are the economic instrument(s) chosen? What is / are its / their objective(s)?

(d) Who are the main stakeholders involved?

(e) What are the main factors for success or failure?

(f) What message can you take for your own country case?

Case 4: Recovering Reasonable Fees from Resource Users

The public sector invests hundreds of millions of dollars to bring services to the populace of many developing countries: electricity, drinking water, and wastewater treatment are examples. Similarly, government owned natural resources comprise an asset of the state, owned by its citizens. There are strong arguments to be made for supporting cost recovery from beneficiaries for both consumptive (e.g., harvesting firewood, grazing) and non-consumptive (e.g., recreation) use. Despite the logic behind cost recovery, there is a widely held belief that many of these municipal services should be free. Here is an example from Country C.

Pasture Lease Agreements (PLAs) for ranchers to graze cattle on public lands have existed for decades in Country C. The lease terms last 25 years, and is renewable for another 25. Grazing fees were first imposed in 1961 through Administrative Order 08 at an average rate of less than

US $0.01/hectare per year. An initial fee increase was authorized in the Forest Land Grazing Lease Agreement of 1982. Fees were raised again in 1991 to the current rate of US $0.30.

Compliance with the fees has generally been quite high given the still very low rate. The low rates also led to a relatively small group of people gaining control over much of the public grasslands for the 50-year lease period. The ability to shift cattle to new pastures they control has also reduced the incentive for sound management of the pastureland, and led to land degradation in many parts of the country.

Although existing rules require ranches to file annual operating plans as well as a management plan every eight years, the Department of Environment and Natural Resources (DENR) has lacked resources to oversee management plans. This is the result of insufficient funding as well as difficult terrain to oversee. To address the problem, DENR's Ecosystems Research Development Board (ERDB) evaluated what the true economic rent should be, accounting for the cost of various measures to rehabilitate existing damages, and the economics of alternative land uses. While more than 10 times higher than the prior charge, the new rates were still believed to be only slightly more than half the lowest economically justifiable rent on the land. In addition, the charge had a five-year phase-in period. To support the transition, the policy included increased technical assistance as well as fee reductions for sound land management. Rights have continued with existing holders, with the price of those rights (through an annual rental fee) set by statute. The fee adjustment was authorized by Department Administrative Order 2001-05, which took effect in August 2001.

Despite some evidence that even this fee was still low, and the fact that 80 per cent of the surcharge could be used to correct existing damage on the grassland the ranchers have fiercely resisted the increase. A number have refused to pay the higher rates, a situation the DENR had not been prepared for. There had been a series of public hearings run by ERDB to discuss existing and proposed grazing fees. Ranchers were already well organized as a stakeholder group, and strongly opposed rate increases. They argued that the government should view their presence on the land as a benefit in that it curbed squatting by migrants. They also mobilized strong political actions against the ERDB and DENR to oppose the rate increases.

As a result, DENR ended up collecting nothing from them mainly due to its little capability to carry out full enforcement. Furthermore, during a trip to the region in early 2002, a top government official promised to reduce the fee substantially "to encourage breeding and create 60,000 jobs". This statement undermined current efforts to collect the higher fees, and led DENR to suspend its collection pending formal clarification on how to proceed. DENR has been unable to overcome local political opposition. As a result, the grasslands remain under great threat, and additional resources that the higher fees would have brought in are not available to stem the damage. Existing ranching practices are unsustainable, and current regulations on management reporting and planning by ranchers are not enforced. As a result, ranchers continue to have low cost, long-term access to public grazing lands with little incentive for proper land management.

In the face of such opposition regarding fee levels and enforcement, auctioning of rights could have offered a substitute for a user fee. Although auctions will not work for cost recovery on government owned or built infrastructure, they can be very helpful for applications where there is little fixed infrastructure and the users can be quickly changed.

Individual/Group Assignment/Term paper

1. Examine and evaluate forest management reform in Botswana/your country.

2. Examine and evaluate Wildlife User Rights and Wildlife conservation in Zimbabwe/your country

3. Provide a case study of a successful/an unsuccessful common property resource (CPR) management system in your country

4. Evaluate the consensus on the UNEP report on Ogoniland, Nigeria.

5. Evaluate progress on Eco-tourism in Kenya

6. Explain the factors militating against the effective use of legal, Voluntary and Information-Based Instruments in Sub-Saharan Africa

7. Evaluate initiatives to regulate the use of plastic bags in Sub-Sharan Africa

8. Why is it that tradeable permits may not be as effective in Sub-Saharan Africa in addressing environmental problems as it would be in developed countries?

Exercise

1. Consider an industry that produces electricity from coal. A REP system is being considered that would involve imposing a tax per unit of carbon dioxide emitted by firms in the industry. The money would then be returned to the power plants according to their share of output of electricity. Use the knowledge gained from this lecture to assess the proposed policy.

Materials used for this Module

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6. UNEP (2009): The Use of Economic Instruments for Environmental and Natural Resource Management First Edition.

7. Titenberg, T. & Lewis, L. (2012). Environmental & Natural Resource Economics 9th Edition, The Pearson Series in Economics

8. Sterner, T. and J. Coria (2012). Policy Instruments for Environmental and Natural Resource Management. Resources for the Future.

Module 4.3: Evaluating Policy Instruments (5.5 hours)

Learning Outcome

This Module describe how to choose between and evaluate various policy options to address environmental problems. By the end of the module, you should be able to

- ✓ Identify the various steps involved in choosing an effective environmental policy package to address a target environmental problem
- ✓ Understand the importance of the policy environment and baseline conditions
- ✓ Know the factors that should guide policymakers in the choice of the most appropriate policy option for a given problem and why context matters.
- ✓ Know some basic criteria for evaluating environmental policies.
- ✓ Understand cost-effectiveness criterion and know how to apply it to different types of pollution problems.
- ✓ Understand why market-based policy instruments are often preferred to command-and-Control Instruments.
- ✓ Appreciate the importance of political feasibility, social and distributional considerations in choosing policy instruments.

Content Outline

4.3.1 Choosing an effective environmental policy package to address a target environmental problem

4.3.1.1 Introduction

4.3.1.2 Understanding the nature and extent of the problem and determining baseline conditions

4.3.1.3. Making Policy Choices

8.2.2 Evaluation Criteria

4.3.2.1 Introduction

4.3.2.2. Cost-Effective Policies for Uniformly-Mixed Fund Pollutants

4.3.2.3 Cost-effective Policy for Nonuniformly-mixed Pollutants

4.3.2.4. Cost-effectiveness and Renewable Resources

4.3.2.5 Beyond cost-effectiveness: Political feasibility, social and distributional Issues

Summary

Discussion Questions/Case studies

Exercises

Materials used for the Lecture

4.3.1 Choosing an effective environmental policy package to address a target environmental problem

4.3.1.1 Introduction

While an understanding of the theoretical benefits of particular economic instruments can be useful, the existing institutional capabilities and environmental policies in the country need to be taken into account in the choice of an effective environmental policy package that will address a given environmental problem. Practical consideration of the status quo in a country, including institutional strength, existing policies, and stakeholder power dynamics, will have enormous influence in deciding the most viable policy approach.

Policy choice and implementation generally encompasses four main phases.

- **Phase 1: Conducting Policy Analysis**.This entails a careful analysis of the perceived problem, a review of the instruments available to address the problem, the conditions under which these instruments will be used,and the likely effect of various instruments or combinations of instruments on the problem. This phase is usually concluded with the drafting of initial policy recommendations.
- **Phase 2: Engaging Stakeholders.** This involves bringing in stakeholders for feedback on initial policy recommendations and collecting important information on how to refine these to increase their likelihood of success or to gauge any majorresistance. This input is then fed back into the information bank developed in Phase 1.
- **Phase 3: Finalizing Policy.** This phase takes the general information assembled in Phase 1 and 2 and uses it to develop final policy proposals.
- **Phase 4: Implementing and Evaluating**. This involves gaining political support, passage of any necessary legislation, establishing regulations, and establishing administrative, monitoring, enforcement, and evaluation procedures. Once legislation is enacted a strict timeline for implementing the chosen policypackage should be prepared. Similarly, additional work on any measures needed to assess impacts of the change on poverty, the environment or other variables of interest may also be required (see UNEP for detailed discussion).

4.3.1.2 Understanding the nature and extent of the problem and determining baseline conditions

Deciding on the most appropriate instruments to address an environmental challenge requires that policymakers must first determine the nature and extent of the problem. What is, for instance, the:

(i) Nature of the problem: overuse of a resource or a pollutant problem?

(ii) Potential effect on human welfare and the environment, including the nature of the problem over time. (The passage of time becomes important if one is interested in a pollutant that bio-accumulates in the environment or if a natural resource is irreversibly degraded.)

(iii) Geographical reach of the affected area. Is the problem a local or regional problem?

(iv) Vertical dimension of the pollutant. Are the effects felt on the surface or in the upper reaches of the atmosphere?

(v) Number of people involved. (The damage a pollutant causes depends very much on the number of people exposed to the pollutant. Similarly, the magnitude of the welfare losses associated with the degradation of a natural resource dependson the number of people involved.)

(vi) Number of stakeholders interested in a solution. This will affect the design of the implementation procedure for the selected policy instrument.

The nature and extent of environmental problems themselves place distinct policy constraints upon decision makers in a variety of ways. For instance, economic instruments that may work for one set of environmental problems in one country may not be sufficient to address a more severe problem in another. Similarly, a less developed country with severe environmental problems will naturally face greater constraints than a developed country with more resources and fewer problems. Further, a country that is economically dependent upon a marginally profitable and polluting industry will have fewer policy options than countries with more diverse and profitable industries. Policymakers often have to make choices among which environmental problems to address, because the resources are not available to address all of the issues at one time.

In general, environmental problems can only be understood and addressed in the context of the larger economy and society. The state of economic development, cultural values, and population pressures, often constrains the options available to address problems. The level of economic development determines the type of environmental issues to be addressed and the effectiveness of the various environmental protection instruments available. For example, low levels of development will likely mean greater rural than urban environmental concerns. Less developed countries also have fewer available instruments to use. They have less tax base to enforce environmental protections laws and a restricted range of economic instruments. The industrial makeup of the economy is another critical factor. Many countries depend on one or a few major industries. Others have a diverse economic base. These conditions greatly impact the type of environmental instruments needed for environmental protection and natural resources management,

The appropriate policy response hinges on a clear and realistic understanding of **baseline conditions.** Sometimes this may mean a less effective policy on a theoretical basis is actually the most appropriate one, given institutional capabilities. Though every country wants to portray an image of clean and efficient governance, few nations can truly boast of such systems. The level of competence and honesty of any institution that will be used to develop, promulgate, monitor or enforce the policy in question needs to be realistically assessed. If these limitations are not recognized, there is strong likelihood that policy instruments will fail, leaving the underlying environmental problem unsolved. While improvement in the structure or performance of institutions can improve over time, it is unwise to depend on them in the short run. In particular, the following areas critical to the success of any environmental initiative need to be considered: Governmental capacity, Environmental agency power, Fiscal cash flow implications, Social, cultural, and demographic implications, and Economic conditions.

4.3.1.3. Making Policy Choices

Given the uniqueness of any given situation, it is difficult to offer specific guidance on how to make policy choices to address environmental problems. However, some general guidelines can help policymakers to choose the most appropriate options for further consideration. These include specifically the recognition of policy trade-offs and realistic assessments of policy limitations. The following practical guide have been recommended.

- **Choose the Simpler Approach**: Policy design should be commensurate with the problem to be solved. There is always need to avoid overly complicated policies. If the problem is local, local solutions may be best. If the problem involves a handful of industries with similar production processes, establishing a national trading system probably does not make sense as costs of control will be similar across plants. Simple easy to administer solutions, however, are often more difficult to arrive at, or even imagine, but they are almost always more efficient and effective.

- **Match the Policy to the Problem**. In the end, actual reduction of pollution or conservation of natural resources depends upon choosing the right policy instruments given baseline conditions, the problem to be solved, and stakeholder feedback. Obviously, the option with the highest efficacy, lowest side-effects and greatest feasibility given existing power and institutional dynamics would be best. However, it is unlikely that any option will score the highest for each category, so trade-offs will be needed. Unfortunately, there is no formula for finding the right balance. Box 4.4 below presents some common problems and policy instruments useful in addressing them.

- **Mitigate Hardships.** Policy proposals should include appropriate measures to ameliorate negative impacts, for example transitional support for displaced individuals or poor segments of society. Where policy implementation is anticipated to cause undue hardships on segments of the population, transitional measures need to be built into the initial policy package. Possibilities include phasing in limits slowly to avoid sudden changes in prices or access rights; exemptions for groups who face high compliance costs but are minor contributors to the problem; or transitional subsidies to highly affected groups. Solutions that mitigate hardships should adhere to the polluter pays principle as closely as possible, resisting the inevitable efforts by industry groups to have their entire transition costs shifted to the taxpayer. Aside from the reduction in hardship, the flanking measures play an important role in mitigating political opposition to the new policy.

- **Avoid Inappropriate Use of Economic Instruments.** It is important to understand and acknowledge the conditions under which the use of economic instruments is not likely to be appropriate. Box 4.5 identifies specific conditions where the use of economic instruments may not achieve the desired environmental and economic objectives while Box 4.6 examines an application of transferable quotas for international fisheries protection.

- **Use Subsidies Carefully.** In attempting to mitigate hardships, or to achieve political consensus, it is quite common to offer subsidies to affected parties. However, providing temporary or transitional subsidies to facilitate changes should be used sparingly since any subsidy distorts markets and makes them less efficient. In addition, they are often very difficult to end once started. Rather, subsidies should focus on protecting the poorest sectors of society from any severe impacts of the change. This could be done with:

    (i) Payments to affected poor individuals for transitional assistance. Examples are subsidies for the introduction of environmentally sound technologies, in situations where social benefits greatly exceed private benefits (e.g. the reduction of overgrazing among traditional herders), or in situations where payments can be decoupled from any activities causing environmental damage, and limited in time.

    (ii) Pricing mechanisms (such as offering subsidies flowing only to basic foodstuffs) in societies where central governments cannot be relied upon to provide direct subsidies to the poor.

    (iii) Support for subsistence sectors decoupled from environmentally damaging production and shifted to subsistence consumption.

- **Prioritize Options.** This has to do with comparing the final options across key criteria. Table 4.3 provides a simple template that can be used to compare the final options across key criteria. The use of a matrix ensures that important data and impact categories are compared for each option. Each separate option generates two columns in the table. The first, "Option Review" will provide very brief text summaries of the policy alternative. The second, "Ranking", provides comparative rankings that will make policy comparisons easier to do. Ranking methods can be changed to suit needs and preferences (e.g. use of numbers rather than high, medium low; or by weighting some criteria more than others). Similarly, evaluation criteria can be modified as well to better reflect the objectives of policymakers. This type of comparison can be helpful in trying to decide amongst the final slate of options.

Box 4.4 Common Environmental Problems and Useful Policy Responses

Overuse of Natural Resources. Property rights-oriented approaches, such as granting or selling the rights to access or develop particular resources to specific groups, can work well in situations where current use patterns are depleting the resource base. Where informal access patterns by local users are codified, subsistence livelihoods can be protected while concurrently providing much improved direct incentives to manage the resource for the long-term.

Even in more international markets, permits that differentiate commercial and subsistence users can help achieve a balance between resource protection and employment. If consumption must be curbed, buy-out or phase-out of the existing de facto rights is a possibility.

Industrial Pollution - **Disparate Technologies**. Where emissions of pollutants come from many industrial sources, there is likely to be widely varying costs to abate the pollution. In these circumstances, there are often large efficiency gains from imposing pollution taxes, fees, or tradable permits relative to mandatory standards under a command and control regime.

Industrial Pollution - Standard Technology, Few Producers. Where there are few producers, all relying on similar production technologies, disparities in control costs are generally much lower. These circumstances suggest minor gains from trading alongside potentially large oversight costs to create a market. Command and control regulatory approaches may be the more efficient option.

Known Damage Thresholds. Where regulators have a good sense of the point at which emissions will cause health problems or ecosystems begin to fray, tradable permits are often the best choice. Caps on emission/extraction can be set in advance, either based on absolute values (e.g., tons of salmon that can be caught) or on relative values (e.g., percent of total allowable catch), allowing markets to allocate the rights efficiently. Policy adjustments should be made on a regular basis to adapt to changing conditions or errors in the initial caps.

Publicly Provided Services. The objective of policies affecting publicly owned service organizations (e.g. water, sewer, or electrical utilities) is to institute pricing that achieves full recovery of costs through user fees, but with a rate design that protects the poor. Attempts to cover costs of the enterprises often bring to light their inefficiencies, increasing pressure for improved management and governance structures. The combination of revenue collection and increased organizational efficiency can be a powerful help to governments. Improved cost recovery can make system upkeep easier, with resultant improvements in efficiency of resource use, and more feasible system extensions, often with associated equity benefits such as providing electricity or sewage services to poorer regions for the first time.

Box 4.4. Contd.

Highly Politicized Government Enterprises. Influencing government-owned enterprises, especially in highly politicized natural resource extraction areas (e.g. oil, natural gas, and other minerals), presents special challenges. Such enterprises face difficult obstacles in preventing corruption given large cash flows and poor transparency and therefore in instituting appropriate environmental controls (government litigation against itself being uncommon). In such cases, most experts believe that both the fiscal and environmental well-being of the country can be served through privatizing the enterprise if not ownership of the resource itself. This can be done either through a direct sale, or by floating a portion of the company in international stock markets. Stock market listing requirements provide important leverage to facilitate disclosure and transparency, and to overcome special interests benefiting from the status quo.

Transitioning to New Technology. Moving an existing market structure to one that includes more environmentally-friendly approaches involves multiple challenges: developing a technology that works; convincing firms to use the technology; and ensuring that the final product can actually be sold.

Some market shifts that mostly require changes in management (e.g., soil conservation on farms) can often be accomplished by making the continuation of existing subsidies contingent on the adoption of sustainable practices.

Where new equipment must enter the marketplace but is still more expensive, policies should reward initiatives once they are sold. Therefore, rather than subsidizing research and development (R&D) or plant construction for wind power, a subsidy per unit of wind power purchased in the market would be provided. (**Source**: UNEP,2009. p.192)

Box 4.5. When not to Use Economic Instruments

Emergency Conditions. When problems have severe implications, emergency conditions arise, and behaviour needs to stop immediately, directive bans may be more appropriate. Property rights or licensing approaches could work where some activity, albeit a much lower level, would be acceptable.

Excessive Monitoring Costs. Where monitoring costs are too high to achieve a specific environmental outcome, as when there are a large number of very small transactions (e.g., emissions trades), command and control instruments may be a better fit. Similarly, where there are a very small number of homogenous parties, emissions trading would not have an effective market and few efficiency gains would be achieved through trading. Monitoring and oversight costs would exceed the benefit of economic instruments.

Fragmented Oversight Authority. Where authority to set and enforce regulations for the implementation of economic instruments is highly fragmented across institutions, effective oversight of market-based instruments might become impossible. In such cases, command and control instruments tailored to the existing oversight authorities might be more efficient.

Social Stigma. Societal factors can also make market-based approaches more difficult. For example, communal societies may not adapt well to individual members of the society holding particular rights or paying particular fees. In other societies, the activities that would be affected by the economic instruments may have a close link to social status, generating strong resistance to change.

An example is the loss of cattle (and with it, prestige) if market-based individual grazing rights policies are attempted in some cultures. However, in these circumstances, economic instruments might work when applied at the community level since the communal decision-making can maintain the existing social hierarchy as access rights are granted.

Insurmountable Opposition. Where political power and interest group factions remain strong, policymakers need to judge the most prudent course. Political power can be used when establishing economic instruments to generate loopholes, exemptions or windfalls, in exactly the same way as this power is applied in command and control instruments. Privatization can be used as a front for corrupt sales to transfer state-owned assets to private parties with no gain to the public.

High Level of Dislocation. Where large numbers of people will be displaced or unemployed as a result of economic instruments and there is little that can be done to mitigate hardships, caution is required.

(**Source**: UNEP,2009. p.194)

Box 4.6 Transferable Quotas for International Fisheries Protection

Fisheries have long been a "commons" problem, since fish dwell in unmanaged ecosystems accessible by many countries. Historical controls to address this problem have focused on restricting access. Nationalization of 200 miles of coastline by most countries helped reduce fishing pressure for a while, by curbing access of foreign fleets to domestic waters. However, even with such restrictions, problems remained. Two main economic counter currents undermined the effect of restricted access to the fisheries.

These were:

- Continual technical improvements in fleets that made each boat a more efficient vessel for harvesting fish and,
- Large subsidies of fishing-related operations and capital equipment (e.g., subsidized loans for boats) created a massive overcapacity of vessels. The World Bank has estimated that during the 1990s, annual subsidies were equal to between 20 and 25 percent of global fishery revenues.

The combination of these two developments has depleted many fisheries to the point of total collapse of the fishery.

Using transferable quotas over the past 30 years, many countries have implemented market-based approaches to ration access to fisheries and manage both local and international fisheries. Variously called Individual Transferable Quotas (ITQs) or Individual Fishery Quotas (IFQs), the rights allow the holder to catch a specified proportion of the total allowable catch each year. The total catch represents the central government's estimate of how many pounds of a particular fish species can be sustainably harvested.

The theory of ITQs is clear. Where there once was unlimited and free access to fish, users must now be licensed. This has a number of advantages:

- With quotas users can space out their catch more regularly without fearing that others will overuse the resource, enabling them to fish more when prices are high, increasing their profits.
- The aggregate catch of the vessels is limited, ensuring sufficient fish survive to rebuild stocks.
- Each license holder has an incentive to ensure other vessels do not fish illegally, since this reduces the available catch for license holders and depresses the value of the licenses on the spot market, which existing quota holders can sell.

The Organization for Economic Co-operation and Development (OECD) has reviewed 31 fisheries across six countries using some variant of this approach and concluded that catch levels were maintained at or below catch limits in 24 cases. In 23 cases, the permits also improved the cost-effectiveness and profits of the fishery. While overall employment generally fell, part-time and seasonal jobs were often replaced by more stable, year-round work.

The success of the programmes seems to be dependent upon some key criteria:

- **Accurate Estimates of Sustainable Catch.** If the total catch values are too high, transferable permits have the perverse effect of increasing the cost-effectiveness of the unsustainable exhausting the resource. OECD noted that there were at least temporary declines in fish stocks within 24 fisheries. This seems to have been caused by a basic problem in the way total catch was calculated, and that the error eliminated many of the environmental and ecological benefits of the economic instrument.

Box 4.6. Contd.

- **Consistent Administration.** In the Netherlands (sole and place fisheries) and Norway (cod fishery), ITQs failed to halt the increase in catch because license holders found that the state was shutting entire fisheries down even if individual quota holders had not yet met their quotas. As a result, quota holders continued to have a "race to fish" to exhaust their catch limits first before access was closed off.

- **Resistance to Political Pressure.** Errors in total catch values may not all be technical. Regulators in South Africa have been under continued and intense political pressure to increase total catch figures, irrespective of the environmental cost of doing so. Such pressure exists in most countries, but total catch figures are most likely to be manipulated for private gain where institutions are weak or corruption is widespread.

- **Correct and Complete Information.** Catch quotas are often based on landing statistics. Many fishermen destroy catch at sea to produce acceptable landing numbers making it impossible to reconcile the landing statistics with the actual pressure placed on marine ecosystems. It has been suggested that a post-landing spot market for ITQs, allowing fisherman to purchase excess quotas, may alleviate this pressure to some degree.

- **Avoidance of High Grading.** In a practice called "high grading" fishing crews discard smaller fish (that often die) at sea in order to maximize the value of the catch that is officially landed. Differential landing taxes, with higher levies on bigger fish, in theory could make fishermen neutral with regards to the maturity of their catch. However, the cost of monitoring needed to accurately set and implement such taxes could be quite large.

Thus far, fisheries managers have steered clear of multi-catch fisheries because of the complications involved. The programmes have instead been targeted to single species. While bundled ITQs covering common mixtures of species could be created, implementing it in practice is difficult as by-catch (i.e. the catch of unwanted species) is likely to vary by region. (Source: UNEP, 2009).

Table 4.3. Policy Ranking Template

Policy parameter	Option review*	Ranking* (H,M,L)
Description		
Main policy		
Choices re: distribution of initial rights, ability to transfer, duration and caps		
Performance		
Environmental efficacy		
Complexity		
Cost of implementation and operation		
Anticipated side-effects		
Social: highly impacted groups (exposure, job loss, increased poverty)		
Short-term economic impacts		
Long-term economic impacts		
Trade and competitiveness impact		
Proposed flanking measures		
Feasibility		
Institutional capability to implement?		
Powerful opposition?		
Other factors of interest/concern		

* Each of the final policy options should have its own review and ranking columns. (**Source:** UNEP, 2009. p.196)

4.3.2 Evaluation Criteria

4.3.2.1 Introduction

What criteria should be used to evaluate environmental policies? Box 4.7 provides a listing of some yardsticks. Among these criteria, cost effectiveness has been a traditional focus both at the theoretical and empirical level. However, it is obvious from the listing that cost effectiveness is not the only important, and is not even likely to be the most important, criterion in many contexts. More recently, the role of political feasibility and distributional issues have gained traction. In this subsection, we will examine the core issues in cost effectiveness as an evaluation criterion after which we will focus on political feasibility and distributional issues.

Box 4.7 Evaluating Economic Instruments

Environmental Effectiveness: Are emissions levels or resource depletion rates falling? Are ambient concentrations in the surrounding environment declining? These are critical metrics to establish both baseline values and measurements over time. Unfortunately, even this basic data is often lacking.

Economic Efficiency: Are costs of emissions rights stable or declining? Are they less expensive than projected in advance? (Falling values normally indicate that businesses are finding more efficient abatement methods.) Are new abatement technologies entering the market? Are trades being used? (Falling values with declining trades suggest either that new non-polluting options have emerged or that polluters are not purchasing required permits).

Administration and Compliance Costs: Has the public sector implemented an effective administrative oversight programme for the policies? How expensive is this to run relative to the value of trades occurring, emissions reductions realized, or anticipated cost of command and control programmes? How expensive are the administrative costs to the private sector relative to those normally incurred under a command and control approach? Are institutions cooperating to achieve the policy objective, or are efforts being blocked?

Revenue Generation: Are user fees sufficient to cover the full costs of providing particular public services? Are fees appropriately levied on different user groups? Are environmental taxes high enough to trigger appropriate price increases in the products/production processes of concern? Are revenues retained to support additional environmental protection efforts or diverted to the general treasury?

Political feasibility: Is the policy politically feasible? Is it likely to gain the support of the Legislature, bureaucrats or policy-makers? Is the implementation feasible? Is it going to be resisted by those who hold de facto political power, civil society, or those who have ability to influence public opinion?

Distributional Issues: How will the policy affect the distribution of resources; particularly, how will it affect the poor or less-privileged? Is it going to redistribute resources in favour of the more-privileged in society?

Wider Economic and Social Effects: Are there noticeable (positive or negative) effects on employment, poverty, trade, competitiveness, growth, or rates of innovation that can be reasonably attributed to the environmental policies being evaluated? Where these impacts are negative, are they transitory or permanent? Can policy modifications mitigate the transitional dislocations?

Source: Adapted with modifications from OECD, (1997) Evaluating Economic Instruments for Environmental Policy, pp. 91-99; UNEP (2009). p198 and Damon and Sterner (2012) "Policy Instruments for Sustainable Development at Rio +20, Journal of Environment & Development 21(2) 143–151.

4.3.2.2. Cost-Effective Policies for Uniformly-Mixed Fund Pollutants

Cost effectiveness relates to achieving the target control level in a manner that minimizes the cost of control. For the purpose of this lecture, we will focus on pollution.

For uniformly-mixed fund pollutants, the damage caused depends on the amount entering the atmosphere and is relatively insensitive to where the emissions are injected into the atmosphere. Assume for example, two emission sources (firm 1 and firm 2); each of them is currently emitting 15 units making a total 30 units. Suppose that two firms can control emissions at the following marginal costs:

$$MC_1 = \$100q_1 \quad (4.16)$$

and

$$MC_2 = \$200q_2 \quad (4.17)$$

where q_1 and q_2 is, respectively, the amount of emissions reductions by the first and second firm. Assume the regulatory authorities have, however, set a total emission target of 15 units so that a reduction of 15 units is necessary. How should this 15-unit reduction be allocated between the two sources in order to minimize the total cost of the reduction?

Assume the government intend to use a CAC policy instrument, such as emissions standard: In the absence of any information on control costs at its disposal, the easiest method would be simply to allocate each source an equal reduction. That is to say, each firm reduces emissions by 7.5 units. By integrating their respective MC functions at the values of $q_1 = q_2 = 7.5$ we can find the total cost of emission reduction for each firm. Summing up, we get a total cost of reduction equal to \$ 8,437.50.

Now, assume that instead of emission standard (a CAC policy), the regulatory agency decides to use a market-based instrument, like an emission charge, a fee levied on each unit of pollution. The total payment any source would make to the government could be found by multiplying the fee times the amount of pollution emitted. Here, each firm has an incentive to reduce pollution because paying the fees costs the firm money. How much pollution control would the firm choose in this circumstance?

A profit-maximizing firm would control, rather than emit, pollution whenever it proved cheaper to do so. Consider Figure 4.8 which sketches the marginal cost function for firm 1. The level of uncontrolled emission is 15 units and the emissions charge is T. Thus, if the firm were to decide against controlling any emissions, it would have to pay T times 15, represented by area 0TBC. It is obvious that the firm will not choose this option because it can control some pollution at a lower cost than paying the emissions charge. It would profit the firm more to reduce emissions until the marginal cost of reduction is equal to the emissions charge.

$$MC_1 = \$100q_1 = Tq_1 \quad (4.18)$$

As illustrated in the diagram, the firm would minimize its cost by choosing to clean up 10 units of pollution and to emit 5 units. At this allocation the firm would pay control costs equal to area 0AD and total emissions charge payments equal to area ABCD. Doing this allows the firm to save 0AT in cost.

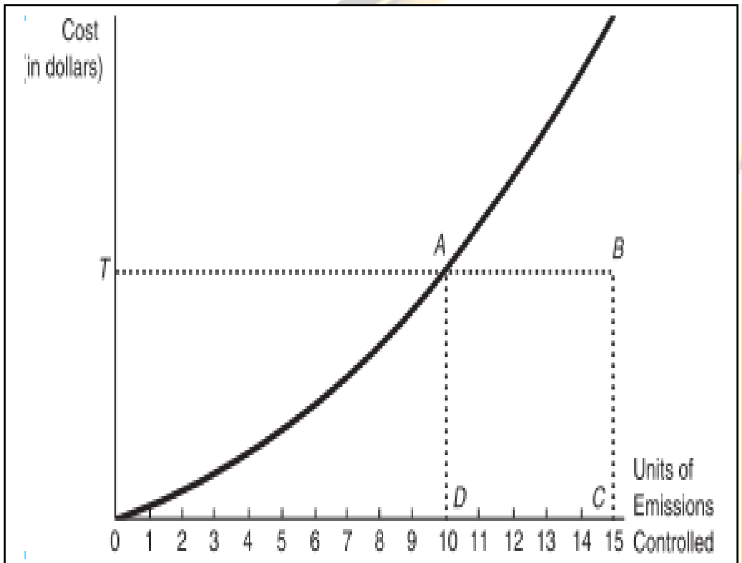

Fig. 4.8a. Cost-Minimizing Control of Pollution with an Emissions Charge (**Source:** Tietenberg & Lewis, 2012. p371)

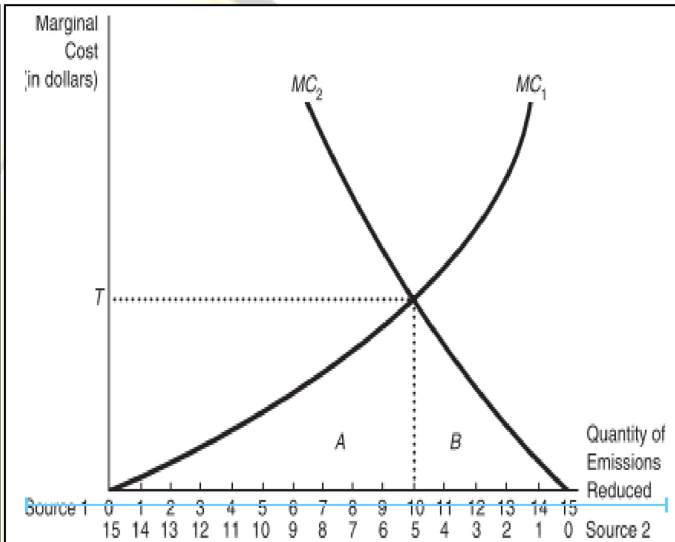

Fig. 4.8b Cost-Effective Allocation of a Uniformly Mixed Fund Pollutant **(Source**: Tietenberg & Lewis, 2012. p.369)

The second firm will follow the same cost minimization principle and pollute up to 10 units and clean up 5 units. Since emissions charge, is the same for both firms, they will independently choose levels of control consistent with equal marginal control costs.

$$MC_1 = MC_2 = T \qquad (4.19)$$

The result is illustrated in Figure 4.8b. In the diagram, the marginal cost of control for firm 1, MC_1, is measured from the left-hand axis, while the marginal cost of control for firm 2, MC_2, is measured from the right-hand axis. A total 15-unit reduction is achieved for every point on the graph; each point represents some different combination of reduction by the two sources. Thus, the diagram represents all possible allocations of the 15-unit reduction between the two sources. All points in between represent different allocations between the two firms. Indeed, we can use equation (4.) to derive the algebraic solution illustrated in Fig. 4.8b by equating (4.16) and (4.17), given that $q_1 + q_2 = 15$ and solving for the values of q_1 and q_2 that satisfy the conditions, It is not difficult to see that these values are $q_1 = 10$ and $q_2 = 5$.

The condition indicated in (4.19) is the cost effectiveness criterion. It yields the cost-minimizing allocation that achieves the pollution target. In other words, cost-effectiveness is achieved when firms equalize their marginal abatement costs (the equi-marginal principle that underlies the efficiency principle). Given increasing marginal costs of pollution control, the cost of achieving a given reduction in emissions will be minimized if and only if the marginal costs of control are equalized for all emitters. In Figure 4.8b this is demonstrated by the fact that the marginal cost curves for the two firms cross at the cost-effective allocation.

It is easy to show that the total cost of emission control is lower in this case, compared to under the emission standard policy. Substituting q_1= 10 and q_2 = 5 into the integral of the MC functions for the firm and adding up gives a total cost of $7, 500 indicating a cost saving of $8,437.50 - $ 7,500 = $937.59. Thus, by using economic instruments, the economy is able to reduce its pollution abatement costs. As long as the control authority imposes the same emissions charge on all sources, the resulting incentives are automatically compatible with minimizing the costs of achieving that level of control. This is true in spite of the fact that the control authority may not have sufficient knowledge of control costs for each firm.

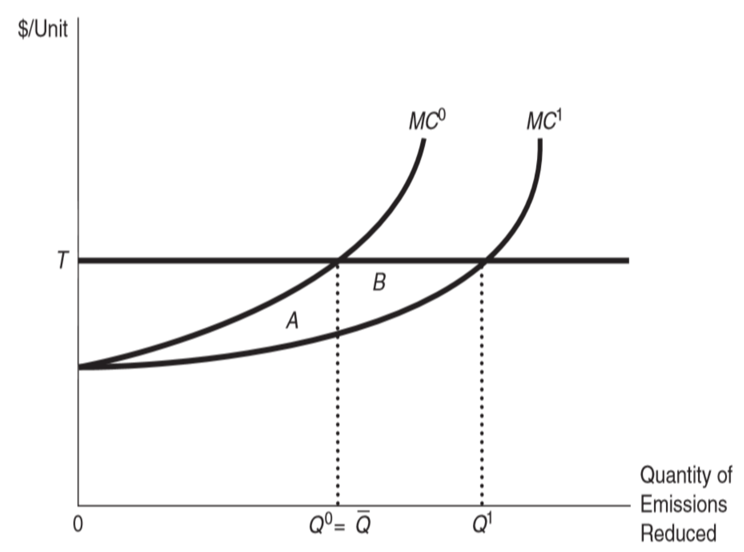

Fig. 4.9 Cost Savings from Technological Change under emission charges (Source: Titenberg & Lewis, 2012. p.373)

Emission charges not only causes cost-minimizing sources to choose a cost- effective allocation of the control responsibility, it also stimulates the development of newer, cheaper means of controlling emissions, as well as promoting technological progress. With an emissions charge system, the firm saves money by adopting cheaper new technologies. As long as the firm can reduce its pollution at a marginal cost lower than the emission charge, it pays to adopt the new technology.[20] This is illustrated in Figure 4.9. The firm

[20] In contrast, under emission standard, firms have an incentive to hide technological changes from the control authority. This is because control authorities base the emissions standards on specific technologies. As new technologies are discovered by the control authority, the standards are tightened. These stricter standards force firms to bear higher costs.

saves A and B by adopting the new technology and voluntarily increases its emissions reduction from Q_0 to Q_1.

However, it has a major drawback in the sense that it is not possible to determine onset what the efficient level of emission will be. Put differently, it is not possible to know ahead the emission charge that will be consistent with the target (desired) level of emission. How high should the charge be set to ensure that the resulting emissions reduction is the desired level? Without having the requisite information on control costs, the control authority cannot establish the correct tax rate on the first try.[21]

It is possible, however, to develop an iterative, trial-and-error process to find the appropriate rate. This process is initiated by choosing an arbitrary charge rate and observing the amount of reduction that occurs when that charge is imposed. If the observed reduction is larger than desired, it means the charge should be lowered; if the reduction is smaller, the charge should be raised. The new reduction that results from the adjusted charge can then be observed and compared with the desired reduction. Further adjustments in the charge can be made as needed. This process can be repeated until the actual and desired reductions are equal. At that point the correct emissions charge would have been found. But during the trial-and-error period of finding the appropriate rate, firms would be faced with a volatile emissions charge which makes planning for the future difficult. Investments that would make sense under a high emissions charge might not make sense when it falls. This does not bode well for both policy-makers and business firms.

It is believed that the use of Cap-and-Trade helps to overcome this limitation. Under this system, all sources face a limit on their emissions and they are allocated (or sold) allowances to emit. Each allowance authorizes a specific amount of emissions (commonly 1 ton). The control authority issues exactly the number of allowances needed to produce the desired emissions level. These can be distributed among the firms either by auctioning them off to the highest bidder or by granting them directly to firms free of charge (an allocation referred to as "gifting"). However, they are acquired, the allowances are freely transferable; they can be bought and sold. Firms emitting more than their holdings would buy additional allowances from firms who are emitting less than authorized. Any emissions by a source in excess of those allowed by its allowance holdings at the end of the year would cause the source to face severe monetary sanctions. Figure

[21] Firms generally have a large menu of options for controlling the amount of pollution they inject into the environment. The cheapest method of control will differ widely not only among industries, but also among plants in the same industry. Generally, plant managers are able to acquire this information for their plants when it is in their interest to do so. However, the government authorities responsible for meeting pollution targets are not likely to have this information. Since the degree to which these plants would be regulated depends on cost information, it is unrealistic to expect these plant managers to transfer unbiased information to the government. Plant managers would have a strong incentive to overstate control costs in hopes of reducing their ultimate control burden.

4.10 below, which treats the same set of circumstances as in Figure 4.8b illustrates why this system automatically leads to a cost-effective allocation.

Consider first the gifting alternative. Suppose that the first source was allocated 7 allowances (each allowance corresponds to one emission unit). Because it has 15 units of uncontrolled emissions, this would mean it must control 8 units. Similarly, suppose that the second source was granted the remaining 8 allowances, meaning that it would have to clean up 7 units. Notice that both firms have an incentive to trade. The marginal cost of control for the second firm (MC_2 = 200 = C in the diagram) is substantially higher than that for the first (MC_2 = 200 = A) in the diagram. The second source could lower its cost if it could buy an allowance from the first source at a price lower than C. Meanwhile, the first source would be better off if it could sell an allowance for a price higher than A. Because C is greater than A, grounds for trade certainly exist. A transfer of allowances would take place until the first source had only 5 allowances left (and controlled 10 units), while the second source had 10 allowances (and controlled 5 units). At this point, the allowance price would equal B, because that is the marginal value of that allowance to both sources, and neither source would have any incentive to trade further. The allowance market would be in equilibrium.

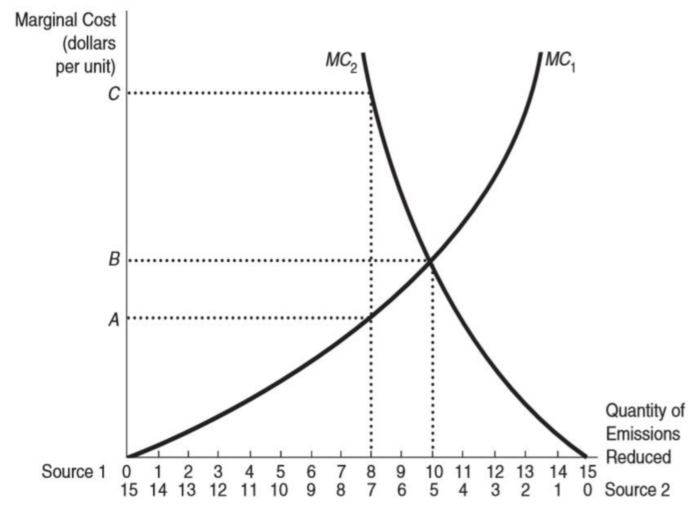

Fig. 4.10 Cost-Effectiveness and Emissions Trading (Source: Titenberg & Lewis, 2012. p.374

Notice that the market equilibrium for an emission-allowance system is the cost-effective allocation! Simply by issuing the appropriate number of allowances (15) and letting the market do the rest, the control authority can achieve a cost-effective allocation without having even the slightest knowledge about control costs. This system allows the government to meet its policy objective, while allowing greater flexibility in how that objective is met. Even if the allowances were auctioned off, the outcome will be the same. The incentives created by this system ensure that sources use this flexibility to achieve the objective at the lowest possible cost. This remarkable property has been responsible for the prominence of this type of approach in current attempts to reform the regulatory process.

4.3.2.3 Cost-effective Policy for Nonuniformly-mixed Pollutants

The problem is more complicated when dealing with nonuniformly mixed surface pollutants. For these pollutants, the policy must be concerned not only with the weight of emissions entering the atmosphere, but also with the location and timing of emissions. For nonuniformly mixed pollutants, it is the concentration in the air, soil, or water that counts. This is measured as the amount of pollutant found in a given volume of air, soil, or water at a given location and at a given point in time.

It is easy to see why pollutant concentrations are sensitive to the location of emissions. Suppose that three emissions sources are clustered and emit the same amount as three distant but otherwise-identical sources. The emissions from the clustered sources generally cause higher pollution concentrations because they are all entering the same volume of air or water. Because the two sets of emissions do not share a common receiving volume, those from the dispersed sources result in lower concentrations. This is the main reason why cities generally face more severe pollution problems than do rural areas; urban sources tend to be more densely clustered. The timing of emissions can also matter in two rather different senses. First, when pollutants are emitted in bursts rather than distributed over time they can result in higher concentrations. Second, the time of year in which some pollutants are emitted can matter.

Since the damage caused by nonuniformly mixed surface pollutants is related to their concentration levels, the search for cost-effective policies for controlling these pollutants focuses on the attainment of ambient standards. Ambient standards are legal ceilings placed on the concentration level of specified pollutants in the air, soil, or water. They represent the target concentration levels that are not to be exceeded. A cost-effective policy results in the lowest cost allocation of control responsibility consistent with ensuring that the predetermined ambient standards are met at specified locations called receptor sites. We will analyze this first in the case of a single receptor, and later extend to the case of many receptors.

Since emissions are what can be controlled, but the concentrations at the receptor, R are the policy target, our first task must be to relate the two. (In a single receptor case, R = 1). This can be accomplished by using a transfer coefficient. A transfer coefficient (a_i) captures the constant amount the concentration at the receptor will rise if source *i* emits one more unit of pollution. Using this definition and the knowledge that the a_is are constant, we can relate the concentration level at R to emissions from all sources:

$$K_R = \sum_{i=1}^{I} a_i E_i + B \qquad (4.20)$$

where K_R = concentration at the receptor, E_i = emissions level of the i^{th} source, I = total number of sources in the region, B = background concentration level (resulting from natural sources or sources outside the control region).

In Table 4.4, we present a numerical example involving two which are assumed to have the same marginal cost curves for cleaning up emissions but are located at different distances from the receptor. The first source is closer to the receptor, so it has a larger transfer coefficient than the second (1.0 as opposed to 0.5). The objective is to meet a given concentration target at minimum cost. Column 3 of the table translates emissions reductions into concentration reductions for each source. This is product of the emissions reduction and the transfer coefficient. Column 4 records the marginal cost of each unit of concentration reduced and is derived by dividing the marginal cost of the emissions reduction by the transfer coefficient (this translates the marginal cost of emissions reduction into a marginal cost of concentration reduction).

Table 4.4 Cost-Effectiveness for Nonuniformly Mixed Pollutants: A Hypothetical Example

Emissions Units Reduced	Marginal Cost of Emissions Reduction (dollars per unit)	Concentration Units Reduced[1]	Marginal Cost of Concentration Reduction (dollars per unit)[2]
Source 1 ($a_1 = 1.0$)			
1	1	1.0	1
2	2	2.0	2
3	3	3.0	3
4	4	4.0	4
5	5	5.0	5
6	6	6.0	6
7	7	7.0	7
Source 2 ($a_2 = 0.5$)			
1	1	0.5	2
2	2	1.0	4
3	3	1.5	6
4	4	2.0	8
5	5	2.5	10
6	6	3.0	12
7	7	3.5	14

[1]Computed by multiplying the emissions reduction (column 1) by the transfer coefficient (a_i).

[2]Computed by dividing the marginal cost of emissions reduction (column 2) by the transfer coefficient (a_i).

Source: Tietenberg & Lewis, 2012. p.379

Suppose the concentration at the receptor has to be reduced by 7.5 units in order to comply with the ambient standard. The cost-effective allocation would be achieved when the marginal costs of concentration reduction are equalized for all sources. In the Table, this occurs when the first source reduces 6 units of emissions (and 6 units of concentration) and the second source reduces 3 units of emissions (and 1.5 units of concentration). At this allocation the marginal cost of concentration reduction is equal to $6 for both sources. By adding all marginal costs for each unit reduced, we calculate the total variable cost of this allocation to be $27. From the definition of cost-effectiveness, no other allocation resulting in 7.5 units of concentration reduction would be cheaper.

With the above framework, we can evaluate various policy approaches that the control authority might use beginning with ambient charge.

An ambient charge will take the form

$$t_i = a_i \mathrm{F} \qquad (4.21)$$

where t_i is the per-unit charge paid by the i^{th}source on each unit emitted, a_i is the i^{th} source's transfer coefficient, and *F* is the marginal cost of a unit of concentration reduction, which is the same for all sources. In our example, *F* is \$6, so the first source would pay a per-unit emissions charge of \$6, while the second source would pay \$3. Unlike in the case of uniformly mixed pollutant in which a cost-effective allocation required that all sources pay the same charge, here where the objective is to meet an ambient standard at minimum cost, the sources pay different charges because their transfer coefficients differ.

How can the cost-effective t_i be found by a control authority with insufficient information on control costs? The transfer coefficients can be calculated using knowledge of hydrology and meteorology.[22] However, the marginal cost of a unit of concentration reduction, *F* cannot be so determined. Here a striking similarity to the uniformly mixed case becomes evident. Any level of *F* would yield a cost-effective allocation of control responsibility for achieving some level of concentration reduction at the receptor. That level might not, however, be compatible with the ambient standard. We could ensure compatibility by changing *F* in an iterative process until the desired concentration is achieved. If the actual pollutant concentration is below the standard, the tax could be lowered; if it is above, the tax could be raised. The correct level of *F* would be reached when the resulting pollution concentration is equal to the desired level. That equilibrium allocation would be the one that meets the ambient standard at minimum cost.

It is worth considering what is lost if the simpler emissions charge system (where each source faces the same charge) is used to pursue a surface-concentration target. Another way of saying that is that we ignore location. Can location be safely ignored? From Table 8.3, a uniform emission charge equal to \$5 would achieve the desired 7.5 units of reduction (5 from the first source and 2.5 from the second). Yet the total variable cost of this allocation (calculated as the sum of the marginal costs) would be \$30 (\$15 paid by each source). This is \$3 higher than the allocation resulting from the use of ambient charge discussed earlier. In addition, with a uniform emissions charge, 10 units of emission are cleaned up, whereas with the ambient charge, only 9

[22] Thus, the cost-effective allocation of control responsibility for achieving surface-concentration targets places a larger information burden on control authorities; they have to calculate the transfer coefficients.

units are cleaned up even though the same concentration target is achieved. Thus, the ambient charge results in a lower cost allocation than the emissions charge because it results in less emissions control.

With the ambient charge, we have the same problem that we encountered with emissions charges in the uniformly mixed pollutant case—the cost-effective level can be determined only by an iterative process. As in the case of uniformly mixed pollutants, emissions trading can help get around this problem when the allowance trading system is designed in the correct way. An ambient allowance market (as opposed to an emissions allowance market) entitles the owner to cause the concentration to rise at the receptor by a specified amount. Using ΔK_R to represent this permitted rise and E to indicate the units of emissions allowed to the i^{th} source, we can see from Equation (4.20) that

$$\frac{\Delta K_R}{a_i} = \Delta E_i \qquad (4.22)$$

The larger the transfer coefficient (i.e., the closer the source is to the receptor), the smaller the amount of emissions legitimized by the allowances held by that firm. Proximate sources must purchase more allowances than distant sources to legitimize a given level of emissions. In this ambient allowance market, the sources pay the same price for each allowance (with respect to Table 4.4, this will be $6) but the amount of emissions allowed by each allowance varies from location to location. The market automatically determines this common price, and the resulting allocation of allowances is cost-effective. This cost-effective system is called an *ambient allowance system* to differentiate it from the *emissions allowance system*, which is used to achieve a cost-effective allocation of control responsibility for uniformly mixed pollutants.

To fix ideas, using equation (4.20), suppose our two sources want to trade permits with the first source buying from the second. To maintain the same concentration level before and after the trade, we must ensure that

$$a_1 \Delta E_1 = a_2 \Delta E_2 \qquad (4.23)$$

where the subscripts refer to the first source and second source and the ΔE_i refers to a change in emissions by the i^{th} source. Solving this for the allowable increase in emissions by the buyer yields

$$\Delta E_1 = \frac{a_2}{a_1} \Delta E_2 \qquad (4.24)$$

For a_2 = 0.5 and a_1 = 1.0, this equation suggests that for each allowance traded, the buyer (the first source) is allowed to emit only one-half the amount of emissions allowed by that same allowance to the seller. After this trade, the total amount of emissions by both sources goes down.[23] This could not happen in an emissions allowance system, since the design of those allowances causes all trades to leave emissions (but not concentrations!) unchanged.

This analysis generalizes easily to the case where we have many receptors. The cost-effective ambient charge paid by any source would, in this case, be

$$T_i = \sum_{j=1}^{J} a_{ij} F_i \qquad (4.25)$$

where T_i = charge paid by the i^{th} source for each unit of emissions

a_{ij} = transfer coefficient that translates emissions by source *i* into concentration increases at j^{th} receptor

J = number of receptors

F_j = monetary fee associated with the j^{th} receptor

Thus, the source has to pay a charge that incorporates its effect on all receptors. The control authority could manipulate F_j for each receptor location until the desired concentration level is achieved at that receptor.

The extension of the ambient allowance system to the many-receptor case requires that a separate allowance market be created for each receptor. The price prevailing in each of these markets would reflect the difficulty of meeting the ambient standard at that receptor. All other things being equal, ambient allowance markets associated with receptors in heavily congested areas could be expected to sustain higher prices than those affected by relatively few emitters.

Since both the ambient allowance and the ambient charge systems take location into account, when these policies are chosen, the marginal cost of emissions control varies from location to location. Sources located in heavily populated portions of the region would pay higher marginal costs, since their emissions have a greater impact on the receptors of interest. This create incentives for new sources to choose their location carefully. Since heavily polluted areas have high control costs, new firms have some incentive to locate elsewhere, even though pollution-control expenditures are only part of the costs a firm considers when deciding where to locate. For nonuniformly mixed pollution problems, where the emissions occur is important and relocation may be one way to approach the least cost allocation. With the ambient allowance and charge systems, this is precisely what occurs.

However, in practice, ambient charge and allowance systems have proved to be excessively complex to implement. Regulatory agencies often employ a number of rule-of-thumb procedures designed to deal adequately with spatial issues while promoting cost-effectiveness. For a review of these approaches, where they have been applied, and the evidence on their success, see Tietenberg (1995).

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[23] Emissions would rise with ambient allowance trades if the transfer coefficient of the seller was larger than that of the buyer

4.3.2.4. Cost-effectiveness and Renewable Resources

The following case studies applies the results from comparing command-and-control and market-based policies to overharvesting of renewable resources.

Box 4.8. The Relative Effectiveness of Transferable Quotas and Traditional Size and Effort Restrictions in the Atlantic Sea Scallop Fishery

Theory suggests that transferable quotas will produce more cost-effective outcomes in fisheries than traditional restrictions, such as minimum legal size and maximum effort controls. Is this theoretical expectation compatible with the actual experience in implemented systems? In a fascinating study, economist Robert Repetto (2001) examines this question by comparing Canadian and American approaches to controlling the sea scallop fishery off the Atlantic coast. While Canada adopted a transferable quota system, the United States adopted a mix of size, effort, and area controls. The comparison provides a rare opportunity to exploit a natural experiment since scallops are not migratory and the two countries use similar fishing technologies. Hence, it is reasonable to presume that the differences in experience are largely due to the difference in management approaches. What were the biological consequences of these management strategies for the two fisheries?

- The Canadian fishery was not only able to maintain the stock at a higher level of abundance, it was also able to deter the harvesting of undersized scallops.
- In the United States, stock abundance levels declined and undersized scallops were harvested at high levels. What were the economic consequences?
- Revenue per sea-day increased significantly in the Canadian fishery, due largely to the sevenfold increase in catch per sea-day made possible by the larger stock abundance.
- In the United States, fishery revenue per sea-day fell, due not only to the fall in the catch per day that resulted from the decline in stock abundance, but also to the harvesting of undersized scallops.
- Although the number of Canadian quota holders was reduced from nine to seven over a 14-year period, 65 percent of the quota remained in its original hands. The evidence suggests that smaller players were apparently not at a competitive disadvantage.

What were the equity implications?

- Both U.S. and Canadian fisheries have traditionally operated on the "lay" system, which divides the revenue among crew, captain, and owner according to preset percentages, after subtracting certain operating expenditures. This means that all parties remaining in the fishery after regulation shared in the increasing rents. In this fishery at least, it seems that the expectations flowing from the theory were borne out by the experience.

Source: Robert Repetto. "A Natural Experiment in Fisheries Management," Marine Policy Vol. 25 (2001): 252–264; Also in Titenberg and Lewis, p343.

Box 4.9. Reducing Emissions from Deforestation and Forest Degradation (REDD): A Twofer?

According to the United Nations, deforestation and forest degradation, through agricultural expansion, conversion to pastureland, infrastructure development, destructive logging, fires, etc., account for nearly 20 percent of global greenhouse gas emissions, more than the entire global transportation sector and second only to the energy sector. In response, the United Nations has set up a program to reduce these emissions by reducing the forest degradation in developing countries where they occur. Reducing Emissions from Deforestation and Forest Degradation (REDD) is an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and to invest in low-carbon paths to sustainable development. According to this scheme, nations would receive payments for emissions-reduction credits determined on the basis of actual reductions in forest emissions measured against agreed-upon baselines. Although the details of this program remain to be worked out, these credits could, in principle, be sold in the international compliance carbon markets (where they could be used in combination with domestic reductions to meet assigned national targets) or voluntary carbon markets (where they could be used to pursue other organizational goals, such as demonstrating carbon neutrality). The promise of this program is that it offers opportunities to make progress on two goals at once: (1) reducing forest degradation and (2) reducing emissions that contribute to climate change. The challenges, which are far from trivial, are to establish baselines that are both fair and effective and to assure that monitoring and verification procedures are sufficiently rigorous as to provide reliable, accurate measures of actual emissions reductions.

Sources: Government of Norway (2009). Reducing Emissions from Deforestation and Forest Degradation (REDD): An Options Assessment Report. An electronic copy of this report is available at http://www. REDD-OAR.org; and the United Nations REDD website (http://www.un-redd.org/), Titenberg and Lewis, p316

Royalty Payments and Biodiversity Preservation

One potential source of revenue for biodiversity preservation involves taking advantage of the extremely high degree of interest by the pharmaceutical industry in searching for new drugs derived from these biologically diverse pools of flora and fauna. Establishing the principle that nations containing these biologically rich resources within their borders would be entitled to a stipulated royalty on any and all products developed from genes obtained from these preserves provides both an incentive to preserve the resources and some revenue to accomplish the preservation. Nations harboring rich, biological preserves have begun to realize their value and to extract some of that value from the pharmaceutical industry. The revenue is in part used for inventorying and learning more about the resource as well as preserving it. For example, in 1996, Medichem Research, an Illinois-based pharmaceutical company, entered into a joint venture with the Sarawak government. The organization created by this joint venture has the right to file exclusive patents on two compounds that offer some promise as cancer treatments. The agreement specified a 50–50 split from royalties once the drug is marketed. The Sarawak government was given the exclusive right to supply the latex raw material from which the compounds are derived. Furthermore, Sarawak scientists are involved in screening and isolating the compounds, and Sarawak physicians are involved in the clinical trials. This agreement not only provides a strong rationale for protecting the biological source, but also enables the host country to build its capacity for capturing the value of its biodiversity in the future. These arrangements are particularly significant because they facilitate transboundary sharing of the costs of preservation. It is unrealistic to expect countries harboring these preserves to shoulder the entire cost of preservation when the richer countries of the world are the major beneficiaries.

Box 8.7 illustrates how realistic is the assumption that pharmaceutical demand is sufficient for sufficient preservation while Box 8.8 illustrates the use of Trust Funds for habitat preservation

Box 4.10. Does Pharmaceutical Demand Offer Sufficient Protection to Biodiversity?

Theory suggests that incentives to protect plants are stronger when the plants are valuable to humans. How about practice? The case of Taxol is instructive. Derived from the slow-growing Pacific yew, Taxol is a substance that has been proved effective in treating advanced forms of breast and ovarian cancers. As of 1998, it was the best-selling anticancer drug ever. Since the major site for this tree was in the old-growth forests of the Pacific Northwest, the hope of environmental groups was that the rise in the importance of Taxol might provide both sustainable employment and some protection for old growth forests. In fact, that is not how it worked out. The Taxol for the chemical trials was derived from the bark of the tree. Stripping the tree of its bark killed it. And supplying enough bark for the chemical trials put a tremendous strain on the resource. Ultimately, the private company that marketed Taxol, Bristol-Squibb, developed a semi-synthetic substitute that could be made from imported renewable tree parts. The Pacific yew, the original source of one of the most important medical discoveries in the twentieth century, was left completely unprotected. And the industry that had grown up to supply the bark collapsed. In the end, its value proved transitory and its ability to support a sustainable livelihood in the Pacific Northwest was illusory.

Source: Jordan Goodman and Vivian Walsh. The Story of Taxol: Nature and Politics in the Pursuit of an Anti-Cancer Drug (New York: Cambridge University Press, 2001); Tietenberg and Lewis. P311-312

Box 4.11. Trust Funds for Habitat Preservation

How can local governments finance biodiversity preservation when faced with limited availability of both international and domestic funds? One option being aggressively pursued by the World Wildlife Fund involves trust funds. Trust funds are moneys that are legally restricted to be used for a specific purpose (as opposed to being placed in the general government treasury). They are administered by trustees to assure compliance with the terms of the trust. Most, but not all, trust funds are protected endowments, meaning that the trustees can spend the interest and dividends from the funds, but not the principal. This assures the continuity of funds for an indefinite period. Where does the money come from? Many nations that harbor biodiversity preserves cannot afford to spend the resources necessary to protect them. One possibility is to tap into foreign demands for preservation. In Belize, the revenue comes from a "conservation fee" charged to all arriving foreign visitors. The initial fee, $3.75, was passed by Belize's parliament in January 1996, raising $500,000 in revenues each year for the trust fund. Similar trust funds have been set up in Mexico, Honduras, and Guatemala. Income from the trust funds can be used for many purposes, including training park rangers, developing biological information, paying the salaries of key personnel, and conducting environmental education programs, depending on the terms of the trust agreement. Biodiversity preservation that depends on funds from the general treasury becomes subject to the vagaries of budgetary pressures. When the competition for funds intensifies, the funds may disappear or be severely diminished. The virtue of a trust fund is that it provides long-term, sustained funding targeted for the protection of biodiversity. In 2004, Belize joined with Mexico, Honduras, and Guatemala to form the Mesoamerican Reef (MAR) fund, a regional financing mechanism. It was created to strengthen the alliance among the four country-specific trust funds. The MAR fund is unique as the first environmental fund in the Western Hemisphere to transcend national boundaries and encompass an entire ecoregion. The fund supports projects related to improving water quality, ecotourism, sustainable fisheries, and strengthening public institutions.

Source: Barry Spergel. "Trust Funds for Conservation," FEEM Newsletter Vol. 1 (April 1996): 13–16 and the World Wildlife Foundation's website on conservation trust funds at http://www.worldwildlife.org/what/howwedoit/conservationfinance/conservationtrustfunds2.html (accessed November 18, 2010). Tietenberg and Lewis. P311-312

4.3.2.5 Beyond cost-effectiveness: Political feasibility, social and distributional Issues

Political economists believe that powerful political, economic and security actors fundamentally shape the process of development and state-building by exerting influence and control over institutions of governance, government policies and the distribution of resources. There is now a consensus that this reality needs to be factored into policy and developmental interventions.[24]

[24] Brown & Gra¨vingholt, 2009; John & Putzel, 2009; Department for International Development, 2010, p. 2; Parks & Cole, 2010. See also Oyefusi, A. (2014) Oil Bunkering in Nigeria's Post-amnesty Era: An Ethnopolitical Settlement Analysis. *Ethnopolitics,* Vol. 13, No. 5, 522–545, http://dx.doi.org/10.1080/17449057.2014.931120

Powerful actors in society can easily block a policy or scuttle its implementation if it threatens their interests. In addition to political feasibility is the social and distributional effects of a proposed policy. These considerations may be particularly important in the context of developing countries and are particularly relevant to Sub-Saharan Africa where unemployment and poverty are still major issues. As Zivin and Damon (2012) emphasized, consideration of environmental policy choices must holistically incorporate the ways that choice instruments interact with other political goals if the design is going to be effective and if they are to enjoy widespread support.[25] The authors, showed, for example, that there can be both synergies and the potential conflict between employment and sustainability goals. Of crucial importance is how to manage the joint weights of labor, political, and business interests vested in resource extraction and processing against the long run goal of limiting the idea of employment based on open-access resource harvesting and processing.

As shown in Sahlén and Stage (2012) from a study of Namibia, fiscal reform could help in some settings to address the competing issues of environmental protection and short-term job growth. For example, taxes on fish resources, water, and energy can be directly recycled and put toward employment objectives and income distribution. In particular, the authors found that using fiscal reform revenue to subsidize employment of unskilled labor yield the largest GDP gains (among the alternatives considered) but also had the least attractive environmental outcomes. In contrast, directing revenue toward the poorest households in the form of transfers, rather than in the form of employment subsidies, had the most favorable environmental effects.[26] What the analyses shows is that there is the need for policy instruments to be thoughtfully designed taking account of the context if we are to balance and achieve sustainable development goals.[27]

Summary

- While an understanding of the theoretical benefits of particular economic instruments can be useful, the existing institutional capabilities and environmental policies in the country

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[25] Zivin and Damon (2012), "Environmental Policy and Political Realities: Fisheries Management & Job Creation in the Pacific Islands," Journal of Environment & Development 21(2) 198–218 DOI: 10.1177/1070496512442932

[26] Sahlén and Stage (2012) "Environmental Fiscal Reform in Namibia—A Potential Approach to Reduce Poverty?", Swedish National Institute for Economic Research, Stockholm, https://core.ac.uk/display/36243158

[27] For more on these issues, see Damon and Sterner (2012) "Policy Instruments for Sustainable Development at Rio +20, Journal of Environment & Development 21(2) 143–151.

need to be taken into account in the choice of an effective environmental policy package that will address a given environmental problem.

- Deciding on the most appropriate instruments to address an environmental challenge requires that policymakers must first determine the nature and extent of the problem. In general, environmental problems can only be understood and addressed in the context of the larger economy and society. The state of economic development, cultural values, and population pressures, often constrains the options available to address problems

- The appropriate policy response hinges on a clear and realistic understanding of baseline conditions. Sometimes this may mean a less effective policy on a theoretical basis is actually the most appropriate one, given institutional capabilities

- Given the uniqueness of any given situation, it is difficult to offer specific guidance on how to make policy choices to address environmental problems. However, some general guidelines can help policymakers to choose the most appropriate options for further consideration. These include specifically the recognition of policy trade-offs and realistic assessments of policy limitations.

- Among the various criteria that could be used to evaluate environmental policies, cost effectiveness has been a major focus, both at the theoretical and empirical level. Cost effectiveness relates to achieving a target control level in a manner that minimizes the cost of control.

- Given increasing marginal costs of pollution control, the cost of achieving a given reduction in emissions will be minimized if and only if the marginal costs of control are equalized for all emitters.

- Use of economic instruments, such as emission charges or transferable quotas, rather than CAC instrument such as emission standard, allows regulatory authorities to achieve the cost-effective solution even when they have limited information at their disposal.

- Emission charges not only causes cost-minimizing sources to choose a cost- effective allocation of the control responsibility, it also stimulates the development of newer, cheaper means of controlling emissions, as well as promoting technological progress. However, it has a major drawback in the sense that it is not possible to know ahead the emission charge that will be consistent with the target (desired) level of emission.

- Cap-and-Trade helps to overcome this limitation as it allows the government to meet its policy objective, while allowing greater flexibility in how that objective is met. The incentives created by this system ensure that emission sources use this flexibility to achieve the desired objective at the lowest possible cost.

- Determining the cost-effective level of pollution is more complicated when dealing with nonuniformly mixed surface pollutants. For these pollutants, the policy must be concerned not only with the weight of emissions entering the atmosphere, but also with the location and timing of emissions.

- Since the damage caused by nonuniformly mixed surface pollutants is related to their concentration levels, the search for cost-effective policies for controlling these pollutants focuses on the attainment of ambient standards. Ambient standards are legal ceilings placed on the concentration level of specified pollutants in the air, soil, or water. A cost-effective policy results in the lowest cost allocation of control responsibility consistent with ensuring that the predetermined ambient standards are met at specified locations.

Discussion/Review Questions and Exercises

1. In his book What Price Incentives? Steven Kelman suggests that from an ethical point of view, the use of economic incentives (such as emissions charges or emissions trading) in environmental policy is undesirable. He argues that transforming our mental image of the environment from a sanctified preserve to a marketable commodity has detrimental effects not only on our use of the environment, but also on our attitude toward it. His point is that applying economic incentives to environmental policy weakens and cheapens our traditional values toward the environment.

(a). Consider the effects of economic incentive systems on prices paid by the poor, on employment, and on the speed of compliance with pollution-control laws—as well as the Kelman arguments. Are economic incentive systems more or less ethically justifiable than the traditional regulatory approach?

(b.) Kelman seems to feel that because emissions allowances automatically prevent environmental degradation, they are more ethically desirable than emissions charges. Do you agree? Why or why not?

2. Why do many countries in Sub-Sharan Africa have problems with enforcing environmental control in their extractive industries?

3. Examine the progress in the development and implementation of the United Nations' Reducing Emissions from Deforestation and Forest Degradation (REDD). Do Sub-Saharan African countries stand to benefit from this programme. Why or Why not?

4. How realistic is the assumption that pharmaceutical demand is sufficient for forestry preservation in Sub-Saharan Africa?

5. Two firms can control emissions at the following marginal costs: MC_1= \$200q_1, MC_2= \$100q_2, where q_1 and q_2, are, respectively, the amount of emissions reduced by the first and second firms. Assume that with no control at all, each firm would be emitting 20 units of emissions or a total of 40 units for both firms.

(a). Compute the cost-effective allocation of control responsibility if a total reduction of 21 units of emissions is necessary.

(b). Compute the cost-effective allocation of control responsibility if the ambient standard is 27 ppm, and the transfer coefficients that translate a unit of emissions into a ppm concentration at the receptor are, respectively, a_1= 2.0 and a_2= 1.0.

6. Assume that the control authority wanted to reach its objective in 5(a) by using an emissions charge system.

(a). What per-unit charge should be imposed?

(b). How much revenue would the control authority collect?

7. In a region that must reduce emissions, three polluters currently emit 30 units of emissions. The three firms have the following marginal abatement cost functions that describe how marginal costs vary with the amount of emissions each firm reduces.

Firm Emissions Reduction	Firm 1 Marginal cost	Firm 2 Marginal Cost	Firm 3 Marginal Cost
1	\$1.00	\$1.00	\$2.00
2	\$1.50	\$2.00	\$3.00
3	\$2.00	\$3.00	\$4.00
4	\$2.50	\$4.00	\$5.00
5	\$3.00	\$5.00	\$6.00
6	\$3.50	\$6.00	\$7.00
7	\$4.00	\$7.00	\$8.00
8	\$4.50	\$8.00	\$9.00
9	\$5.00	\$9.00	\$10.00
10	\$5.50	\$10.00	\$11.00

Suppose this region needs to reduce emissions by 14 units and plans to do it using a form of cap-and-trade that auctions allowances off to the highest bidder.

(a). How many allowances will the control authority auction off? Why?

(b). Assuming no market power, how many of the allowances would each firm be expected to buy? Why?

(c) Assuming that demand equals supply, what price would be paid for those allowances? Why?

(d). If the control authority decided to use an emissions tax rather than cap-and-trade, what tax rate would achieve the 14-unit reduction cost-effectively? Why?

Materials used for this section

1. Damon and Sterner (2012) "Policy Instruments for Sustainable Development at Rio +20, Journal of Environment & Development 21(2) 143–151.
2. UNEP (2009): The Use of Economic Instruments for Environmental and Natural Resource Management First Edition.
3. Titenberg, T. & Lewis, L. (2012). Environmental & Natural Resource Economics 9th Edition, The Pearson Series in Economics
4. Sterner, T. and J. Coria (2012). Policy Instruments for Environmental and Natural Resource Management. Resources for the Future.

Module 4.4. Application to Sub-Saharan Africa (1 hour)

Sub-Saharan African countries faces many environmental challenges, including urban pollution, over-exploitation of renewable resources, such as fisheries; deforestation, and loss of biodiversity. The peculiar characteristics of most of these countries (high and increasing population, high rate of rural-urban migration, dependence on natural resources for sources of livelihood and government revenue, monocultural nature of the economy, high levels of poverty, poor service delivery, and weak institutional arrangements among others) complicates these problems. Understanding these baseline conditions is crucial to developing policies to address the environmental challenges in the continent.

For example, many countries depend on the extractive sector for government revenue and foreign earnings. Activities in this sector often generate environmental problems, thus imposing damages on communities and huge costs on residents. In many cases, the problem is not the absence of environmental laws but the political will and technical capacity to enforce them.

An associated issue is earmarking environmental tax revenues for environmental purposes. This may be a controversial issue, especially in developing countries were public funds are often scarce and corruption levels are high. If the environmental tax itself gives enough incentive to reduce pollution or resource overuse sufficiently, the tax benefits may be diverted to the general treasury. If on the other hand, the tax does not give enough incentive to fully solve the environmental problem (which is often the case), it may be argued that tax revenues should be earmarked for environmental purposes such as publicly-financed abatement (e.g. sewage treatment). Another consideration in this direction will be how to compensate the direct victims of environmental degradation.

An important question to ask is what is the relative importance of Command-and-Control policy instruments compared to market-based instruments, in the context of Sub-Saharan Africa. Put differently, how far can reforms aimed at promoting the use of market-based instruments to solve environmental problems go? Can Sub-Saharan African countries use the experience of the industrialized countries to move directly into using market-based instruments to control environmental problems? The debate in Box 4.12 shows that the answers to these questions are not as straight-forward. Coria and Sterner (2010, 2011), and Damon and Sterner (2012) examine the same issue in the broad sense of whether developing countries have the administrative capacity to deal with complex environmental policy instruments. In their view, many developing countries simply need to develop this capacity just the same way they need to develop many basic government functions such as tax systems, public expenditure, social security, etc. While striving for instruments that are simple and transparent, such as taxes on fossil fuels, is of first-order importance, these instruments are in many cases, inadequate. According to the authors, the tradeoffs between better governance with environmental instruments and the risk that such instruments may pose in terms of sophisticated management, as well as risks posed by rent seeking, need to be managed cautiously from case to case. What is evident overall is that many

Box 4.12. Should developing Countries rely on Market-based Instruments to Control Pollution?

Since the case for using market-based instruments seems so strong in principle, some observers, most prominently the World Bank (2000), have suggested that developing countries should capitalize on the experience of the industrialized countries to move directly to market-based instruments to control pollution. The desirability of this strategy is seen as flowing from the level of poverty in developing countries; abating pollution in the least expensive manner would seem especially important to poorer nations. Furthermore, since developing countries are frequently also starved for revenue, revenue-generating instruments (such as emissions charges or auctioned allowances) would seem especially useful. Proponents also point out that a number of developing countries already use market-based instruments. Another school of thought (e.g., Russell and Vaughan, 2003) suggests that the differences in infrastructure between the developing and industrialized countries make the transfer of lessons from one context to another fraught with peril. To illustrate their more general point, they note that the effectiveness of market-based instruments presumes an effective monitoring and enforcement system, something that is frequently not present in developing countries. In its absence, the superiority of market-based instruments is much less obvious. Some middle ground is clearly emerging. Russell and Vaughan do not argue that market-based instruments should never be used in developing countries, but rather that they may not be as universally appropriate as the most enthusiastic proponents seem to suggest. They see themselves as telling a cautionary tale. And proponents are certainly beginning to see the crucial importance of infrastructure. Recognizing that some developing countries may be much better suited (by virtue of their infrastructure) to implement market-based systems than others, proponents are beginning to see capacity building as a logical prior step for those countries that need it. For market-based instruments, as well as for other aspects of life, if it looks too good to be true, it probably is. Source: World Bank. Greening Industry: New Roles for Communities, Markets and Governments (Washington, DC: World Bank and Oxford University Press, 2000); and Clifford S. Russell and William J. Vaughan. "The Choice of Pollution Control Policy Instruments in Developing Countries: Arguments, Evidence and Suggestions," in Henk Folmer and Tom Tietenberg, eds. The International Yearbook of Environmental and Resource Economics 2003/2004 (Cheltenham, UK: Edward Elgar, 2003): 331–371.

countries, and even more so Sub-Saharan African countries, need more capacity building in the area of environmental management. Also vital is the urgent need for more pragmatic instruments that can be adopted in the face of many deeply connected goals, complications, and political realities.

The previous Moules on this topic (Modules 4.1 through 4.3) have raised questions that can be directly applied in case studies of countries in Sub-Saharan Africa. The reader from the Continent may be interested in identifying the main environmental challenges in his/her community/country and what is the role of economics in addressing them; in particular, what control policy will be most effective. Finally, ecotourism is an emerging trend in Sub-Sharan Africa. It will be revealing to examine the progress being made in this direction through some case studies, for example, a study of the Eco-tourism Society of Kenya (ESOK). Of relevance also will be a focus on the prospects for the use of information systems as a policy instrument in the sector.

Materials used for this section

1. Damon and Sterner (2012) "Policy Instruments for Sustainable Development at Rio +20, Journal of Environment & Development 21(2) 143–151.
2. UNEP (2009): The Use of Economic Instruments for Environmental and Natural Resource Management First Edition.
3. Sterner, T. and J. Coria (2012). Policy Instruments for Environmental and Natural Resource Management. Resources for the Future.

Module 5.1. Value and Welfare (5 hours)

Learning Outcomes

This Module provides a discussion on the value of natural and environmental resources and the need to find monetary expressions for it, the rationale for such valuation and the underlying theory. After going through the module, the reader is expected to:

- ✓ know the various types of value associated with natural and environmental resource.
- ✓ appreciate the importance of deriving monetary expressions of value for these resources
- ✓ understand the role of substitutability in the theory of value
- ✓ understand the concepts of willingness to pay and willingness to accept compensation and how they relate to the determination of value
- ✓ know the various monetary measures of changes in welfare that are used to express willingness to pay and willingness to accept compensation
- ✓ know which welfare measure may be most appropriate to use under various contexts
- ✓ understand the concept of weak complementarity and its relevance in determining the approach to valuation.

Outline

5.1.1. Rationale for Natural and Environmental Resource Valuation
5.1.2. Types of Economic Value
- 5.1.2.1 Use value
- 5.1.2.2 Option value
- 5.1.2.3 Nonuse value

5.1.3. Welfare Foundation of Environmental Valuation
- 5.1.3.1. Substitutability, willingness to pay, and willingness to accept compensation
- 5.1.3.2. Welfare measures for changes in price
- 5.1.3.3. Divergence and choice between WTP and WTA
- 5.1.3.4. Welfare measures for changes in quantity and quality of environmental goods
- 5.1.3.5. Weak complementarity

Summary

Discussion/Review Questions and Exercises

Materials used for the Lecture

5.1.1. Rationale for Natural and Environmental Resource Valuation

As we learnt in Module 4, natural resource and environmental policy-making involves weighing the cost and benefit of a reallocation. From the efficiency viewpoint, a reallocation should go ahead only when the benefit at least covers the cost. In other words, if society wishes to make the most (in terms of individuals' well-being) of its endowment of all resources, it should compare the values of what its members receive from any environmental change or use of a resource (the benefits) with the values of what its members give up by taking resources and factor inputs from other uses (that is, the costs). A society that is concerned with the economic well-being of its citizens should make changes in environmental and resource allocations only if what is gained by the change is worth more in terms of individuals' welfare than what is given up by diverting resources and inputs from other uses. Even though decisions may not always be based on efficiency consideration alone, or even at all, yet having an idea of the cost and benefit of an allocation offers policy-makers a set of useful information to guide decision-making.[28] Estimation of benefits and costs is also used for natural resources damage assessments, such as for oil spills.

To make sense of comparison of cost and benefits, they must be expressed in monetary terms. In other words, we will need monetary estimates of values placed by individuals on both market and non-market goods (including environmental amenities) which goes into producing welfare. Environmental valuation deals with the methods used to derive monetary values for natural and environmental resources. Some have queried the very idea of attaching monetary values to environmental resources (see Box 5.1). While there are still controversies over appropriability and accuracy of processes and methodologies, there is however, growing acknowledgement on all sides of the importance of economic valuation as a way to demonstrate the enormous value of the environment to modern society. The more open decision-makers are about the problems of making choices and the values involved, and the more information they have about the implications of their choices, the better their choices are likely to be. Estimates of values in monetary terms are one such source of information.

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[28] Policy choices about resources and environmental quality are made in a political context. This involves comparisons and tradeoffs among variables for which there is no agreement about commensurate values. Hence, monetary benefit and cost data will not always be the determining factors in decision-making. There may be policy settings where other concepts (such as equity considerations, intergenerational effects, the sustainability of resource systems, or social risk aversion) may aid decision making (Freeman III, Herriges and Kling, 2014. p. 1-2).

Box 5.1. Should Humans Place an Economic Value on the Environment?

Arne Naess, the late Norwegian philosopher, used the term deep ecology to refer to the view that the nonhuman environment has “intrinsic” value, a value that is independent of human interests. Intrinsic value is contrasted with “instrumental” value in which the value of the environment is derived from its usefulness in satisfying human wants. Two issues are raised by the Naess critique: (1) What is the basis for the valuing of the environment? and (2) how is the valuation accomplished? The belief that the environment may have a value that goes beyond its direct usefulness to humans is in fact quite consistent with modern economic valuation techniques. As we shall see in this chapter, economic valuation techniques now include the ability to quantify a wide range of “nonuse” values as well as the more traditional “use” values. Controversies over how the values are derived are less easily resolved. As described in this chapter, economic valuation is based firmly upon human preferences. Proponents of deep ecology, on the other hand, would argue that allowing humans to determine the value of other species would have no more moral basis than allowing other species to determine the value of humans. Rather, deep ecologists argue, humans should only use environmental resources when necessary for survival; otherwise, nature should be left alone. And, because economic valuation is not helpful in determining survival necessity, deep ecologists argue that it contributes little to environmental management. Those who oppose all economic valuation face a dilemma: when humans fail to value the environment, it may be assigned a default value of zero in calculations designed to guide policy. A value of zero, however derived, will tend to justify a great deal of environmental degradation that could not be justified with proper economic valuation. As a 1998 issue of Ecological Economics demonstrated, a number of environmental professionals now support economic valuation as a way to demonstrate the enormous value of the environment to modern society. At the very least, support seems to be growing for the proposition that economic valuation can be a very useful means of demonstrating when environmental degradation is senseless, even when judged from a limited anthropomorphic perspective.

Sources: R. Costanza et al., “The Value of Ecosystem Services: Putting the Issues in Perspective.” ECOLOGICAL ECONOMICS, Vol. 25, No. 1 (1998), pp. 67–72; and Gretchen Daily and Katherine Ellison, THE NEW ECONOMY OF NATURE: THE QUEST TO MAKE CONSERVATION PROFITABLE (Washington, DC: Island Press, 2003). Also, in Tietinberg and Lewis, 2012. p78).

5.1.2. Types of Economic Value

The concept of value was originally applied to market goods to denote the exchange price. It was later applied to non-market environmental goods. The economic theory of value is based on the ability of things to satisfy human needs and wants, or to increase the well-being or utility of individuals. It has its foundation in neoclassical economics. The individual/household derives utility from a broad range of goods and services, including private goods (X), public goods provided by the government (G) and natural resource and environmental goods (Q).

Economists have decomposed the total economic value conferred by natural and environmental resources into three main components: (1) use value, (2) option value, and (3) nonuse value.

5.1.2.1 Use value

This reflects the benefit from direct use of the environmental resource (e.g., fish harvested from the sea, timber harvested from the forest, water extracted from a stream for irrigation, the scenic beauty conferred by a natural vista). Use in this case depicts consumption in any form involving use of any of the senses (sight, sound, touch, taste, or smell). There is a further attempt to break down the use value of natural and environmental resources to those that involves using up the resource, and others for which the resource is not actually used up (consumed) in the process of experiencing it. The latter type of use value is often called passive-use values or non-consumptive use values.

A lot of focus is given in the literature to addressing factors that affect the use value of natural and environmental resources. For example, pollution can cause a loss of use value, such as when air pollution increases the vulnerability to illness, an oil spill adversely affects a fishery, or when smog enshrouds a scenic vista.

5.1.2.2 Option value

This reflects the value people place on a future ability to use the environment. Option value reflects the willingness to pay to preserve the option to use the environment in the future even if one is not currently using it. Whereas use value reflects the value derived from current use, option value reflects the desire to preserve the potential for possible future use. Are you planning to go to a National Park when next you are on holiday/vacation? Perhaps not, but would you like to preserve the option to go someday? If you do, then the National Park has an option value to you. Whether you actually go or not during the next vacation then becomes a secondary issue. If indeed you end up visiting the Park, the value of the Park at that time becomes a use value (no longer an option value).

5.1.2.3 Nonuse value

This reflects the common observation that people are more than willing to pay for improving or preserving resources that they will never use. What could be the motivation for this? One reason may be the desire to see a resource is available for others to use even though one does not intend to use it oneself (interpersonal altruism) or to see it passed on to future generation (intergenerational altruism or bequest). Another is the desire to just have the resource exist even though there is no contemplation of ever using it.

Thus, there are two types of non-use value. The first is **bequest value** (the benefit that an individual derives from knowing that a natural or environmental resource is available to others, particular future generation, one's children and grandchildren). A second is **existence value** (the benefit that an individual derives from knowing that a natural or environmental resource continues to exist even though she is not thinking of using it now or in the future). Existence value is also called **pure nonuse value.**[29]

Since nonuse values are derived from motivations other than personal use, they are obviously less tangible than use values. However, to ignore them in the estimation of value will amount to a grievous error. Estimated nonuse values can be quite large. This and the fact that they are not observable often generate controversies.

Figure 5.1 summarizes the components of the total economic value from a natural or environmental resource.

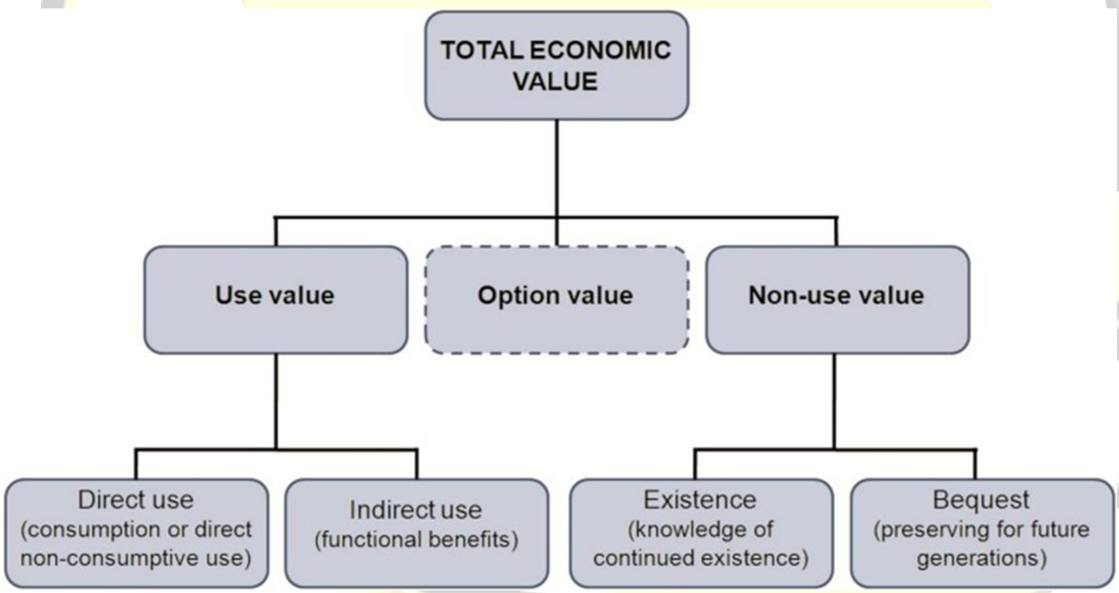

Fig. 5.1. The Total Economic Value conferred by resources (**Source**: Tietenberg and Lewis, 2016. P.)

Pollination is one example of a valuable ecosystem service with multiple benefits, including nonmarket impacts such as aiding in genetic diversity, ecosystem resilience and nutrient cycling, as well as direct economic impacts of increasing the productivity of agricultural crops. Many agricultural crops rely on bee pollination. Unfortunately, this important ecosystem service may be in jeopardy. What would be the global cost of losing or reducing this valuable ecosystem

[29] The term existence value was coined by economist John Krutilla in his now-famous quote, "There are many persons who obtain satisfaction from mere knowledge that part of wilderness North America remains even though they would be appalled by the prospect of being exposed to it (Tietinberg and Lewis, 2012. P80).

service? One study (illustrated in Box 5.2) argues that possible future shortages are likely to have quite different economic impacts around the globe with significant adverse effect on some parts of Sub-Saharan Africa.

Box. 5.2. Valuing Ecosystem Services: Pollination, Food Security, and the Collapse of Honeybee Colonies

Utilizing a multi-region, computable general equilibrium (CGE) model of agricultural production and trade, Bauer and Wing (2010) examined the global economic impacts of pollinator declines. CGE models produce numerical assessments of economy-wide consequences of various events or programs. This general equilibrium model includes both direct effects on the crop sector and the indirect, noncrop effects. The value of a CGE model over other methods previously utilized in the literature to value pollination services lies in its ability to "track changes in prices across multiple interrelated markets in a consistent fashion …" (p. 377). Using this model, the authors can estimate not only the impacts, but also how the impacts are affected by the presence of different substitutes for pollination services. Since fruits, vegetables, and nuts are most dependent on pollination (for some crops pollination is essential), they begin by identifying the pollination dependency of various world crops and how that production could be affected by shortages of pollination services (when the demand for pollinator services exceeds the supply). They find that the annual, global losses to the crop sector, attributable to a decline in pollination services, are estimated to be $10.5 billion, but economy-wide losses (noncrop sectors) are estimated to be much larger, namely $334 billion. Examples of the noncrop sectors that are impacted by pollinator declines include livestock since some pollinated plants are used as feed, processed food (e.g., Mrs. Smith's Blueberry Pie, Sara Lee Pecan Rolls), and chemicals such as fertilizers and pesticides. They also show that some regions of the world, especially western Africa, are likely to suffer disproportionately. This is due not only to the fact that pollinator-dependent crops make up a relatively large share of western Africa's agricultural output, but also to the relative importance of the agriculture sector in the African economy. Whether mechanized or manual pollination could reduce the potential losses remains an open question. Source: Dana Marie Bauer and Ian Sue Sing, "Economic Consequences of Pollinator Declines: A Synthesis." AGRICULTURAL AND RESOURCE ECONOMICS REVIEW, 39(3): October 2010, pp. 368–383. Also, in Tietinberg and Lewis, 2012. p77).

5.1.3 Welfare Foundation of Environmental Valuation

5.1.3.1. Substitutability, willingness to pay, and willingness to accept compensation

The basic premises underlying economic theory of value include the following

(i) Individual's welfare depends on consumption of private goods, goods and services produced by the government (public goods) and on quantities and qualities received of nonmarket goods and service flows from the resource-environmental system

(ii) People have well-defined preferences among alternative bundles of goods (bundles consist of various quantities of both market and nonmarket goods).

(iii) Preferences have the property of substitutability among the market and nonmarket goods making up the bundles.

Substitutability is at the core of the economist's concept of value. It establishes the possibility of tradeoff ratios between pairs of goods that matter to people and affords opportunity to consider models of a variety of individuals' behaviors related to environmental and health considerations (e.g., participation in outdoor recreation activities, choices among jobs with varying degrees of risk of fatal accident, choices of where to live and work when houses and urban centers offer different packages of amenities and environmental pollution).[30]

The tradeoffs that people make as they choose less of one good and substitute more of some other good reveal something about the values placed on those goods. Value measures based on substitutability can be expressed in terms of either willingness to pay (WTP) or willingness to accept compensation (WTA). WTP and WTA measures can be defined in terms of money or any good that the individual is willing to substitute for the good being valued.

Willingness to pay (WTP) is the maximum sum of money the individual would be willing to pay rather than do without an increase in some good or environmental amenity; amount of money that would make the individual indifferent between paying for and having the improvement and forgoing the improvement while keeping the money to spend on other things.

Willingness to accept compensation (WTA) is the minimum sum of money the individual would require to voluntarily forgo an improvement that otherwise would be experienced; amount that would make a person indifferent between having the improvement and forgoing the improvement while getting extra money. Both value measures are based on the assumption of substitutability in preferences (assumes that environmental quality can be traded off for income or some other goods).

Defining an acceptable monetary measure of changes in economic welfare for an individual depends partially on what the measure would be used for. Theory suggests several alternative

[30] It is important to acknowledge the absence or limit of substitutability in preferences that are not well-behaved, such as lexicographic preferences and the ecological view on substitutability (discussed in Module 1). Researchers from the academic disciplines that must be relied upon in valuing environmental and resource system changes do not always share the economists' commitment to the anthropocentric and preference-based perspectives on value. Nor do they all accept the assumptions of well-formed and stable preference orderings, substitutability, and rational choice that underlie the economist's methods of economic valuation (Freeman III, Herriges and Kling, 2014. *p. 2*).

ways of calculating either exact or approximate welfare measures using data on observed behavior of individuals. It is assumed that preferences can be deduced from observed demand behaviour.[31] This involves the derivation of the expenditure function (which gives the minimum dollar expenditure necessary to achieve a specified utility level given market prices) from the observed demand behaviour. The latter is then used to derive the indirect and direct utility functions. It may then be possible to utilize empirically derived descriptions of demand behavior to obtain a complete description of the underlying preferences, as well as exact measures of welfare change for a wide range of postulated changes in economic circumstances.

There are three often-cited measures of welfare change that can be derived from the above processes. They include (i) Change in consumer's surplus: ΔCS (ii) Compensating variation (CV) and (iii) Equivalent variation (EV).

5.1.3.2. Welfare measures for changes in price

Assume two goods, x_1 and x_2 where x_1 is the commodity of interest (in which case, x_2 can be used to represent all other goods). Assume **non-marginal** reduction in price of x_1. Since utility cannot be measured directly, the basic approach is to use a "money metric". Take x_2 as the numeraire good so that x_2 can be viewed as money spent on all other goods. Price of x_2, p_2 is set equals to 1 so that the slope of the budget line (p_1/ p_2) would reflect the price of x_1. We assume, consumers are able to rank all combinations of $x_1$and other expenditures according to a utility function- the benefit to the consumer simply depends on physical quantities and their combinations.

The **change in consumer's surplus** (ΔCS) is illustrated as the change in the area under the observed market (Marshallian) demand curve that is above the horizontal price line. This measure of welfare change has been known to be only an **approximate** (not an exact) measure**.** The reasons are because

(i) it is not a cardinal measure of welfare except under very restrictive and unrealistic circumstances: consumer surplus measure cannot be defined in terms of the underlying utility function) and

(ii) its value is ambiguous when more than one price change is being considered.

However, change in consumer's surplus could be a close approximation under certain conditions. Some have also argued that it is more accessible (operational) because it does not require

[31] This is true If the demand functions satisfy the so called *integrability* conditions, that is, the Slutsky matrix of substitution terms is symmetric and negative semi-definite.

knowledge of the utility function (preferences) underlying the demand curve and that cases of more than one price change have not often been a practical issue.

The other measures of welfare change are theoretical refinements of the ordinary consumer's surplus, each can be defined in terms of the underlying individual preference mapping, and constitute exact measures. To fix ideas, assume that an environmental improvement reduces the cost of producing x_1, so that its price drops from $p_1{}'$ to $p_1{}''$. In response to the price reduction, the individual shifts from the consumption bundle marked A at utility level u^0 to consumption bundle B at utility level u^1 (Figure 5.2). What is the welfare benefit of the price reduction to this individual? The two additional measures of the welfare change can be defined in terms of the numeraire good x_2:

The **Compensating Variation (CV)** measure asks what compensating payment (that is, an offsetting change in income) is necessary to make the individual indifferent between the original situation (A in Figure 5.2) and the new price set. Given the new price set with consumption point B, the individual's income could be reduced by the amount of CV and that person would still be as well off at point C as at point A with the original price set and money income. The measure CV is often interpreted as the maximum amount that the individual would be willing to pay (WTP) for the opportunity to consume at the new price set. However, for a price increase, CV measures what must be paid to the individual to make that person indifferent to the price change (WTA). For price decreases, the CV cannot be greater than the individual's income (a person cannot be willing to pay more than the income she has!); but for a price increase, the CV could exceed income (a person can be willing to accept more than his income in settlement).

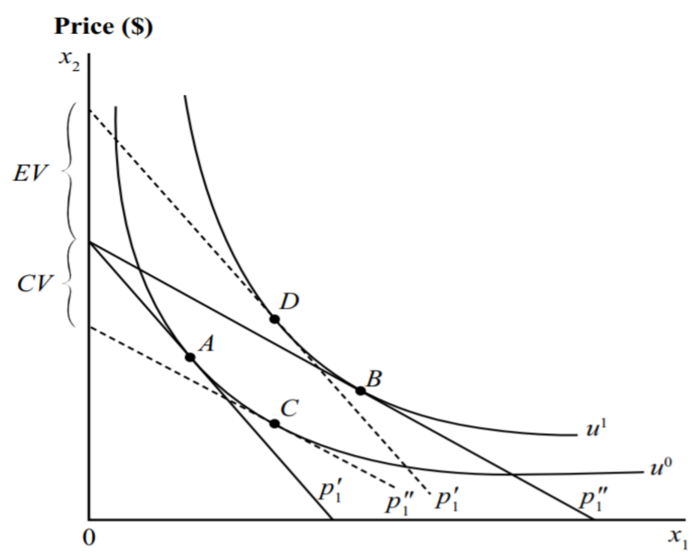

Fig.5.2 Measures of welfare gain from a price decrease.
Source: FHK (2014).p48.

The **Equivalent Variation (EV)** measure asks what change in income (given the original prices) would lead to the same utility change as the change in the price of x_1. Given the original prices, the individual could reach utility level u1 at point D in Figure 5.2, with an income increase equal to EV. Thus, EV is the income change equivalent to the welfare gain due to the price change. The EV measure has also been described as the minimum lump sum payment the individual would have to receive to induce that person to voluntarily forgo the opportunity to purchase at the new price set (WTA). For a price increase, EV is the maximum amount the individual would be willing to pay (WTP) to avoid the change in prices. Table 5.1 summarizes the relationships between the CV and EV measures of welfare change and the consumer's willing to pay or accept compensation WTP and WTA).

Table 5.1 Relationship between willingness to pay for or accept compensation for a price change and the exact measures of welfare change

Price change	CV	EV
Decrease in price	WTP for *change occurring*	WTA compensation for *change not occurring*
Increase in price	WTA compensation for *change occurring*	WTP for *change not occurring*

Source: Adapted with modifications from Perman et al., 2003, p.407

It is important to note that both the EV and CV measures allow the individual to adjust the quantities consumed of both goods in response to both changes in relative prices and income levels. There are corresponding measures of welfare change where the levels of the goods remain the same. They are referred to as compensating and equivalent surplus. The measures do not, however, answer very useful questions since they both arbitrarily restrict the individual to consuming a specific quantity of the good whose price has changed. But they are the measure to use when dealing with environmental good of fixed quantity.

For a marginal change in p_1, the basic welfare measure is the change in expenditure necessary to hold utility constant.

$$w_{p_1} = x_1 = -\frac{\partial v/\partial p_1}{\partial v/\partial M} \quad (5.1)$$

or

$$\frac{\partial M}{\partial p_1} = x_1 \quad (5.2)$$

where w_{p_1} is the marginal welfare measure, M is income and v(.) is the consumer's indirect utility function. In equation (5.1), the marginal utility of the price change is converted to monetary units by dividing by the marginal utility of income. The equation says that the change in income required to hold utility constant is equal to the change in price multiplied by the quantity of the good being purchased (equation 5.2)

It is conventional to measure both CV and EV measures of welfare change as positive when there is a price fall, and negative for a price rise. Note also that for the case of a price rise the EV of the price rise is the CV of the price fall in the original situation, and the CV of the price rise is the EV of the price fall (but opposite in sign). This symmetry relates to the interpretation of CV and EV as measures of WTP and WTA. For the case of a change in the price of a single good, one result immediately follows: For a fall in price, the EV (WTA) will be greater than the CV (WTP). The higher the price level at which the difference between the utility curves is measured, the greater the money income required for compensation. Conversely for a rise in price, the CV (WTA) is greater than the EV (WTP) (in absolute magnitude).

Figure 5.3 illustrate the differences between the three measures of welfare change examined above focusing on a reduction in price. Figure 5.3a shows the difference between ΔCS and CV. The response of the consumer to the fall in the price of x_1, from $p_1{}'$ to $p_1{}''$ illustrated in the movement from the initial equilibrium point A to the new equilibrium point B in the upper panel (panel A) is plotted in the lower panel (panel B) as relationship between price and quantity (demand curve). x_1(**P**, **M**) is the observed consumer's (Marshallian) demand curve for x_1 while h_1(**P**, u^0) is the unobserved consumer's Hicks-compensated demand curve for x_1. The latter incorporates the income that needs to be taken away from the consumer in her new position (after the price decrease) so that she is just as well-off as she was in her initial condition. In other words, it compensates for (removes) the **income effect** of the price change and retains only the **substitution effect**. In this case of a decrease in price, the consumer enjoys a positive income effect (**assuming of course that x_1 is a normal good**) so that the compensation takes the form of a payment by the consumer (a reduction in nominal income).

Note that in this case, the Hicks-compensated demand curve is less price-elastic than the ordinary (Marshallian or uncompensated) demand curve because of the income effect of the price change. The difference between the two is one of the main considerations in the comparison of EV, CV, and ΔCS measures of welfare change. Panel A of Figure 5.3a shows the CV measure of the welfare change associated with the price decrease—that is, the reduction in income needed to hold the individual on the original indifference curve. It can be interpreted as the income level associated with the **imaginary budget line** (the dashed budget line) less the income level associated with the **new budget line** generated by the price change. Because the income level associated with the imaginary budget line is able to give the consumer the same utility level (u^0) as she had before the price decrease, we can represent it by Y’ while the income level associated with the new

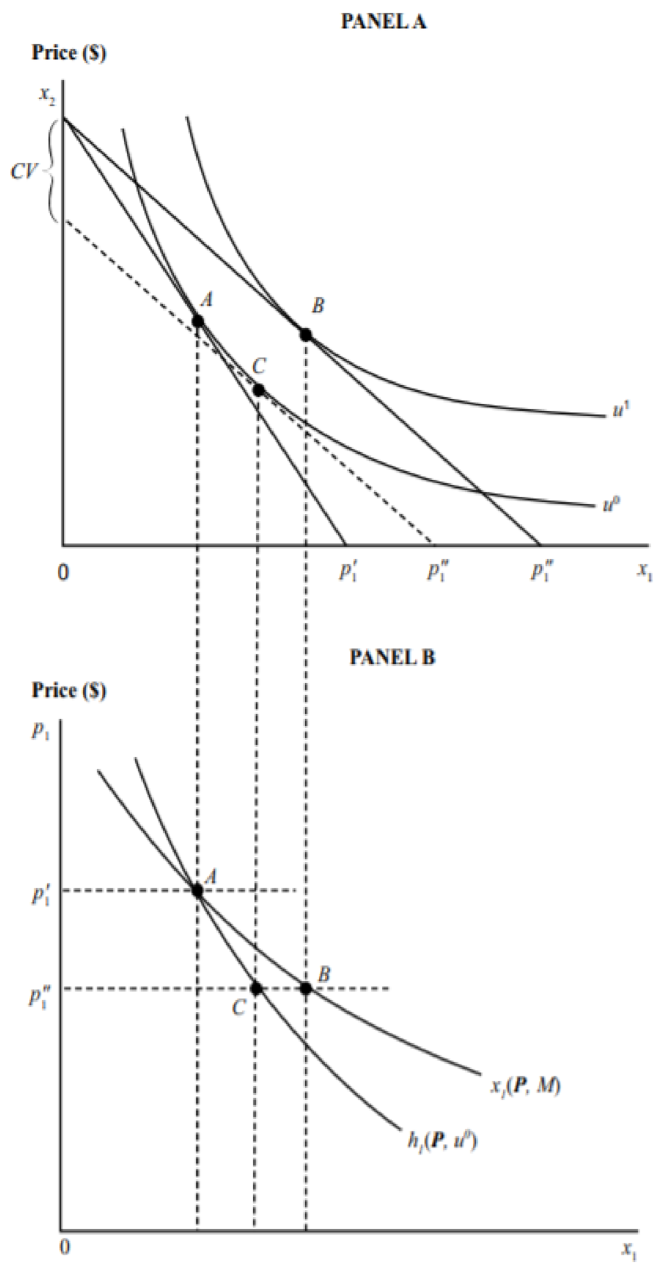

Fig. 5.3a. Comparing the change in consumer’s surplus (ΔCS) and the CV of a decrease in price

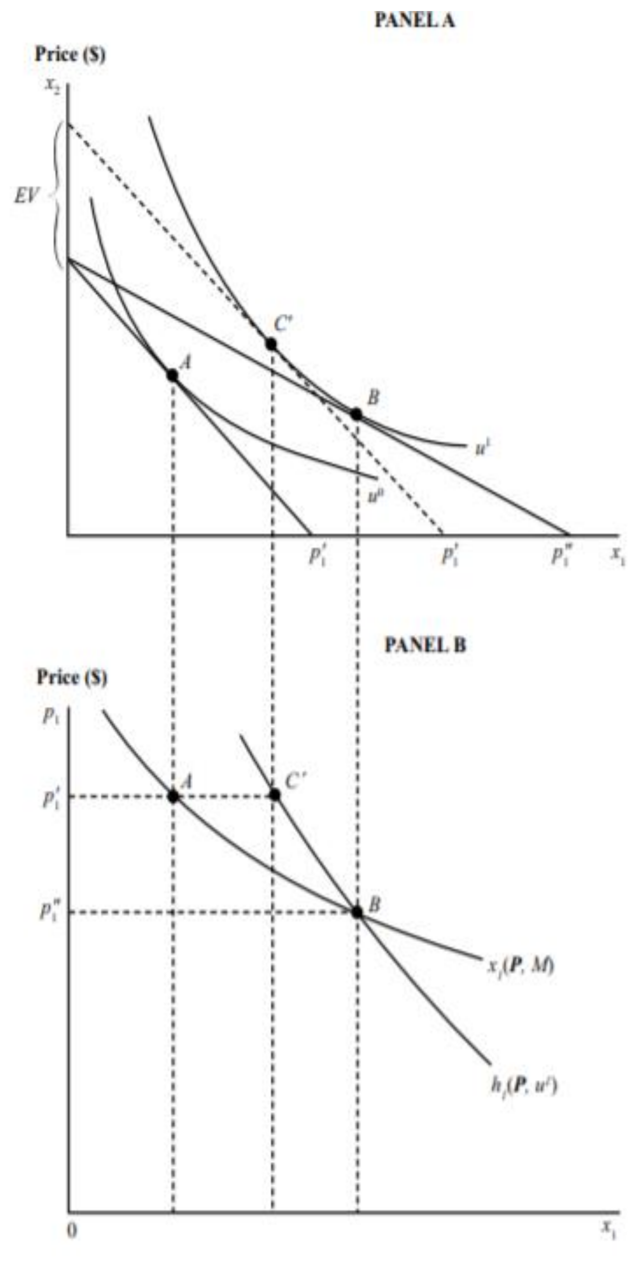

Fig. 5.3a. Comparing the change in consumer’s surplus (ΔCS) and the CV of a decrease in price

Source: FHK, 2014. Pp. 49, 53.

budget line which allows the consumer to buy more bundle and thus enjoy a higher utility (u^1) is represented by Y'', so that CV= (Y' – Y'') = - (Y'' – Y'). The negative sign here serves to indicate that in this case, the consumer pays to get back to original utility level.

In panel B, CV is represented as the change in the area under the Hicks-compensated demand curve $\lfloor h_1(\mathbf{P}, u^0) \rfloor$ that is above the horizontal price line (the trapezium $p_1{}'$A$p_1{}''$C). In contrast, ΔCS is represented as the change in the area under Marshallian demand curve $\lfloor x_1(\mathbf{P}, \mathbf{M}) \rfloor$ above the horizontal price line (the trapezium $p_1{}'$A$p_1{}''$B). It is obvious that in this case of a decrease in price, ΔCS > CV, the difference being a result of the positive income effect associated with the Marshallian (uncompensated) demand curve but not reflected in the Hicks-compensated demand curve. It can be shown by the same token that for an increase in price, ΔCS < CV.

Figure 5.3 b illustrates the relationship between ΔCS and EV for the price decrease. With a price decrease, the EV is defined as the additional expenditure (income) necessary to reach utility level u^1, given the initial set of prices. Again, it is illustrated in panel A as the income difference associated with the two budge lines, EV= (Y' – Y''), which in this case is positive since the In panel B, EV is represented as the change in the area under Hicks-compensated demand curve $\lfloor h_1(\mathbf{P}, u^1) \rfloor$ that is above the horizontal price line (the trapezium $p_1{}'$C'B$p_1{}''$). Note carefully the difference between the Hicks-compensated demand curve in this case, $h_1(\mathbf{P}, u^1)$ and that associated with the CV measure, $h_1(\mathbf{P}, u^0)$. The reference points for utility level are different. For the CV measure, utility level is measured at the point **before** the price change. Thus, we are seeking a measure of income that will make the consumer as well of as she was **before** the price change. In the case of the EV measure, utility is measured **after** the price change; we are seeking a measure that makes the consumer as well off as she will be **after** the price change even though she does not enjoy the price change. It is obvious that in this case of a decrease in price, the measure will involve giving the consumer some additional income to compensate for the income effect. Thus, at any given price level, the Hicks-compensated demand curve associated with the EV measure implies a higher level of output than that associated with the CV measure as long as the good is a normal good (compare $h_1(\mathbf{P}, u^0)$ in Figure 5.3a with $h_1(\mathbf{P}, u^1)$ in Figure 5.3b, the latter is just a blown out version of the former, the difference being due to the income effect). The converse holds true in the case of an inferior good.

The change in consumer's surplus, ΔCS, remains the same in Figure 5.3b as in Figure 5.3a but is now less than the EV measure. Thus, for a price decrease we have the following relationship between the three measures of welfare change in the case of a normal good.

$$\text{CV (WTP)} < \Delta\text{CS} < \text{EV (WTA)} \qquad (5.3)$$

For an increase in price, we will have

$$\text{EV (WTP)} < \Delta\text{CS} < \text{CV (WTA)} \qquad (5.4)$$

The above comparison assist us to see that although ΔCS cannot be put forward as a welfare measure in its own right (it is not a measure of gain or loss that can be employed in a potential compensation test), there is an important justification for its use as a measure of welfare change, in that it lies between the true EV and CV in the case of a single price change. In addition, as an approximation to either, it is close when the income elasticity is low, the budget share of the good is low, and the change in prices is small (Willig, 1976). In contrast, where consumers have high income elasticities for the good in question and the price change in question is large, we cannot be confident that ΔCS measure will be close to either EV or CV. The EV and CV measures will also tend to be far apart. Indeed, indirect methods of deriving monetary measures of welfare changes are based on the Marshallian demand functions (and hence, the concept of changes in consumer surplus) with the hope that the errors involved, with respect to the exact measures, are not too great.

For two alternative price changes, CV and EV should be the same if both changes place the individual on the same higher indifference curve. However, if the two price changes place the individual on different indifference curves, the welfare measure should correctly indicate the preference ranking of the two alternatives. It turns out that the EV measure always provides a consistent ranking in this sense, but the CV measure does not.

Note that both CV and EV can be interpreted as WTP or WTA depending on the direction of the price change. The two measures can also be interpreted in terms of the implied *rights and obligations* associated with alternative price sets. The *CV* carries an implicit presumption that the individual or HH has no right to make purchases at a new set of lower prices (in the case of an environmental improvement that lowers price for example), but does have a right to the original price set in the case of price increases (in the case of an environmental damage that raises price for example). In contrast, the *EV* contains the presumption that the individual has a right to the new lower price set, and must be compensated if the new price set is not to be attained or has an obligation to accept the higher price set. These points are illustrated in Table 5.2. It is worthwhile to note the harmony in the information contained here with that presented in Table 5.1.

Table 5.2. Implied Rights and Obligations associated with Alternative Price sets (FHK, 2014, p56)

Welfare measure	Price increase	Price decrease
EV – Implied property right in the change	WTP to avoid	WAC to forgo
CV – Implied property right in the status quo	WAC to accept	WTP to obtain

Source: FHK, 2014, p56

Based on this interpretation of the two measures, some economists have argued that the choice between them is basically an ethical one—that is, one that depends on a value judgment as to which underlying distribution of property rights is more equitable (Krutilla 1967; Mishan 1976). This point is pursued further in the next subsection.

5.1.3.3. Divergence and choice between WTP and WTA

Willig's (1976) show that measures of CV should in theory generally be very close to their associated EV measures: the WTP to acquire a price change should typically be approximately equal to the WTA compensation to do without the change. However, substantial body of evidence (see Horowitz and McConnell 2002; Sayman and Onculer, 2005 for reviews) suggest that differences between WTP and WTA for the same good can be quite large. Some economists have attributed the discrepancy to a psychological endowment effect; the psychological value of something you own is greater than something you do not. In other words, you would require more compensation to be as well off without it than you would be willing to pay to get that same good and as such you would be less willing to give it up (WTA > WTP) (Kahneman, Knetsch, and Thaler, 1990). This is a form of 'loss aversion' —the psychological premise that losses are more highly valued than gains.

Others have suggested that the difference is explainable in terms of the market context. In the absence of good substitutes, large differences between WTA and WTP would be the expected outcome. In the presence of close substitutes, WTP and WTA should not be that different, but the divergence between the two measures should increase as the degree of substitution decreases (Hanemann, 1991; Shogren et al., 1994). The characteristics of the good may matter as well. Some authors suggest that for "ordinary goods" the difference between WTA and WTP is smaller than the ratio of WTA/WTP for public and nonmarket goods (Horowitz and McConnell, 2002). Their results support the notion that the nature of the property rights involved are not neutral.

The moral context of the valuation may matter as well. Croson et al. (Draft 2005) show that the amount of WTA compensation estimated in a damage case increases with the culpability of the party causing the damage as long as that party is also paying for the repairs. If, however, a third party is paying, WTA is insensitive to culpability. This difference suggests that the valuation implicitly includes an amount levied in punishment for the party who caused the damage (the valuation becomes the lost value plus a sanction).

Ultimately, the choice of which concept to use in environmental valuation comes down to how the associated property right is allocated. If someone owns the right to the resource, asking how much compensation they would take to give it up is the appropriate question. If the respondent does not have the right, using WTP to estimate the value of acquiring it is the right approach. However, since the holders and non-holders of "rights" value them differently, the initial allocation of property rights can have strong influence on valuation decisions for environmental amenities (Horowitz and McConnell, 2002).

Of equal importance in choosing between WTP and WTA is the type of questions being asked by policy makers (the goal or purpose) as well as the attitude to the policy change being proposed.

It is clear that the CV and EV measures answer different kinds of policy-relevant questions because they make different implicit assumptions about the relevant status quo. For example, if the question being asked by policymakers is, "does the proposed change pass the Kaldor potential compensation test (KCT)?", then CV is the measure to use. This is because for each person, the CV gives the compensating income change required to maintain that person at his or her initial utility level. If the sum of what could be collected from all gainers exceeds the sum of the required compensations for losers, the proposal passes this form of the potential Pareto improvement test. In this case, the fact that the CV cannot rank consistently two or more policy changes is no obstacle to its use because the potential Pareto improvement criterion itself provides no basis for ranking two or more proposed policy changes. If two proposed changes both pass the KCT, the potential Pareto improvement criterion provides no basis for choosing between them. That task can only be handled through the construction of a social welfare function (SWF).

In contrast to the above, if the question being asked by policymakers is, "does the policy pass the Hicks potential compensation test (HCT)?" then EV is the appropriate measure. The potential gainers would accept a compensation only if it were large enough to raise their utility by the same amount as the proposed policy would have. The offered compensation would have to be as large as each individual's EV measure of welfare gain; and the maximum compensation that would be offered by the potential losers would be their EV measure of loss. Thus, if the sum of the EV of all gainers exceeded the sum of the EVs of all losers, the proposal would pass HCT. In addition, since the Hicks form of the compensation test is based on the EV measure, it will consistently rank two or more policy changes, provided that society is indifferent as to the distribution of gains and losses across individuals.

The other consideration relates to the attitude to the policy change being proposed. If, for example, the government is firmly committed to an increase in the price of the market or environmental good, then it is reasonable to evaluate the welfare changes at these new prices (implying CV measures), since they will be the relevant ones at which consumer reaction will be felt, and if some form of compensation is to be paid to the lowest income households this also will need to be evaluated at the new set of prices. In contrast, if a project is less definitely committed, then the use of base prices (implying EV measures) may be more appropriate, since they represent today's regret if the project were not to be carried out. (Bacon, 1995).

As a hypothetical example, suppose we want to decide on whether to locate a landfill in a particular neighborhood. The residents are likely to oppose this proposal. Now suppose that it is accepted that the residents have a right to an undisturbed neighborhood. What is the appropriate monetary measure to use to illustrate (i) the welfare loss to the neighborhood and (ii) the welfare gain/benefit to those who will use the landfill? What if it can be argued that the larger society has a right to locate the landfill anywhere, what will be the appropriate monetary measure in each case?

Now suppose, instead, that the offending facility is a polluting factory that has been in the neighborhood for a long time. If the residents are deemed to have a right to a clean neighborhood, what is the appropriate measure for (i) the welfare loss to the neighbourhood and (ii) the welfare gain/benefit to factory owners? What if it is argued that the factory has a right to pollute?

In each case, the appropriate welfare measure can be found by examining the nature of the social transaction that is implied by the policy decision at hand, and by the implicit rights to the services of the environment presumed to be held by the various parties to the transaction (see Table 5.3).

Table 5.3. Implied property rights and associated welfare measures

Implicit "rights"	Policy question	Gainers	Losers
To the *present* Polluter	Require cleanup?	Residents (CV-WTP)	Polluter (CV-WTA)
To the *potential* Polluter	Allow pollution?	Polluter (EV- WTA)	Residents (EV-WTP)
To the Residents	Require cleanup?	Residents (EV-WTA)	Polluter (EV-WTP)
To the Residents	Allow pollution?	Polluter (CV-WTP)	Residents (CV-WTA)

5.1.3.4. Welfare measures for changes in quantity and quality of environmental goods

Many environmental policy proposals involve changes in either the quantities or qualities of nonmarket environmental goods and services, rather than changes in the price of a marketable good. From the individual's point of view, the most important characteristic of some environmental goods is that they are available only in fixed, unalterable quantities. These quantities act as constraints on each individual's choice of a consumption bundle. The imposition of quantity constraints raises some new issues, the analysis of which has evolved out of the theory of rationing as initially developed by Tobin and Houthakker (1950/1), and Neary and Roberts (1980).

The exact welfare measures that are used to capture the welfare changes associated with changes in quantity or quality of environmental goods are the **Compensating surplus** (SC) and **Equivalent surplus** (ES) as opposed to the CV and EV used for price changes, since the relevant change in this case is one of a quantity or quality change (note it is possible to increase/reduce the quantity or quality of a fixed good). The measures are still obtained and defined in the same way as in the case of changes in price.

We begin by taking note that changes in the level of the environmental good (E) can refer to quantity changes or quality changes, depending on the particular environmental service involved. Analytically both usages refer to the same thing. Where there is reference to 'environmental quality', there is generally some quantitative measure involved, as with, for example, water quality. The measure may be ordinal rather than cardinal, and may be based on subjective evaluations. Typically, as quality or quantity, E would be nonexclusive and non-divisible, so that the individual cannot adjust his or her consumption level. For present purposes, we shall assume that E is a public good (e.g., water quality in a lake).

Figure 5.4 illustrates the two monetary measures of the utility change associated with a change in the level of E, from E' to E'', the CS and ES, respectively. The mode of analysis is essentially the same as in the case of change in price of a market good. Note that increasing *E* with nothing else changing is equivalent to a reduction in the price of E. In panel a, the *CS* is *bf* = $Y_0 - Y_N$, the amount of money that, if forgone by the individual with the policy change, would result in her experiencing the pre-change level of utility. Put another way, it is the maximum willingness to pay for the environmental improvement **–** if the individual experienced E going from E' to E'' and paid an amount $Y_0 - Y_N$, she would remain at a constant level of utility U_0. In panel B, the ES is $Y_N - Y_0$ = *ha*. It is the amount of money that, at the original prices, would, if paid to the individual, move her to the same utility level as the environmental improvement would have done, given that the improvement does not, in fact, take place. Put another way, ha is the individual's minimum willingness to accept compensation for the prospective environmental improvement not happening. If we consider a deterioration in the environment, a reduction in E, and examine CS and ES for that case, we find that CS is willingness to accept compensation for the lower E while ES is willingness to pay to avoid it.

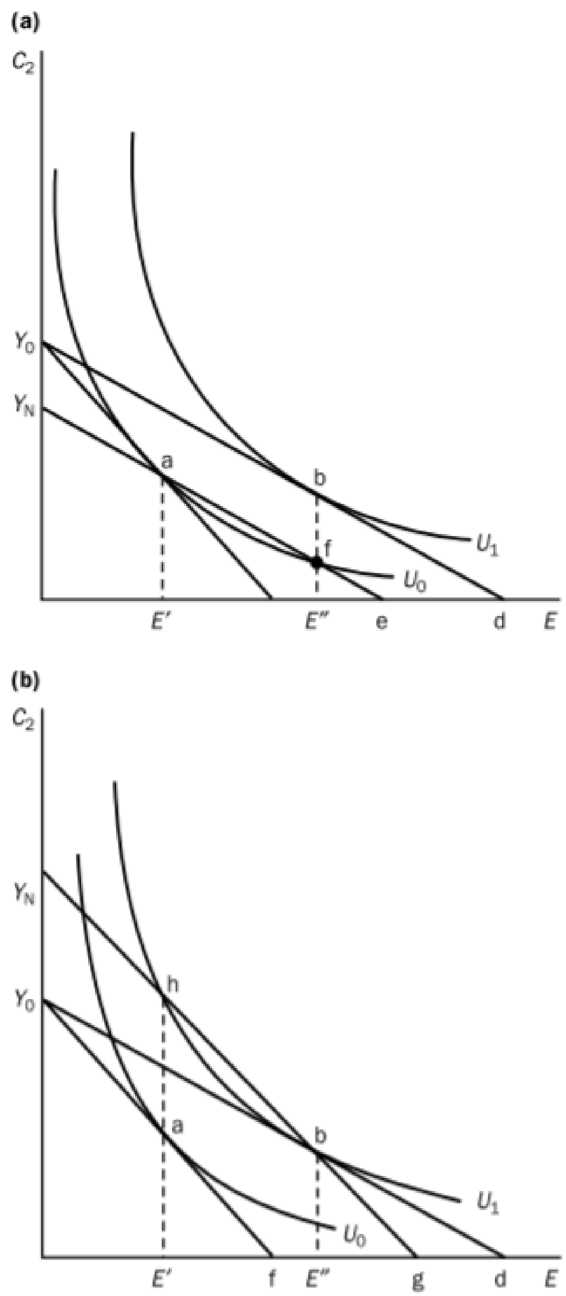

Fig.5.4 Monetary measures of the welfare effect of a change in quantity/quality of an environmental good. **Source:** Perman et al, 2003, p.408.

Table 5.4 below summarizes the measures of welfare change discussed in this section. It is easy to see the similarity with that presented in Table 5.1. Indeed, the two tables will be identical if we replace environmental change in Table 5.3 with price change.

Table 5.4 Monetary measures for environmental quality changes

Environmental Change	CS	ES
Improvement	WTP for *change occurring*	WTA compensation for *change not occurring*
Deterioration	WTA compensation for *change occurring*	WTP for *change not occurring*

Source: Adapted with modifications from Perman et al., 2003, p.409

.Despite the similarity between the analysis carried out here and that related to the effect of price changes, there is a very important difference that must be taken note of. The results for CV, EV and ΔCS do not carry over to CS, ES and ΔCS. This means that for environmental quality changes it is not possible to use ΔCS as an approximation for the proper monetary measure of utility change. In fact, ordinary Marshallian demand functions cannot be estimated in this case, given that environmental quality is generally an unpriced public good. The next subsection addresses the solution paths to this difficulty

5.1.3.5. Weak complementarity

The basic idea behind the indirect methods of environmental valuation is to infer the monetary value of a change in the level of the environmental service of interest from observed market data on some ordinary commodity. If, for example, we observed an increase in the demand for fishing permits following an improvement in water quality, we could try to use the observed increase in demand for the permits to put a value on the water quality change. In order to explain how this might work, we need first to revisit the difference between the variation and surplus measures of utility change. We associated CV and EV with price changes, and CS and ES with changes in quality or quantity. Reviewing the discussion, it will be seen that in the price change case the individual can adjust his or her consumption level for the commodity the price of which changes, whereas in the quality/quantity change case the consumption level for the environmental service is beyond the individual's control. In the latter case the change in the level of *E* is exogenously imposed on the individual.

Now, consider an individual consuming *N* ordinary commodities. Let C_1 be the quantity of daily fishing permits purchased, and let *E* be the level of water quality in the lake to which the permits relate. Then, we can write the compensated demand function for fishing days as:

$$C_1 = H_1 (P_1, \ldots, P_N, E, U_0) \qquad (5.5)$$

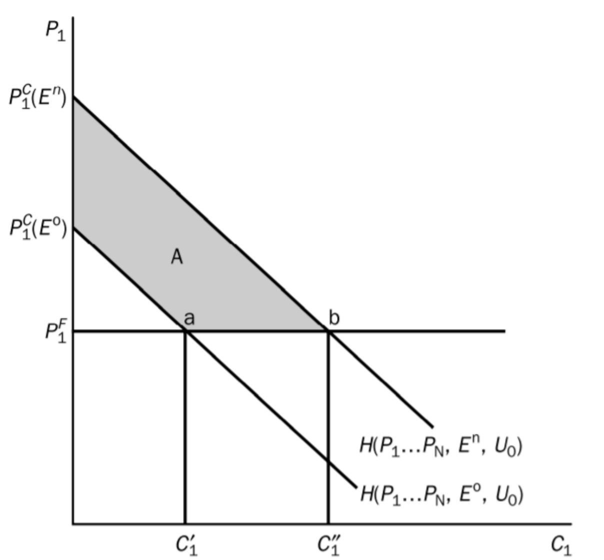

Fig. 5.5. Environmental quality as a commodity demand function parameter. **Source**: Perman et al, 2003, p.410.

A change in the level of *E* will shift this demand function for a given set of $P_1, \ldots, P_N$, so that *E* is a parameter of the function, as illustrated in Figure 5.5 below. An improvement in water quality, an increase in E from E^0 to E^n, shifts the demand for fishing days so that at the constant permit price P_1^F, the individual's consumption increases from C_1' to C_1''. The price $P_1^C(E^o)$ is the price which would drive demand to zero – the 'choke price' – with E equal to E^o, and $P_1^C(E^n)$ is the price which would drive demand to zero for E equal to E^n. The shaded area $aP_1^C(E^o)P_1^C(E^n)b$, call it A, gives the CV **change** associated with the increased consumption of C_1 due to the parametric shift of the Hicksian demand function for C_1.

For the purposes of environmental valuation, what is actually needed is the CS associated with the environmental improvement that is the cause of the parametric shift in the compensated demand function for C_1. It has been established that the area A is exactly equal to the required CS if two conditions hold. The conditions are that

(i) C_1 is non-essential, and that
(ii) C_1 and E are weak complements

For an individual, C_1 is non-essential if it is possible to compensate him or her for the complete loss of C_1. In terms of the fishing example, suppose that an individual who has been using the lake is prohibited from doing so. Then C_1, days spent fishing at this lake, is a non-essential commodity for this individual if there is some income level that would enable his or her original level of utility to be regained after the prohibition. The complementarity between E and C_1 is weak if it is the case that for C_1 = 0, utility is not affected by variations in the level of E. In the example here, fishing and water quality are weak complements for an individual if it is the case that given that the individual does not go fishing, perhaps because the price of a permit is above his or her choke price, then he or she does not care about variations in water quality in the lake.

Now, given that all this is in terms of the unobservable Hicksian demand for C_1 as reflected in equation (5.5), the fact that, if non-essentialness and weak complementarity hold, the area A is exactly equal to the WTP for the environmental improvement is not in itself of much use as A is inherently unknown. However, one could hope to determine a Marshallian, uncompensated, demand function for $C_1$and thus derive the ΔCS associated with a change in E. We saw above that, for price changes, Willig (1976) established that ΔCS is close to CV and could be a good approximation under certain condition. If this were also true for quantity changes, ΔCS could be used to give a close approximation to the CV associated with the change in the consumption of C_1, and hence to the CS monetary measure of the utility change arising from the improvement in environmental quality. Unfortunately, the Willig results for variational measures do not, carry over to the surplus measures. Using an environmental quality-induced change in consumer surplus as an estimate of either CS or ES involves errors for which little is known about the potential size, or indeed the sign. Notwithstanding the above observations, environmental economists continue to use **indirect** methods based on Marshallian demand functions, in the hope that the errors involved, with respect to the true surplus measures, are not too great.

As an alternative, methods involving asking people about their willingness to pay (or accept) (WTP and WTA) are often used to **directly** get the compensating surplus (CS) associated with an environmental improvement, for example, thus avoiding the problem outlined above. However, this direct method has not supplanted indirect methods because it too has problems, as we will see in Module 5.2.

Finally, in the special case, where the weak complementarity condition is violated (In terms of the lake water-quality example, this implies that for C_1 = 0, the individual's utility is affected by variations in E), only direct methods can be used to elicit the WTP (WTA). This is because in this case, the environmental good has an existence value which cannot be estimated by indirect methods since it leaves no behavioural traces in observed behaviour in relation to marketed commodities. Simply using some indirect method to value a water-quality improvement in the lake would result in a downward-biased result to the extent that there were individuals for whom there was existence value. Note that since actual use of the lake by an individual for fishing, or anything else, is not necessary for that individual to have existence value in regard to it, the relevant population for estimating total value is not just those who actually use the lake. It may be very much larger.

Summary

- Natural resource and environmental policy-making involves weighing the cost and benefit of a reallocation. This requires finding monetary values for all resources, including natural and environmental resources.

- The total value of a natural or environmental recourse includes a use value, option value and a non-use value. Use value reflects the benefit from direct use of the environmental resource. It includes value from consumptive and passive uses. Option value reflects the value people place on a future ability to use the environment. Non-use value reflects the value people derive for improving or preserving resources that they will never use. It is often borne out of interpersonal or intergenerational altruism (bequest value) and/or the desire to just have the resource exist even though there is no contemplation of ever using it (pure existence value).

- Substitutability is at the core of the economist's concept of value. It establishes the possibility of tradeoff ratios between pairs of goods that matter to people and affords opportunity to consider models of a variety of individuals' behaviors related to environmental and health considerations.

- Value measures based on substitutability can be expressed in terms of either willingness to pay (WTP) or willingness to accept compensation (WTA)

- The three measures of the monetary valuation of the welfare change associated with changes in the price of a resource are change in consumer's surplus, compensating variation (CV) and equivalent variation (EV). These are not likely to yield exactly the same figures for either a rise or a fall in price. For a fall in price, the change in consumer surplus is usually greater than the compensating variation but lower than the equivalent variation if the resource is a normal good. The converse holds in the case of an increase in price.

- Change in consumer surplus is not considered an accurate measure of the monetary value of the welfare change occasioned by a change in price due to the income effect. The CV and EV expunge the income effect so that the monetary measure of the change in welfare is due to the pure substitution effect of the price change. CV and EV can each be expressed in terms of willingness to pay and willingness to accept compensation.

- Differences in estimated willingness to pay and willingness to accept compensation can be due a psychological endowment effect, availability f close substitutes, the nature of the good, the moral context of the valuation. Ultimately, the choice of which concept to use in environmental valuation comes down to how the associated property right is allocated, the type of questions being asked by policy makers (the goal or purpose) as well as the attitude to the policy change being proposed.

- Despite the limitations of consumer surplus, it is still used as a monetary measure of welfare change with the hope that the errors involved, with respect to the exact measures, are not too great.

- The appropriate measure of the welfare effect of changes in the quantity or quality of an environmental good are compensating surplus and equivalent surplus. The analytical approach is similar to that used to derive compensating and equivalent variation measures. However, the relationship between the latter measures and changes in consumer surplus do not carry over. For environmental quality changes, it is not possible to use change in consumer surplus as an approximation for the proper monetary measure of utility change.

- Compensating and Equivalent surplus could each be expressed in terms of willingness to pay and willingness to accept compensation if non-essentialness and weak complementarity hold. But we are still faced with the difficulty of using observed changes in consumer surplus as an approximation.

- Using an environmental quality-induced change in consumer surplus as an estimate of either compensating or equivalent surplus involves errors for which little is known about the potential size, or indeed the sign. Notwithstanding, as with compensating and equivalent variation, indirect methods based on Marshallian demand functions are still used to estimate compensating and equivalent surplus.

- Where a resource has significant non-use value, it will not be possible to use indirect method based on observed market demand to derive measures of compensating and equivalent surplus. In this case, alternative methods must be employed.

Discussion/Review Questions and Exercises

1. Why would a person be willing to pay for a resource she is not ready to use?

2. Explain the various monetary measures of welfare change identified in the theory of valuation of natural and environmental resources.

3. Explain the relationship between
   (i) Consumer surplus, compensating variation, and equivalent variation.
   (ii) Consumer surplus, compensating surplus, and equivalent surplus.

4. Explain why we may witness disparities between estimated willingness to pay and willingness to accept compensation.

5. As a researcher and policy maker, what are the issues that should guide you in the choice between compensating and equivalent measures of welfare change?

6. Explain the role of weak complementarity in the monetary valuation of the welfare benefits/loss from the change in the quantity or quality of an environmental resource.

7. With E as some index of environmental quality and C_1 and C_2 as two 'ordinary' commodities, consider the following utility functions in regard to whether C_1 is non-essential and whether C_1 and E are weak complements:
   (a) $U = E^{\alpha} + C_1^{\beta} + C_2^{\delta}$
   (b) $U = E^{\alpha} C_1^{\beta} C_2^{\delta}$
   (c) $U = E^{\alpha} C_1^{\beta} + C_2^{\delta}$

Materials used for the Lecture

Freeman III, A., Herriges, J.A. and C. L. Kling (2014), **Measurement of Environmental and Resource Values, Theory and Methods** Third Edition, RFF Press.

Titenberg, T. & Lewis, L. (2012). **Environmental & Natural Resource Economics** 9th Edition, The Pearson Series in Economics

Perman, R., Ma Y., McGilvray J. and Common M. (2012). **Natural Resource and Environmental Economics**, 4th Edition, Edinburgh, Longman.

Module 5.2. Environmental Valuation Techniques and Analysis (7 hours)

Learning Outcomes

After completing this Module, you will be able to

- ✓ Know the different methods used for deriving monetary values for natural and environmental resources.
- ✓ Develop a sound understanding of revealed and stated preference methods of valuation, and the alternatives available under each category.
- ✓ Be able to think through the appropriate choice of a method or methods for application to real world valuation problems.
- ✓ Appreciate the general problems with finding true monetary values for natural and environmental resources.

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Materials used for the Lecture

5.2.1 Introduction

In Module 5.1, we leant that monetary measures of welfare changes associated with changes in prices or the quantity/quality of natural resources and environmental goods, that is the willingness to pay (WTP) and willingness to accept compensation (WAC) can yield insights into the values placed on these resources by private agents and society. For a market good, calculating WTP and WAC is relatively straightforward. However, nonmarket goods and services require the estimation of WTP and WAC either through examining behavior, drawing inferences from the demand for related goods, or through responses to surveys. This Module presents an overview of some of the methods available to estimate these values and how they are used.

Valuation methods can be separated into two broad categories: stated preference and revealed preference methods. **Revealed preference methods** are based on actual observable choices that allow resource values to be inferred from those choices. In other words, they are based on data generated from observations of people acting in real-world settings. The methods involve a kind of detective work in which clues about the values individuals place on environmental services are pieced together from the evidence that people leave behind as they respond to prices and other economic signals.

In contrast **Stated preference methods** use survey techniques to elicit willingness to pay for an environmental improvement (or for avoiding a loss) and willingness to accept compensation for an environmental damage. Thus. They involve creating hypothetical market scenarios. In other words, they are based on data generated from people's responses to hypothetical questions rather than from observations of real-world choices

Data from each approach could be obtained **directly** or **indirectly**. In the case of Revealed Preference, it might be possible. for example. to directly observe the consumer's behaviour in relation to the demand for the natural resource or environmental good as the price or quantity/quality changes. For example, in calculating how much local fishermen lost from an oil spill, the revealed preference method might calculate how much the catch declined and the resulting diminished value of the catch. In this case, prices are **directly observable**, and their use allows the direct calculation of the loss in value.

In other settings, the environmental service does not have a direct offering price, but sometimes its quantity does affect the choices people make about other things such as quantities of market goods. The value of the environmental service can then be inferred (an **indirect approach**) through the application of some model of the relationship (substitutionary, complementary etc.) between market goods and the environmental service. Examples of models used in this case are the household production models (including models of household spending on cleaning and on repair of materials damaged by air pollution etc.), travel cost demand model for visits to a recreation site, and hedonic property value and hedonic wage models. To illustrate, suppose we want to estimate the value an occupational environmental risk (such as some exposure to a substance that could pose some health risk), we might examine the differences in wages across industries in which workers take on different levels of risk.

Direct Stated Preference methods involve asking people directly about the values they place on environmental services, Indirect forms of Stated Preference techniques do not directly ask people of values but attempt to infer values by their responses to some given questions. Table 5.4 summarizes these different approaches to valuation of natural and environmental resources. In the sections that follow, we will be examining some of these methods in greater details.

Table 5.5 Valuation Methods for Natural and Environmental resources

Methods	Revealed Preference (OBSERVED BEHAVIOUR)	Stated Preference (HYPOTHETICAL)
Direct	Market Prices Simulated Markets	Bidding games Contingent Valuation
Indirect	Travel Cost Hedonic Property Values Hedonic Wage Values Avoidance Expenditures Referendum voting	Attribute-Based Models Conjoint Analysis Choice Experiments Contingent Activity Contingent Ranking Contingent Referendum

Source: With modifications from Tietenberg and Lewis (2012.p.82)HFK, 201...

5.2.2 Revealed Preference Methods

5.2.2.1 Theoretical Basis

Under what circumstances can the demands for environmental services be inferred from information on market transactions for a related private good? The degree to which inferences about the benefits of increases in some measure of environmental or resource quality (*Q)* can be drawn from market observations and the appropriate techniques to be used both depend on the way in which *Q* enters individual utility functions. There are three ways that *Q* can affect an individual's utility

(i) ***Q* can produce utility indirectly as a factor input in the production of a marketed good that yields utility.**

For example, quality of river water diverted for irrigation affects the agricultural productivity of irrigated land; quality of intake water may influence the costs of treating domestic water supplies and the costs of production in industrial operations that utilize water for processing purposes. Agricultural productivity may be impaired by some forms of air pollution; pollution can cause materials damages, which affect the costs of production for a wide variety of goods and services.

(ii) ***Q* can be an input in the household production of utility-yielding commodities.**

(iii) ***Q* can produce utility directly by being an argument in an individual's utility function**, e.g., plantation timber, commercial fisheries, tourism. *Q* will typically be a substitute or complement to other utility-yielding private goods.

Exploitation of possible relationships between environmental goods and private goods leads to several empirical techniques for estimating environmental and resource values

5.2.2.2 Environmental Quality as a Factor Input

Changes in quantity or quality of the environmental good, Q, lead to changes in production costs of the market good (X), which in turn affect the price and quantity of output or the returns to other factor inputs, or both. The benefits of changes in *Q* can be inferred from these changes in observable market data. Implementation of measures of welfare changes requires knowledge of the effects of changes in Q on the cost of production, the supply conditions for output, the demand curve for good *X*, and factor supplies. There are two special cases where the estimation of benefits/cost is relatively straightforward

(i) where *Q* is a *perfect* substitute for other inputs in the production of X.

Suppose an increase in *Q* leads to a reduction in factor input costs. If the substitution relationship is known, the decrease in per unit production costs can be readily calculated. For example, if water quality improvement results in a decrease in chlorination requirements for drinking water supplies, the decrease in chlorination costs per unit of output can be readily calculated. Where the change in total cost does not affect marginal cost and output, the cost saving is a true measure of the benefit of the change in *Q*. In contrast, if the change in *Q* affects marginal cost, the benefits should include the effect of the lower cost on output and price. However, if the percentage reduction in marginal costs is small or the marginal cost curve is inelastic, or both, the corresponding increase in output would be relatively small and the decrease in total cost could still be used to provide a rough approximation of true benefits. This approach (sometimes referred to as the "*damage function*" approach), has been the basis of a number of estimates of the materials, household cleaning, and agricultural crop-loss benefits of air pollution control, and of the benefits to municipalities, industries, and households of reduced contamination of intake water supplies.

(ii) Where knowledge of cost, demand, and market structure suggests that the benefits of a change in *Q* will accrue to producers.

Benefits may be estimated from observed or predicted changes in the net income of factor inputs. If the production unit in question is small relative to the market for the final product and for variable factors, it can be assumed that product and variable factor prices will remain fixed after the change in *q.* The increased productivity then accrues to the fixed factors of production in the form of profit or quasi-rent.

Most situations may not fit into any of the above two cases, in which case, estimates of the value of *Q* will require knowledge of the cost and demand functions. In some studies, it has been possible to use econometric methods to estimate a cost function that includes an environmental quality variable (for example, Mjelde et al. 1984; Garcia et al. 1986; Neeliah and Shankar 2010). Other studies have used various simulation approaches to model the behavior of producers and their responses to changes in an environmental variable.

5.2.2.2.1. Damage function Approach

Most of the early studies of the effects of air and water pollution on producers based on the damage function approach. It involves estimating a dose/damage function that relates some measure of pollution to a physical measure of damage, applying this function to estimates of the inventory of materials exposed or at risk; and multiplying the result by some unit value. For example, consider a case of damages to materials and structures, such as corrosion, soiling, or loss of thickness of paint. This measure would have to be translated into an estimate of the increase in the frequency of some repair or replacement activity. The unit cost of this activity would provide the basis for estimating a monetary damage. In the case of agriculture, the damage function approach focuses on reduction in harvestable yield and multiplies this by a market price.

The damage function approach conceived in this narrow sense, has some limitations.

(i) It ignores adaptive behavior on part of agents (e.g., material substitution, increased protection activities, and changes in maintenance and repair schedules in the case of production).
(ii) ignores impacts on consumers resulting from possible changes in market price and changes in the cost of production

5.2.2.2.2. Averting/Defensive expenditure approach

This approach recognizes that agents undertake adaptive behavior in response to a change in the quantity/quality of an environmental resource. It involves examining "averting or defensive expenditures." Averting expenditures are those designed to reduce the damage caused by pollution by taking some kind of averting or defensive action. An example would be to install indoor air purifiers in response to an influx of polluted air or to rely on bottled water as a response to the pollution of local drinking water supplies (see Box 5.3 for an illustration).

Since people would not normally spend more to prevent a problem than would be caused by the problem itself, averting expenditures can provide a lower-bound estimate of the damage caused by pollution.

5.2.2.2.3. Production/cost function Approaches

Production function approach link the physical effects of changes in environmental quality to changes in market prices and quantities, and ultimately to changes in consumers' and producers' surpluses. For example, they have been applied to

Box 5.3. Valuing Damage from Groundwater Contamination Using Averting Expenditures

In late 1987, trichloroethylene (TCE) was detected in one of the town wells in Perkasie, a town in southeastern Pennsylvania. Concentrations of the chemical were seven times the EPA's safety standard. Since no temporary solution was available to reduce concentrations to safe levels, the county required the town to notify customers of the contamination. Once notified, consumers took one or more of the following actions:

(1) they purchased more bottled water;

(2) they started using bottled water;

(3) they installed home water-treatment systems;

(4) they hauled water from alternative sources; and

(5) they boiled water.

Through a survey, analysts were able to discover the extent of each of these actions and combine that information with their associated costs. The results indicated that residents spent between $61,313.29 and $131,334.06 over the 88-week period of the contamination to protect themselves from the effects. They further indicated that families with young children were more likely to take averting actions and, among those families who took averting actions, to spend more on those actions than childless families.

Source: Charles W. Abdalla et al., "Valuing Environmental Quality Changes Using Averting Expenditures: An Application to Groundwater Contamination." LAND ECONOMICS, Vol. 68, No. 2 (1992), pp. 163–169. Also in Tietinberg and Lewis, 2012, p.92

(i) commercial forest where (a) an investment in environmental quality alter the optimum time of harvest and (b) an environmental quality variable affects the economic value of an associated nonmarket output such as recreation

(ii) commercial fishery where environmental parameters are introduced into growth and stock-recruitment models and the effect of varied institutions for ownership or management on the economic value of an environmental quality change are considered.

5.2.2.3 An Individual's Demand for Environmental Quality

In this case, the environmental good, *Q,* is an argument in the consumer's utility function. It is assumed here that the individual perceives the effects of changes in environmental quality. For example, if high ozone levels cause respiratory irritation, the individual is assumed to be aware of the irritation, so that he feels "better" when it is reduced. He need not know the cause of the irritation or the actual levels of air pollution. Note, if the individual is not aware of the effects of changes in *Q*, Revealed Preference methods of benefit estimation cannot be applied. For example, individuals may not perceive the effects of long-term exposure to air pollutants on their probability of chronic illness or death. If that is the case, changes in *Q* will not affect their behavior and observations of market behavior will yield no information about the value of reducing risks to health.

The relationships between *Q* and other goods that have been found to be of use involve, broadly speaking, either substitution or complementarity. The environmental good could be a substitute for a marketed good that enters the utility function. A fundamentally equivalent construct in this case, will be one in which the environmental good is *an* input into a **household production function** and has marketed-good substitutes in the production process. This is the more general and useful way of conceptualizing the problem. Complementarity is often most usefully conceived such that the environmental good is a quality characteristic of the related good. Here the related good could be a nonmarket good produced by the household using a household production process, or could be a marketed good whose units are heterogeneous and quality-differentiated. In this case, because the good is marketed, the prices of units with higher levels of quality embodied in them are bid up. An example of the latter is the Hedonic Price model.

5.2.2.3.1 Hedonic Prices Approach

It is possible to have situations in which, the quantity/quality of the environmental good, Q, (i) varies across space, as in air pollution, or (ii) is a characteristic embodied in some private good so that the level of *Q* can be considered to be a qualitative characteristic of a differentiated market good. In these cases, individuals have some freedom to choose their effective consumption of the public good or environmental quality through their selection of point in space [as in case (i)] or a private goods consumption bundle [as in case (ii)]. In the latter case, there is a kind of complementarity between the public good and the market good; as the quantity of the public good embodied in the market good increases, the demand for the market good increases. In effect, the market for the differentiated private good functions also as a market for the public good or environmental quality. Examples are consumption of local public goods through choice of a residential jurisdiction (here the housing market functions also as a market for the purchase of local public goods), choosing between various job characteristics in terms of risk and amenities (here, the job market functions also as a market for different job characteristics). In these cases, housing price and wage differentials serves as implicit prices for different levels of the public good and job characteristics. (It is well known that workers in high-risk occupations demand higher wages in order to be induced to undertake the risks.)

In situations as described above, the hedonic price approach can then be used to measure the implicit price of *Q;* and, under some circumstances, the demand curve for Q can be identified.[32] It involves the use of multiple regression analysis, to "tease out" the environmental component of value in a related market. The results of the multiple regression analysis can be used to construct a willingness to pay to avoid the environmental risk in question.

Basic Model

The Hedonic Price Model (HPM) is based on a theory of consumer behavior suggesting that people value a good based on its characteristics, rather than the good itself. A good is a bundle of attributes. For example, an individual values a car not for possession but for attributes such as safety; speed; cost per mileage; luxury; comfort and status. In this case, the examination of how the car price changes with changes in those attributes, can reveal the prices of the attribute. Housing price is related to the characteristics of the house (such as number of bathrooms, plot size, number of rooms, construction quality, etc.), the neighborhood attributes (such as distance to employment center, crime rate, quality of schools, air quality, etc.). In principle, if the product class contains enough products with different combinations of characteristics, it should be possible to estimate an implicit price relationship that gives the price of any model as a function of the quantities of its various characteristics. This relationship is called the **hedonic price function**. The partial derivative of the hedonic price function with respect to any characteristic gives its marginal implicit price (the additional expenditure required to purchase a unit of the product with a marginally larger quantity of that characteristic). Let *Y* represent a product class. Any model of *Y* can be completely described by a vector of its characteristics;

$$Q = (q_1,\dots, q_k) \qquad (5.6)$$

Thus, any configuration of *Y* (e.g., y_i) can be described by its characteristics,

$$y_i = y_i(q_1,\dots, q_k) = y_i\,(Q_i) \qquad (5.7)$$

where q_k is the quantity of the k^{th} characteristic provided by configuration *i* of good Y.

[32] Colwell and Dilmore (1999) cited examples of the application of the technique to prices of farmland as early as 1922. Earliest modern example appears to be Griliches' (1961) application to the prices of automobiles. Rosen (1974) developed the formal theory of hedonic prices in the context of competitive markets. Freeman (1974) provides an early development of the use of hedonic prices for estimating the demand for environmental quality characteristics.

The hedonic price function for Y gives the price of any configuration, as a function of its characteristics. Specifically, for y_i,

$$p_y = p_y\ (q_{i1},\ldots,\ q_{ik}\ ) \qquad (5.8)$$

If $p_y(\cdot)$ can be estimated from observations of the prices and characteristics of different models, the price of any model can be calculated from knowledge of its characteristics.

As a simple illustration, assume we want to estimate housing prices in one neighborhood. The neighborhood is divided into a polluted east (E) area, due to a nearby factory, and a cleaner western (W) area. If people prefer to live in the west, this will push prices for houses in the area up, and push prices down for houses in the east. The price movements will continue until the price differential is large enough to make individual indifferent between living in the clean west or the dirty east. Therefore, the price differentials reveal the people's WTP to avoid the air pollution.

We can use the Hedonic Pricing Method (HPM) to analyze such value. Assume that all houses in the area have the same attributes, except for air quality, due to pollution. Using regression analysis, we can determine a statistical relationship between the housing price and the air quality associated with each house in the area/city. This should show a positive relationship between housing prices and air pollution (See Perman et al. 2003, Box 12.6, page 436-437 for an application)

Another application of hedonic prices is the hedonic travel cost method, a variant of the travel cost method which seeks to use data on the attributes of recreation sites together with data on visitation rates and travel cost to value site attributes. The basic idea is to consider two sites which are the same in all respects save that one has some attribute that the other does not. The valuation of that attribute would then be inferred from the difference in the relationship between visitation and travel costs at the two sites.

Hedonic Prices and Geographic Information Systems

Geographic Information Systems (GIS) are computerized mapping models and analysis tools. A GIS map is made up of layers such that many variables can be visualized simultaneously using overlays. Use of GIS to inform economic analysis is a relatively recent addition to the economist's tool kit. GIS offers a powerful collection of tools for depicting and examining spatial relationships. Most simply, GIS can be used to produce compelling graphics that communicate the spatial structure of data and analytic results with a force and clarity otherwise impossible. But the technology's real value lies in the potential it brings to ask novel questions and enrich our understanding of social and economic processes by explicitly considering their spatial structure. Models that address environmental externalities have, almost by definition, a strong spatial component.

For nonmarket valuation, GIS has proven to be especially helpful in enhancing hedonic property value models by incorporating both the proximity of environmental characteristics and their size or amount. GIS studies have also allowed for the incorporation of variables that reflect nearby types and diversity of land use. GIS allows other spatial data, such as land use, watercourses, and census data, to be "layered" on top of the map. By drawing a circle around each house of the desired circumference, GIS can help us to calculate the amount of each amenity that is in that circle as well as the density and types of people who live there. Numerous census data are available on variables such as income, age, education, crime rates, and commuting time. GIS also makes it relatively easy to calculate straight-line distances to desired (or undesired) locations, such as parks, lakes, schools, or landfills.

5.2.2.3.2. Travel Cost Method (TCM)

The travel cost method (TCM) is an application of weak complementarity examined in Module 5.1. This method was first proposed by Hotelling in 1947 and was developed principally in papers by Clawson (1959) and Clawson and Knetsch (1966). It was based on the simple idea that it ought to be possible to infer the values placed by visitors on environmental amenity services from the costs that they incurred in order to experience the services. Travel cost models have been used to value beach closures during oil spills, fish consumption advisories, and the cost of development that has eliminated a recreation area.

The original TCM proposals related to national parks where entry was unpriced. In this context the environmental good (E) in Fig 5.5 (Module 5.1) is the amenity service that is enjoyed by a park visitor and C_1 is travel to the park so that E and C_1 are complementary. The nonessentialness assumption is that there is some income level that would compensate for the closure of the park. The weak complementarity assumption is that if the individual does not visit the park, he or she does not care about the services that it provides.

Now suppose that some project threatens the amenity services currently provided by a protected area, for example, a national park for which there is no access fee. Those responsible for deciding whether the project should go ahead are going to use environmental cost benefit analysis (ECBA) (to be considered in Module 5.3), and wish to know the environmental cost to compare with the net development benefit. For analytical simplicity, assume that if the project goes ahead, the value of the recreational amenity services from the area in question will go to zero.

We can use the TCM to determine the value of the park, at least to the users. The method rests on two basic assumptions.

(i) Visits to the park are determined by a trip- or visit-generating function

$$V_i = f(C_i, X_{1i}, X_{2i}, \ldots, X_{Ni}) \qquad (5.9)$$

where V_i = visits from the i^{th}origin or by the i^{th} individual,

C_i = the cost of a visit from origin i or by individual i, and the Xs = other relevant variables.

(ii) The cost of a visit comprises both travel cost T_i varying with individual *i* and admission price P similar for all individuals. In addition, visitors treat travel costs and the price of admission as equivalent elements of the total cost of a visit with ∂Vi/∂C_i < 0. If we assume that the function *f*(.) is linear in costs and suppress the role of other variables, then the trip generating equation to be estimated is;

$$V_i = \alpha + \beta C_i + \varepsilon_i = \alpha + \beta(T_i + P) + \varepsilon_i \qquad (5.10)$$

Where ε = error term component, or error term, assumed to be normally and independently distributed, with zero expectation, $\beta < 0; since\ ^{\partial V}/_{\partial C_i} < 0$

α and β can be estimated from data on V_i and V_i and used to figure the effects on visits of hypothetical changes in P. Note that this could be useful for figuring the effects on visits of the introduction of access charging, as well as for figuring a monetary measure of the utility of the recreational amenity with free access.

Equation (5.10) is a Marshallian, uncompensated, demand function for visits. Given the assumption of zero expectation for the error term in the equation, the relationship between expected visits from origin *i* or by individual *i* and the price of access to the park is

$$E(V_i) = \alpha + \beta P + \beta T_i \qquad (5.11)$$

where E[ ] is the expectation operator.

Equation (5.11) is drawn as downward-sloping straight line (Fig 5.6). Where E[V_i^*] is visits when the access price is zero, and P_i^* is the choke price that drives E[V_i] to zero. Setting E[V_i] equal to zero in equation (5.11) and solving for P gives

$$P_i^* = -(\alpha/\beta) - T_i \qquad (5.12)$$

and for P equal to zero:

$$E[V_i^*] = \alpha + \beta T_i \qquad (5.13)$$

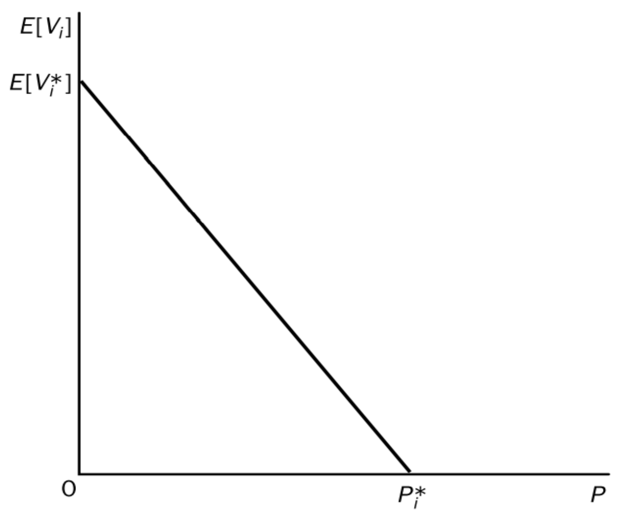


Fig. 5.6. The linear trip-generating function.
Source: Perman et al., 2003.p.412

The Marshallian consumer surplus (MCS) for origin/individual i at P = 0 is given by the area of the triangle 0E[V_i^*] times 0P_i^* in Figure 5.6. The area of a triangle is half base times height, which in this case is 0.5 times 0E[V_i^*] times 0P_i^*. Using equations 5.12 and 5.13 that is

$$0.5\,(\alpha + \beta T_i)(-\left(\frac{\alpha}{\beta}\right) - T) \qquad (5.14)$$

or

$$\left(-\frac{0.5}{\beta}\right)(\alpha + \beta T_i)(\alpha + \ \beta T_i) \qquad (5.15)$$

so that using equation 12.11 again we have

$$MCS_i = -\frac{(E[V_i^*]^2}{2\beta} \qquad (5.16)$$

Summing over i total consumer surplus when P= 0 is,

$$MSC = -\frac{\sum(E[V_i^*]^2}{2\beta} \qquad (5.17)$$

In some application of TCM, surplus for P=0 is determined using actual observed visits for each individual as.

$$MCS \ = \varepsilon_i \ \frac{V_i^2}{2\beta} \qquad (5.18)$$

In either case, the underlying assumption is that visits respond in the same way to changes in P but vary with travel costs. The operation problem is to estimate $\alpha \ and \ \beta$ from data on $V_i \ and \ T_i$ These data could be obtained from a survey of visitors in the park.

A second variant of the TCM allows the analysis of how specific site characteristics influence choice and, therefore, indirectly how valuable those characteristics are. Knowledge of how the value of each site varies with respect to its characteristics allows the analyst to value how degradation of those characteristics (e.g., from pollution) would lower the value of the site. This second variant includes using a special class of models, known as random utility models (RUMs), to value quality changes. In the RUM, a person choosing a particular site takes into consideration site characteristics and its price (trip cost). Characteristics affecting the site choice include ease of access and environmental quality. Each site results in a unique level of utility and a person is assumed to choose the site giving the highest level of utility to that person. Welfare losses from an event such as an oil spill can then be measured by the resulting change in utility should the person have to choose an alternate, less desirable site.

One interesting paradox that arises with the travel-cost model is that those who live closest to the site and may actually visit frequently, will have low travel costs. These users will appear to have a lower value for that site even if their (unmeasured) willingness to pay for the experience is very high. Another challenge in this model is how to incorporate the opportunity cost of time. Usually, this is represented by wages, but that approach is not universally accepted.

5.2.3. Stated Preference Methods for Valuation

5.2.3.1 Introduction

A person's actions in the marketplace reveal information about his core preferences, including his preferences for public goods. However, Revealed Preferences (RP) approach to valuation does not provide answers to most areas of interest in environmental economics. In addition, observation of the choice behavior reveals only whether the value of the offered good to the individual was greater or less than the offering price. Because of this limitation, it is typically necessary for analysts to make assumptions about preferences so that models can be estimated with the data. For this reason (and others), values from RP methods are subject to limitations. The tight linkage between behavior and core preferences has also come into question in recent years by both behavioral economists and psychologists (e.g., Sugden, 2004; Beshears et al., 2008, and Vatn, 2004).

Stated Preferences (SP) Methods are survey-based studies in which respondents are asked questions that are designed to reveal information about their preferences or values. It involves creating hypothetical markets from which measurement of values placed on environmental goods and services could be drawn directly or indirectly. The term encompasses three broad types of questions: (i) Contingent Valuation (CV), (ii) Contingent Behaviour (CB) and Contingent ranking (CR).

5.2.3.2. Contingent Valuation (CVM)

This is perhaps the best known of the SP techniques employed in valuing environmental amenities, with applications dating back to Davis (1963). It seeks Hicksian measures of the welfare impact of hypothetical changes in environmental conditions, or at least bounds on such measures. Various Question formats are possible

5.2.3.2.1. Open-ended Questions

Data obtained from open-ended value questions, taken at face value, are the simplest to interpret. Each respondent is typically asked to state his or her maximum willingness to pay (WTP) for an environmental improvement (compensating surplus) or to avoid a loss (equivalent surplus). An alternative is to ask for the minimum willingness to accept (WTA), as compensation for an environmental degradation or in lieu of an environmental improvement. There are several ways to elicit this number

(a) Bidding game

This is the approach used in many of the earliest studies. It involves an iterative technique, in which individuals are first asked whether they would be willing to pay $\$X$. If the answer is yes, the question is repeated with a higher "price." The procedure is repeated until the individual answers no. The highest price with a yes response is interpreted as the maximum WTP. If the original response is no, the iteration proceeds downward until a yes response is received.

The technique had been largely criticized and abandoned because of perceived "*starting point bias*" (starting point used in the bidding process influenced the individual's purported maximum WTP) (See Whitehead, 2002). The specific source of bias is unknown. Possible explanations include "respondent fatigue" (individual saying "yes" or "no" to simply stop the line of questioning) and misinterpretation of the starting point by respondents as conveying information about either the cost of provision or a "reasonable" estimate of the good's value.

(b) "Direct" open-ended questions

These are question formats, such as "How much would you be willing to pay?". While they help eliminate "starting point bias", they put people in an unfamiliar setting. In most real market settings, individuals are faced with choices among sets of goods with listed prices. They don't have to think of how much they will be willing to pay, they just take the price as given. However, while this is generally true in much of the industrialized world, it is perhaps less of a concern in countries where haggling in local market places is more commonplace (Whittington, 2002)

(c) Payment cards

This is a variation on the open-ended approach. Here, respondents are shown a card with a range of alternative payment values on it and asked to pick a number from the card or to state their own value if that is not to be found on the card. Some authors have also experimented with payment cards that indicate the amounts that typical respondents are paying in the form of taxes for such public programs as police protection, health care, and national defense.

Regardless of the specifics of the elicitation process, the key advantage of the open-ended format is that it provides a specific welfare number W_i for each respondent. If these numbers accurately reflect the individual's preferences, subsequent analysis of the data is relatively straightforward. An estimate of the total value of the welfare change (aggregate willingness to pay) for the population from which the sample is drawn can be obtained by calculating the sample mean and multiplying it by the total population. Alternatively, the responses can be regressed on income (M_i) and other socioeconomic characteristics (S_i) to obtain a bid function for the proposed policy scenario:

$$B_i = B_i \quad (M_i, S_i) \qquad (5.19)$$

If the survey design includes variation in the size or composition of the environmental changes (ΔQ_i) across the sample, then the bid function

$$B_i = B_i(\Delta Q_i, M_i, S_i) \qquad (5.20)$$

can be estimated and used to calculate values for alternative scenarios of environmental or resource change.

Two econometric issues typically arise in estimating either type of bid function. First, parameter estimates can be sensitive to outliers. (at least a few bids may be so large relative to the sample mean, or individual income levels as to be of questionable validity)[33]. Secondly, the approach often yields a large number of zero values. Censored regression models, such as Tobit, or double hurdle models are typically used to address this (See Haab and McConnell, 2002). Aside the measurement issues associated with open-ended Question format, the primary concern is whether the reported welfare measure W_i accurately reflects the respondent's true preferences. There are two related issues here

- **inconsequentiality:** if the survey respondents do not believe that their answers will have any impact on them, either because the survey will not ultimately influence policy or because they believe they will not have to pay for the policy change, then the survey itself is *inconsequential* and they have no incentive to respond truthfully (Carson and Groves, 2007).

- **Incentive incompatibility:** If respondent believes that the survey is inconsequential, he/she has an incentive to exaggerate their reported WTP (Carson and Groves, 2007) since it is not credible that actual payment for the program will be tailored to the individual's reported W_i.

Consider, for example, the simple case in which the respondent believes her portion of the program's cost is fixed, say at C_i. In this setting, she has an incentive to report an arbitrarily high WTP if $W_i > C_i$ (thereby encouraging the policy's adoption) and report a zero WTP if $W_i < C_i$

[33] Varieties of procedures have been suggested to deal with such problem, including trimming or censoring extreme values (e.g., Mitchell and Carson 1989, 226–227). Procedures involve subjective judgment on what constitutes an "extreme value". Hence, sensitivity analysis should be reported.

Thus, the direction of the bias will depend upon individual beliefs regarding C_i. More recent studies suggest that open-ended questions lead to understated WTP estimates

Another problem with open-ended Question format is the possibility of getting large number of "**protest zeros**. These are invalid zero responses which occur when respondents reject some aspect of the constructed market scenario by reporting a zero value even though they place a positive value on the amenity or resource being valued. Some means must be found to identify protest zeros for deletion. One common approach is to follow up the valuation question with a question regarding the individual's motive for his response (**protest questions)**. For example, consider the following reasons given for stating zero maximum WTP and show which indicate a protest zero.

- "I can't afford to pay for the good"
- "The good is not important to me"
- " I don't think that I should have to pay for the good"
- "The proposed program is unrealistic"

Unfortunately, the deletion of protest zeros can also lead to "*item nonresponse bias*" if those who protest are systematically different in some respect from those who give proper responses. Thus, it would be desirable to examine whether the individuals in the protest group differ in observable ways from the general population.

5.2.3.2.2. Binary Discrete Choice Questions

Like the case of open-ended Question format, binary discrete choice questions can take various forms, including

(a) Single-shot binary discrete choice question: Dichotomous choice format

This is perhaps the most commonly used CV elicitation format. Here questions are typically couched in the form of a referendum. After presenting the survey participant with the proposed environmental changes and the cost (also referred to as the "bid amount") that they would bear if the changes were implemented, the individual is asked if they would vote in favor of the referendum. If a respondent answers "yes", that person has indicated a WTP that is greater than or equal to the specified cost. If the response is no, then that sum of money can be taken as an upper bound on true WTP.

If respondents are assigned randomly to different subsamples, with each subsample being asked to respond to a different bid amount. It is then possible to test the hypothesis that the proportion of yes responses decreases with an increase in the price of the environmental good. Data derived using this approach can then be analyzed with a model of discrete choice to obtain estimates of indirect utility functions or bid functions

The dichotomous choice question format has at least three advantages relative to open-ended formats.

- It places people in a relatively familiar social context: many private market transactions involve goods offered on a take-it-or-leave-it basis in which the individual decides whether or not to purchase the good at the offered price. If the "payment vehicle" is a tax, the discrete choice question simulates a true referendum of the sort found everywhere.

- Since only a yes or no answer is required, the format poses a relatively simple decision problem for individuals, which may lead to lower levels of item nonresponse and fewer refusals to participate in the survey.

- It is incentive-compatible in many circumstances; that is, respondents' best strategy is to be truthful in answering the question.

The primary disadvantage is that it yields relatively little information from each survey respondent: one learns only whether the individual's WTP for the proposed program lies above or below the bid value they are presented with (the same problem with RP methods). Thus, relatively large sample sizes are required in order to accurately characterize central tendencies and the distributional characteristics of WTP in the population. This is all the more important if one is interested in recovering a bid function. In addition, just as in the case of open-ended valuation questions, we may have protest zeros (Nos).

(b) Double-bounded discrete choice (DBDC) format

This offers a middle ground between the open=ended format and the dichotomous choice format by trying to squeeze more information out of each survey respondent (thus overcoming the limitation of single-shot binary choice) while also avoiding the problems associated with pure open-ended questions. It augments the standard binary choice format with a follow-up question, asking the individual to further narrow the range of the willingness to pay, W_i. As an example, suppose an individual responds "Yes" to an initial question asking if they would vote for a referendum given a cost of T. The follow-up question would ask if they would still vote for the referendum given a higher cost, say $\boldsymbol{T_H} > T$. On the other hand, if she responded "No" to the first question, she is asked if she would vote "Yes" if the cost were lowered to $\boldsymbol{T_L} < T$.

The responses, if truthful, provide tighter bounds on the individual's WTP, with

(No, No) $\Rightarrow W_i \in (-\infty, \boldsymbol{T_L})$

(No, Yes) $\Rightarrow W_i \in (\boldsymbol{T_L}, \mathrm{T})$

(Yes, No) ⇒ $W_i \in (T, \boldsymbol{T_H})$

(Yes, Yes) ⇒ $W_i \in (\boldsymbol{T_H}, \infty)$

These tighter bounds, in turn, yield more precise parameter estimates. Unfortunately, more data is not the same thing as more useful information! It has been found that this approach leads to biased welfare estimates (see Cameron and Quiggin, 1994). In general, the WTP calculated from both questions together is often less than the WTP based on responses to the first question alone.

Other contingent valuation Question formats suggested in the literature include a one-and-onehalf-bound format (Cooper, Hanemann, and Signorello 2002) and the multibounded discrete choice format (Welsh and Poe 1998). In each case, the formats try to elicit additional bounds on preferences. However, in doing so, they risk loss of the incentive compatibility of the survey questions and open up the possibility of framing effects driven by the structure of the questions themselves.

5.2.3.3. Design of Survey Instrument for application of CV techniques

Specifics of the survey design vary, but based on current best practices (Carson and Hanemann, 2005, 825) survey instruments typically contain the following elements:

- Introductory section: identifying the sponsor and general topic
- Section asking questions concerning prior knowledge about the good and attitudes toward it.
- The presentation of the CV scenario (including what the project was designed to accomplish, how it would be implemented and paid for, and what will happen under the current status quo situation if the project were not implemented,
- Question(s) asking for information about the respondent's WTP/WTA for the good.
- Debriefing questions (to help ascertain how well respondents understood the scenario, and
- Demographic questions

5.2.3.4. Contingent Behavior (CB)

This helps to overcome the classic "omitted variables bias" problem often associated with applications of RP techniques. RP suffers from the lack of sufficient and independent variation in the environmental attributes of interest, which makes it impossible to identify the causal impact that these attributes have on individual behavior and welfare without imposing additional assumptions on consumer preferences. For example, suppose one had used travel cost data to estimate a demand function for visits to a single recreation site, but one wanted to know the value of a change in one of the environmental attributes of that site. In the absence of an observed variation in the environmental attribute, it might not be possible to predict the shift in the demand curve for visits to the site. Even in those studies with substantial variation in the environmental amenity of interest, either through spatial or temporal variation, it is often difficult to isolate the impact of that amenity.

Contingent behavior (CB) asks survey respondents how they would change their behavior if a policy that changes a given attribute of an environmental good occurred (rather than how much they would value proposed policy scenarios as in the case of CV). Contingent change in behaviour (e.g. visitation rates to a recreation site) as a result of the policy change could then be used to estimate the shift in the demand curve for the environmental amenity/services (McConnell, 1986; Cameron et al., 1996; Azevedo, Herriges, and Kling; 2003; and Egan and Herriges, 2006).

The use of CB has the advantage of accurately reflecting what individuals would actually do under the hypothetical scenario presented. Thus, it fills in information that is missing on consumer reactions to alternative environmental conditions in a way that is independent of other unobservable factors (von Haefen and Phaneuf, 2008). However, the incentives for truthful responses are less clear. Studies comparing results from RP techniques to those obtained using CB (e.g., Azevedo, Herriges, and Kling 2003; Jeon and Herriges 2010; von Haefen and Phaneuf 2008) generally suggest inconsistencies, though the divergence, while statistically significant, has not always been substantial.

5.2.3.5. Attribute-Based Methods

Attribute-based valuation methods ask individuals to provide more information about their preferences by giving them more alternatives than the discrete choice approach and by asking them either to select their most preferred option (Choice experiment or choice modelling) or to rank alternatives in order of preference (Contingent ranking). Alternatives are typically presented using a sequence of pairwise or three-way comparisons (conjoint, with one alternative often consisting of the status quo). Each alternative is described in terms of a series of attributes, such that one of the attributes have a monetary dimension (e.g. price) in order to facilitate calculation of monetary values. Objects of choice are differentiated by embodying different levels of a set of attributes. By focusing on the tradeoffs among attributes, the approach yield estimates of the marginal rates of substitution between pairs of attributes and, where price is one of the attributes, the marginal willingness to pay for the attribute.

5.2.3.5.1. Conjoint analysis

A major difference between CVM and conjoint analysis is that in the former respondents are required to evaluate only one or sometimes two alternatives. On the other hand, the latter requires them to evaluate several alternatives separately. Conjoint analysis can be divided into Contingent Rating, Contingent Ranking and Paired Comparisons.

Contingent Rating: In contingent rating, respondents are requested to rate their preferences for several alternatives on, say, a ten-point scale. They are presented with a set of attributes associated with each alternative. The respondents' ratings are then regressed against the attributes. The marginal rate of substitution between a given attribute and its price provides an estimate of the value of the attribute. This is referred to as the 'part-worth' of the attribute. Summing all the part-worths provides an estimate of a respondent's WTP for an aggregate change in the environmental good or service.

Contingent Ranking: Contingent ranking, another survey method, also falls within this final category. Respondents are given a set of hypothetical situations that differ in terms of the environmental amenity available (instead of a bundle of attributes) and are asked to rank-order them. These rankings can then be compared to see the implicit trade-offs between more of the environmental amenity and less of the other characteristics. When one or more of these characteristics is expressed in terms of a monetary value, it is possible to use this information and the rankings to impute a value to the environmental amenity. Sometimes more than one of these techniques may be used simultaneously. In some cases, using multiple techniques is necessary to capture the total economic value; in other cases, it may be used to provide independent estimates of the value being sought as a check on the reliability of the estimate.
A weakness of both contingent rating and contingent ranking is that they do not provide the respondent with an opportunity to reject the good. The only way they allow opposition is by registering a low rating or ranking. In that sense these methods are considered to be unconditional or relative measures of WTP and could be understated.

Paired Comparisons: In the paired comparison approach, respondents are presented with successive sets of two choice and asked to rate the difference between them on a scale (usually, a 5-point scale). A form of paired comparison is adaptive conjoint analysis where the pairs are generated with the aid of a computer. Like the previous two methods, the data from the paired comparison can be analyzed using multiple regression, logit or probit models to provide estimates of a respondent's WTP for an aggregate change in the environmental good or service.

5.2.3.5.2. Choice Experiments

Like contingent valuation, choice experiments are also survey based, but instead of asking respondents to state a willingness to pay, respondents are asked to choose among alternate bundles of goods. Each bundle has a set of attributes and the levels of each attribute vary across bundles. Since one of the attributes in each bundle is a price measure, willingness to pay can be identified. This type of survey has evolved from both contingent valuation and marketing studies. The approach allows the respondent to make a familiar choice (choose a bundle) and allows the researcher to derive marginal willingness to pay for an attribute from that choice. It also affords the analysts larger degree of experimental control through the design of the attributes presented in the choice set. Number of alternatives and attributes could each vary from two to any manageable number.

One of the earliest applications in economics (Beggs, Cardell, and Hausman, 1981) used an ordered logit model to estimate the values of characteristics of alternative models of cars, including electric vehicles. Respondents were to rank sixteen alternative vehicle designs each having nine attributes, including purchase price and fuel costs per mile. Choice experiments (choice modeling) has subsequently been used in the environmental realm to value rural visibility (Rae 1983), water quality (Smith and Desvousges 1986), and the avoidance of diesel odor (Lareau and Rae 1989).

Consider an example (Boyle et al., 2001) that surveyed Maine residents on their preferences for alternative forest-harvesting practices. The State of Maine was considering purchasing a 23,000-acre tract of forest land to manage. Attributes used in the survey included the number of live trees, management practice for dead trees, percent of land set aside, and a tax payment. Three levels of each management attribute and 13 different tax prices were considered. Table 5.6 reproduces the attributes and levels (respondents were given a choice set of four different alternative management plans and the status quo: no purchase). Table 5.7 demonstrates a sample survey question.

Table 5.6: Attributes in the Maine Forest Harvesting Conjoint Analysis

Attribute	Level
Live Trees After Harvesting	No trees (clear-cut)
	153 trees/acre
	459 trees/acre
Dead Trees After Harvesting	Remove all
	5 trees/acre
	10 trees/acre
Percent of Forest Set Aside from Harvest	20%
	50%
	80%

Source: Source: Boyle et al., 2001 and Holmes and Adamovicz, 2003. Also, in Teitenber and Lewis, 2012. p88.

Table 5.7. A simple conjoint Analysis Survey Questionnaire

Attribute	Alternatives				
	A	B	C	D	No change
Live Trees Remaining	No trees	459/acre	No trees	153/acre	
Dead Trees Remaining	Remove all	Remove all	5/acre	10/acre	
Percent Set Aside	80%	20%	50%	20%	
Tax	$40	$200	$10	$80	
I would vote for (please check off)	—	—	—	—	—

Source: Thomas P. Holmes and Wiktor L. Adamowicz, "Attribute-Based Methods." A PRIMER ON NONMARKET VALUATION, Ian Bateman, ed. (New York: Kluwer Academic Publishers, 2003)Also, in Teitenber and Lewis, 2012. p88.

Attribute-based methods are particularly useful when project options have multiple levels of different attributes. They offer possibility of a rich array of data with the application of the technique relative to the single-shot binary discrete choice contingent valuation has led to a significant resurgence of interest in recent years. By systematically varying the attributes both across the sequence of alternatives presented to any one individual and across individuals, the analyst can, in theory, estimate the marginal willingness to pay for each attribute and how that WTP interacts with the level of other attributes. The key advantage of Choice modelling (CM) over CVM is that whereas the latter gets the required answer for just one alternative to the status quo, CM can generate answers about a range of alternatives. It is also relatively more versatile (flexible) than other SP methods. It can be used to value multiple sites or multiple use alternatives. In addition, unlike conjoint analysis, CM can be used to provide conditional or absolute measures of WTP provided a 'choose neither' option is included among the alternatives.

Consider as an example, the use of choice modeling (CM) to study the preservation of a wildness area. The attributes could include the numbers of rare species present; ease of access to the area, size of area and travel cost of household etc. These attributes would then be varied across the various alternatives. The respondents are then required to choose their most preferred alternative. Estimates of respondents' WTP are obtained by estimating a multinational logit model. For instance, suppose there is wilderness/ forest partly with timber harvesting and partly with un-controlled recreational access. The government seeks to turn it into a conservation area (game park) with no logging and restricted recreational access. If the proposal is to be accepted, an environmental cost benefit analysis, ECBA (to be discussed in Module 5.3) should be undertaken to see whether it should go ahead. This will involve deriving monetary values for all (including environmental) costs and benefits. The question is whether the present value of total WTP is equal to or greater that the compensation costs of conservation.

This question could be addressed by means of contingent valuation study. For instance, after providing information on the area, the question could be asked: *Government is proposing to turn forest X into a conservation area, if it did, the number of rare bird species would increase from 5 to 10, the forested area would increase from 1500 to 1800ha. Visitors would be restricted to 2000 per year. Government would need to raise tax by a mount $Y, so as to compensate the logging firms. The question would be; would you vote for this proposal? Tick "yes" or No*.

Now consider as an alternative, a choice modeling approach (CM) approach to the same issue. First the various dimensions of the decision are treated as attributes which can take a small number of specified levels. For example, the researcher could ask the respondent: Please consider carefully each of the following options reelected in the Table below. Which one among them would you choose (circle your choice).

Table 5.8. Alternatives in a Choice Model

Alternatives	1 (status quo)	2	3
Number of species	5	10	15
Old growth forest (Ha)	1500	1800	2000
Visitors per year	4000	3000	2000
Tax/cost to you	0	10	20

(a) I would choose the status quo or no cost to me

(b) I would choose alternative 2 at a cost to me of $10

(c) I would choose alternative 2 at a cost to me of $ 20

The choices that individuals make usually are analyzed using a multinomial logit model. Three main sorts of information can be extracted from the response data. The tradeoffs between attributes, for example, how much access they would give up for more bird species. Given that one of the attributes is a money cost, such tradeoff can be expressed in willingness to pay terms such that an implicit price can be estimated for each non-monetary attribute. It is then possible to estimate WTP for movement from the status quo to an alternative comprising any bundle of attribute levels. The result is the compensating surplus (CS) measure that is required for use in an ECBA for that alternative.

However, additional data provided by choice experiments, comes with a cost. Presenting individuals with a sequence of comparisons can result in respondent fatigue, with participants ignoring portions of the information provided and drawing on simpler decision rules to process the complex set of alternatives (see, for example, DeShazo and Fermo 2002). There are also concerns about “order effects” in the presentation of the choice attributes (see Day et al. 2011 and Boyle and Ozdemir 2009). Finally, the conditions under which choice experiments are incentive compatible are more stringent than those required for the single-shot binary choice referendum (Vossler et al. 2011).

5.2.3.6. Issues and Problems with Stated Preference Approach

There are some problems associated with the use of Stated Preference valuation methods. Some are context-specific, that is, they are specific to the particular form of the question being asked. For example, when people are asked how much they would be willing to pay for something, they might say “zero” because they reject the idea of having to pay for something, they consider to be rightfully theirs. Others are generic, they relate to the nature of Stated Preference itself as a valuation technique that is hypothetical. They include problems in scenario specification, sampling, and item nonresponse. The major questions regarding all SP methods concern the validity and reliability of the data; that is, whether the hypothetical nature of the questions asked inevitably leads to some kind of bias or results in so much “noise” that the data are not useful for drawing inferences.[34] The major concern here has been the potential for survey respondents to give biased answers. Five types of potential bias have been the focus of a large amount of research: (1) strategic bias, (2) information bias, (3) starting-point bias, (4) hypothetical bias, and (5) the observed discrepancy between willingness to pay (WTP) and willingness to accept (WTA).

Strategic bias arises when the respondent provides a biased answer in order to influence a particular outcome. If a decision to preserve a stretch of river for fishing, for example, depends on whether or not the survey produces a sufficiently large value for fishing, the respondents who enjoy fishing may be tempted to provide an answer that ensures a high value, rather than the lower value that reflects their true valuation.

Information bias may arise whenever respondents are forced to value attributes with which they have little or no experience. For example, the valuation by a recreationist of a loss in water quality

[34] For additional discussion of validity and a review of the evidence available see Mitchell and Carson (1989); HFK, 2014, chapter 12)

in one body of water may be based on the ease of substituting recreation on another body of water. If the respondent has no experience using the second body of water, the valuation could be based on an entirely false perception. Consider another example. Visual aides have been shown to reduce uncertainty and unfamiliarity with the good or service being valued. Labao et al. (2008) found that colored photographs, as opposed to black-and-white photographs, influence respondent willingness to pay for the Philippine Eagle. The colored photographs resulted in a higher willingness to pay than black and white photos. Why? The authors suggest that the higher willingness to pay could be explained by photographs in color simply providing more information or by “enhancing respondents’ ability to assimilate information.” In any case, the nature of the visual aide seems important for revealing preferences.

Starting-point bias may arise in those survey instruments in which a respondent is asked to check off his or her answers from a predefined range of possibilities. How that range is defined by the designer of the survey may affect the resulting answers. A range of $0–$100 may produce a valuation by respondents different from, for example, a range of $10–$100, even if no bids are in the $0–$10 range. Ladenburg and Olsen (2008), in a study of willingness to pay to protect nature areas in Denmark from new highway development, found that the starting-point bias in their choice experiment was gender specific, with female respondents exhibiting the greatest sensitivity to the starting point.

Hypothetical bias can enter the picture because the respondent is being confronted by a contrived, rather than an actual, set of choices. Since he or she will not actually have to pay the estimated value, the respondent may treat the survey casually, providing ill-considered answers. One early survey (Hanemann, 1994) found ten studies that directly compared willingness-to-pay estimates derived from surveys with actual expenditures. Although some of the studies found that the willingness-to-pay estimates derived from surveys exceeded actual expenditures, the majority of those found that the differences were not statistically significant.

More recently, Ehmke, Lusk, and List (2008) tested whether hypothetical bias depends on location and/or culture. In a study based on student experiments in China, France, Indiana, Kansas, and Niger, they found significant differences in bias across locations. Given that policy-makers frequently rely on existing benefits estimates when making decisions on other locations, this finding should not be taken lightly.

Benefit transfer is an analytical technique that allow us to use estimates derived in one setting to infer benefits in another. Since original studies are time consuming and expensive, benefit transfer allows the estimates for one site to be based upon estimates from other sites or benefits from an earlier time period to provide the foundation for a current estimate. Benefit transfer methods can take one of three forms: **value transfers**, **benefit function transfers**, or **meta-analysis**. Sometimes the actual benefit values derived from point estimates can simply be directly transferred from one context to another; usually adjusted for differences between the study site and the policy site. Function transfer involves using a previously estimated benefit function that relates site characteristics to site values to adjust the estimates from the original study site by entering the differentiating characteristics of the policy site in order to derive newer, more site-specific values (Johnston et al., 2006). Most recently, meta-analysis has been utilized.

Meta-analysis, sometimes called the "analysis of analyses," takes empirical estimates from a sample of studies, statistically relates them to the characteristics of the studies, and asks whether the reported differences can be attributed to differences in location, subject matter, or methodology. Meta-analysis would use this cross section of contingent valuation studies as a basis for isolating and quantifying the determinants of nonuse value. Once these determinants have been isolated and related to specific policy contexts, it may be possible to transfer estimates from one context to another by finding the value consistent with the new context without incurring the time and expense of conducting new surveys each time.

Benefit transfer methods have been widely used in situations for which financial, time, or data constraints preclude original analysis. Policy-makers frequently look to previously published studies for data that could inform a prospective decision. It has the advantage of being quick and inexpensive, but the accuracy of the estimates deteriorates the further the new context deviates temporally or spatially from the context used to derive the estimates. Additionally, as we noted above, for contingent valuation estimates, Ehmke, Lusk, and List (2008) find that hypothetical bias varies considerably across countries.

In general, economists are divided on the validity of the benefit transfer method. For this method to be meaningful, the following conditions must hold: the goods (or services) in both sites should have roughly similar characteristics; the population in both areas should be similar; and the values in the first study should not have been estimated a long time ago because preferences change over time. Three tests have been suggested to determine the accuracy of benefit transfer. The aims of these tests are to determine the convergent validity (i.e., statistical validity) of benefit transfer and the extent of any bias. The first test involves comparing the benefit transfer values with primary data values obtained from the policy site. If the benefit transfer estimates are not statistically different from the primary data value estimates from the policy site, then it may be concluded that the benefit transfer values are valid. The extent of bias is given by the deviation between the two estimates. The second test involves determining whether different populations have the same preferences for the same non-market good, after controlling for differences in socioeconomic characteristics such as income and education levels. The third type of benefit transfer test is to determine whether transfers are stable over time. Many studies have concluded that value estimates remain relatively stable over a few years. Morrison et al. (1998) investigated the suitability of using choice modeling estimates for benefit transfers both across different populations and across different wetlands in northern New South Wales, Australia. In general, the weight of the evidence appeared to be against the convergent validity of both transfers across sites and across populations. However, they found that transfers across sites tended to be less problematic compared to transfers across population. Johnston and

Rosenberger (2010) also outline some of the potential problems with the use of benefit transfer, including a lack of studies that are both of sufficiently high quality and policy relevant.

Increasingly, environmental economists are using experimental studies to try to determine the severity of some of these biases as well as to learn how to reduce bias. Some of these experiments are conducted in a laboratory setting, such as a computer lab or a classroom designed for this purpose. In one such experiment on voluntary provision of public goods (donations), Landry et al. (2006) found that for door-to-door interviews, an increase in physical attractiveness of the interviewer led to sizable increases in giving. Interestingly, physical attractiveness also led to increases in response rates, particularly by male households.

The final source of bias addresses observed gaps between two supposedly closely related concepts—willingness-to-pay and willingness-to-accept compensation. Respondents to contingent valuation surveys tend to report much higher values when asked for their willingness to accept compensation for a specified loss of some good or service than if asked for their willingness to pay for a specified increase of that same good or service. We have examined the reasons for these discrepancies in Module 4.1.

Other types of biases that have been identified include **embedding effect**, **bid vehicle bias**, **part-whole bias** and **non-response bias.** Embedding effect is said to occur when an individual's WTP is lower when it is valued as part of a more inclusive good or service, rather than on its own. It has been suggested that embedding effect occurs because people are seeking a 'feel good' or 'warm glow' associated with contributing to a 'good' cause. Some researchers attribute embedding to the existence of substitutes. That is, people will reduce their WTP if they are aware of substitutes. Embedding effect is minimized in CM because it allows explicit inclusion of substitutes.

CVM depends on a 'vehicle', that is, a means by which the stated hypothetical amounts would be collected. An individual who dislikes a particular kind of vehicle (e.g. higher taxes) may understate his or her WTP. In some areas, respondents might be dissatisfied with the way their government is using their taxes and therefore such a vehicle might invoke a negative response. A potential solution to bid vehicle bias is to use a 'neutral' vehicle. For example, for preservation values, a useful vehicle could be donations to a trust fund to be administered by an independent non-governmental organization. Vehicle bias is present in CVM and contingent ranking. Contingent rating, paired comparison and CM emphasize multiple attributes which place less emphasis on payment.

There is concern that if people are asked to value one part of a given asset (e.g. all wildlife) and then subsequently asked to value a part of it (e.g. a given species) the response may be similar. It has been suggested that this problem arises from the way people allocated their personal budget, first, dividing their income amongst broad consumption categories, and then allocating to sub-categories of goods. A potential solution to part-whole bias is to remind respondents that their budget constraints and to restrict valuation to whole goods rather than parts of the good. Non-response bias is associated with surveys, in general. Some people cannot be bothered to participate in surveys. Often, it is those with particular interests in the subject who are likely to respond. In such cases, it may be argued that the sample is not representative of the population. Non-response bias can be minimized if questions are easier to answer.

Do these problems invalidate the use of SP methods in the valuation of natural and environmental resources? Faced with the need to compute damages from oil spills, the National Oceanic and Atmospheric Administration (NOAA) in the United States convened a panel of independent economic experts (including two Nobel Prize laureates) to evaluate the use of contingent valuation methods for determining lost passive-use or nonuse values. Their report, issued on January 15, 1993 (58 FR 4602), was cautiously supportive. The committee made clear that it had several concerns with the technique. Among those concerns, the panel listed

- the tendency for contingent valuation willingness-to-pay estimates to seem unreasonably large
- the difficulty in assuring the respondents have understood and absorbed the issues in the survey; and
- the difficulty in assuring that respondents are responding to the specific issues in the survey rather than reflecting general warm feelings about public spiritedness, known as the “warm glow” effect.

But the panel also made clear its conclusion that suitably designed surveys could eliminate or reduce these biases to acceptable levels and it provided, in an appendix, specific guidelines for determining whether a particular study was suitably designed. The panel suggested that when practitioners follow these guidelines, they can produce estimates reliable enough to be the starting point of a judicial process of damage assessment, including lost passive-use values.[35] These guidelines have been influential in shaping more recent studies.

The NOAA panel report has created an interesting dilemma. Although it has legitimized the use of contingent valuation for estimating passive-use (nonconsumptive use) and nonuse values, the panel has also set some rather rigid guidelines that reliable studies should follow. The cost of completing an “acceptable” contingent valuation study could well be so high that they will only be useful for large incidents, those for which the damages are high enough to justify their use.

[35] According to the Panel’s recommendations, ‘… A well-constructed contingent valuation study] contains information that judges and juries will wish to use, in combination with other estimates, including the testimony of expert witnesses. Specifically, they suggested the use of referendum-type (yes/no) willingness to-pay questions, personal interviews when possible, clear scenario descriptions, and follow-up questions’ (Tietinberg and Lewis, 2012, p85.)

Yet, due to the paucity of other techniques, the failure to use contingent valuation may, by default, result in passive-use values of zero. That is not a very appealing alternative.9

Again, in January 2011, a panel of experts gathered at the annual meeting of the American Economics Association (AEA) to reflect on nonmarket valuation 20 years after the Exxon Valdez spill. The consensus among panelists was that while many of the issues with bias have been addressed in the literature, many unanswered questions remain and some areas still need work. While they all agreed that it is “hard to underestimate the powerful need for values” (i.e., some number is definitely better than no number), and we now have in place methods that can be easily utilized by all researchers, they also emphasized several problem areas. First, the value of time in travel cost models has not been resolved. What is the opportunity cost of time if you are unemployed, for example? In discussing other revealed preference methods, they asked the question, “How do the recent numerous foreclosures in the real estate market affect hedonic property value model assumptions?” Second, choice experiments do not resolve all of the potential problems with contingent valuation. While choice experiments do seem to better represent actual market choices, some of the issues that arise in contingent valuation, such as the choice of the payment vehicle, also arise with choice experiments. In addition, some new challenges, such as how the sequencing of choices in choice experiments might affect outcomes, arise. The panel highlighted how this area of research has been enhanced by the field of behavioral economics, an emerging research area that combines economics and psychology to examine human behavior.

5.2.4 Combined Stated and Revealed Preference Models

In the past, SP and RP models have been viewed as substitute valuation methodologies. Some researchers (e.g. Carson et al. 1996) have attempted to test the validity of one of the approaches by making comparisons of welfare estimates derived from both models. However, since each approach is subject to criticism, including a variety of biases and statistical estimation problems, it is not clear that such a validation strategy is effective. Cameron (1992) made the innovative suggestion that, rather than treating, say, the CVM and TCM as competing methods, the two approaches could be successfully combines to estimate welfare measures. Since information from two sources are being combined to estimate a given set of parameters, the combined model should be estimated more precisely than separate models.

Catherine Kling analysed the gains from combining TCM and CVM data using simulation experiments (Kling, 1997). She found that there were definite gains in precision from combining models and there also appeared to be gains in reduced bias. The parameter estimates from the combined model results are generally more efficient because information on the same set of underlying preferences is used to construct the estimates.

The advantages of combing RP and SP methods can be summarized as follows:

- With a combined approach, researchers can afford to work with smaller samples since each person in the sample generates more than one observation;
- The combined approach results in improved statistical efficiency as indicated above; and
- The combined approach allows us to test for the consistency of SP and RP representation of individuals' preferences.

There are, however, some disadvantages of the combined approach. These are:

- The combined models are statistically complex and harder to implement
- The combined approach does not work in all situations. For example, there must be a RP technique that fits the problem
- In practical terms, there is limited experience in using this approach to analyze environmental issues; and
- Using the combined approach implies asking more survey questions. This could reduce the response rates, increase protests, and reduce the overall quality of the responses.

Summary

- Valuation methods can be separated into two broad categories. Revealed preference methods are based on actual observable choices in market settings that allow resource values to be inferred from those choices. In contrast Stated preference methods use survey techniques to elicit willingness to pay for an environmental improvement (or for avoiding a loss) and willingness to accept compensation for an environmental damage. Data from each approach could be obtained directly or indirectly.

- Indirect revealed preference methods include damage functions, averting/avoidance expenditures, hedonic prices and travel costs.

- The appropriate methodology under Indirect Revealed Preference methods depend on the manner in which the environmental good enters into the production or utility function.

- Direct Stated Preference approach include contingent variation. Indirect methods include Contingent behaviour and Attributes-based methods, such as contingent ranking and choice experiments.

- Contingent variation is one of the most popular method of eliciting values for natural and environmental resources. However, there are still observed problems associated with the method. Many of these problems can be avoided by more careful design of the research instrument and the survey processes itself.

- In certain contexts, stated and revealed preference techniques could be combined to derive more robust estimates of value.

Review Questions

1. "Contingent Valuation is superior to all other techniques for valuing non-marketed goods or services because it incorporates both use and non-use values," Discuss.

2. Discuss the contention that, where use values are at issue, contingent valuation is superior to indirect methods as it goes directly to the appropriate theoretical constructs for welfare analysis.

3. Clearly describe the Travel cost technique of environmental valuation

4. Supposing that as a result of a project, the relevant environmental benefits affects the consumer's utility function. Clearly explain how the following can be used as monetary measures of the change in utility and how are they related:

a) Consumer surplus,
b) Compensating variation,
c) Equivalent variation.

5. Explain the basis and context for the use of Hedonic Price model in valuing natural and environmental resources.

6. Clearly explain how Contingent Valuation techniques can be applied in environmental valuation.

7. State and explain the various aspects of a CV Questionnaire

8. What advantages has Stated Preference techniques over Revealed Preference methods of valuation of natural and environmental resource values?

9. What are the problems associated with the use of Stated Preference valuation methods?

10. What are the advantages of Contingent Behaviour over travel cost method of valuing recreational facilities?

11. Explain attribute-based methods of valuation and state their advantages and limitations.

Materials used to prepare this Module

1. Freeman III, A., Herriges, J.A. and C. L. Kling (2014), **Measurement of Environmental and Resource Values, Theory and Methods** Third Edition, RFF Press.
2. Titenberg, T. & Lewis, L. (2012). **Environmental & Natural Resource Economics** 9th Edition, The Pearson Series in Economics
3. Perman, R., Ma Y., McGilvray J. and Common M. (2012). **Natural Resource and Environmental Economics**, 4th Edition, Edinburgh, Longman.

Module 5.3. Environmental Cost-Benefit Analysis (3 hours)

Learning Outcomes

This module discusses the social appraisal of projects/policies involving some environmental costs and/or benefits. After completing the module, you will be able to

- ✓ understand the concept of cost-benefit analysis (social appraisal of projects) and its distinction from private or commercial appraisal
- ✓ understand the concepts of Net Present value (NPV) and Internal Rate of Returns (IRR) often used in commercial appraisal and how to apply them to real world projects.
- ✓ understand the utility-based and consumption-based approaches to social appraisal
- ✓ Know how to apply environmental cost-benefit analysis (ECBA) to a project that have significant environmental benefits and/or costs.
- ✓ Know the limitations and objections against the use of ECBA in environmental projects and possible alternatives.

Outline

5.3.1 Introduction

Cost–Benefit analysis (CBA) or Benefit-Cost analysis (BCA) involve social appraisal of investment projects (something that involves a current commitment with consequences stretching over future time) or, for example, the adoption now of a government policy intended to have future effects. It is generally concerned with analyses of projects that Involve costs and benefits that fall at different times, and could involve trade-offs across generations. The word 'social' signifies that the appraisal is being conducted according to criteria derived from welfare economics, rather than according to commercial criteria. CBA attempts to appraise investment projects in ways that correct for market failure. If there were no market failure, social and commercial criteria would coincide

CBA relates to the environment in two main ways. First, many projects intended to yield benefits in the form of the provision of goods and services have environmental impacts (e.g., damming a river in a wilderness area to generate electricity). These are often externalities, which are not reflected in private, commercial, appraisals, so that the costs of such projects are understated in ordinary financial appraisals. Secondly, there are other projects which have direct beneficial environmental impacts (e.g., the construction of a sewage treatment plant). Such projects typically involve external effects, which would not appear in an ordinary financial appraisal.

Projects where environmental market failure relates to incidental damage arise in both the private and public sectors. For example, in the dam case cited above, there is saleable output which could be privately or publicly financed. Projects intended to provide environmental benefits typically come up as public-sector projects (they provide outputs which are public goods). Some projects have both desirable and undesirable impacts on the environment. For example, waste incinerators are intended to reduce the need for landfill disposal (an environmental benefit), but they generate atmospheric emissions (an environmental cost). In all cases, the basic strategy of CBA is the same: to attach monetary values to the environmental impacts (desired and undesired) so that they are considered along with, and in the same way as the ordinary inputs and outputs from the project.

Analyzing projects involving cash flows (in the form of benefits and costs) over different periods (intertemporal decision-making) requires the use of a **discount factor** (D), which expresses the value of one unit of money in the future (generally in one year) in present value terms. This is given as

$$D=1/(1+r) \qquad (5.21)$$

where r is the **discount** rate (the rate at which future value is discounted).

CBA assess costs and benefits (in different periods) in monetary units by expressing all benefits and costs in present value terms. A project is considered to yield net value to society if the present value of benefits over the lifetime exceeds the present value of the costs.

5.3.2 Private (Commercial) versus Social Appraisal

It is necessary to distinguish between CBA and the private or commercial appraisal of a project. The latter relates to appraisal undertaken by private actors, while the former is a social appraisal undertaken by an agency on the behalf of society. It is obvious that the two exercises may not incorporate the same values and would normally, except under certain unlikely conditions, yield different outcomes. We will first examine the things involved in private/commercial appraisal, after which we will return to our consideration of CBA.

5.3.2.1. Private/Commercial Appraisal

There are two main tools that may be used to carry out a private or commercial appraisal of a project. They are **Net Present Value** (NPV) and the **Internal Rate of Return** (IRR). The Net Present Value of a project is The NPV of a project is the amount by which it increases net worth in present value terms. It is given as

$$\text{NPV} = N_0 + \frac{N_1}{(1+\text{i})} + \frac{N_2}{(1+\text{i})^2} + \ldots \frac{N_T}{(1+\text{i})^T} = \sum_0^T \frac{N_t}{(1+\text{i})^t} \qquad (5.22)$$

where N is net benefit

The decision rule under the NPV approach to project appraisal is to invest in a project if it yields positive net worth (if $NPV \geq 0$). If the NPV of a project is zero, it means that the project is equivalent to any other project, or better still, to an equivalent financial investment at the ongoing commercial interest rate. Thus, there is indifference between the project and other projects or financial investments.

The Internal rate of return (IRR) is the rate at which a project's net cash flow must be discounted to produce an NPV equal to 0. It can be expressed as the solution to x in the equation

$$0 = N_0 + \frac{N_1}{(1+\text{x})} + \frac{N_2}{(1+\text{x})^2} + \ldots \frac{N_T}{(1+\text{x})^T} = \sum_0^T \frac{N_t}{(1+\text{x})^t} \qquad (5.23)$$

Project appraisal using the IRR suggest that the project should go ahead only if it gives an internal rate of return that is greater than or at least equal to the commercial rate of interest (if $x \geq i$). The IRR test will, for the same input data, give the same result as the NPV test. However. in some cases, because of the time profile of the net cash flow, we may have multiple solutions for *x*. This problem does not arise with the NPV test, and it is the recommended test.

5.3.2.2. Social Appraisal

Social appraisal of a project (that is, CBA) is undertaken in circumstances where it is felt that some of the consequences of going ahead with a project would not be adequately represented using market prices. Where a project has consequences that are not traded in markets, a nonmarket evaluation procedure is required to assess the project properly from a social, as opposed to private, commercial, perspective. In Module 1, we saw that the economist's approach to sustainable development is based on utility or consumption. Accordingly, social appraisal could be built on utility or consumption. As in the case of sustainable development, the consumption approach is the preferred because compared to utility, consumption can be easily observed and measured. We examine the two approaches below.

5.3.2.2.1. Utility-based appraisal

Under this approach, we examine the impact of the project on the utility of each and every affected person at each point in time. Any project will typically involve some winners and some losers. We will need to adopt some kind of social welfare function to aggregate across affected individuals based on society's preferences. We then consider the effect of the project on social welfare. The project is approved if its net impact on social welfare is positive.

For example, assume that three individuals (A, B and C) will be affected by a project in each of four consecutive intervals of time (0, 1, 2 and 3) constituting the project's lifetime. Let $\Delta U_{j,\,i}$ denotes the change in utility during time period *i* that would be experienced by individual j on account of the project if it went ahead. If there existed a generally agreed social welfare function with dated individual utilities as arguments, then we can compute the overall change in welfare as a function of the changes in the utilities of the three individuals over time as

$$\Delta W = W(\Delta U_{A,\,0}, \ldots \Delta U_{C,3}) \qquad (5.24)$$

If ΔW > 0, then we should go ahead with the project.

As an alternate, we could imagine that there exists an i**ntratemporal** social welfare function which mapped individual utilities into a social aggregate, ΔU_t in each period, and an **intertemporal** social welfare function for aggregating over time. We can then compute

$$\Delta W = W(\Delta U_0, \Delta U_1, \Delta U_2, \Delta U_3) \qquad (5.25)$$

Once again, the project is recommended If ΔW > 0.

A widely entertained particular form for the intertemporal social welfare function is

$$\Delta W = (\Delta U_0, + \frac{\Delta U_1}{(1+\rho)} + \frac{\Delta U_2,}{(1+\rho)^2} + \frac{\Delta U_3}{(1+\rho)^3}) \qquad (5.26)$$

where aggregation over time involves exponential discounting (aggregation weights decrease exponentially with time, the weights being determined by the discount factor, which is in turn determined by the **utility discount rate,** ρ).

The utility-based approach to social discounting has major limitations. First, there is no generally-agreed social welfare function of any of the above forms. As we noted in Module 2, in practice, economists generally want to avoid the specification of a welfare function when considering policy issues because such an exercise involves some ethical judgments. Secondly, it is not generally agreed that interpersonal utility comparisons are admissible. Thirdly, and perhaps, most importantly, utilities are not observable in practice. Nevertheless, the utility approach lends some useful insights into project evaluation from the social perspective and provides useful theoretical information. In particular, the concept of utility discount rate remains relevant in social appraisal.

5.3.2.2.2. Consumption-based approach

What is actually recommended as the ideal CBA procedure involves consumption, rather than utility, changes. In this case, we will need to trace all of the consequences of the project through to their final impact on consumption by individuals. Stated in monetary units, the impacts can be referred to as net benefits. This will be positive for consumption increases and negative for decreases. We then add net benefits across individuals at a point in time to get contemporaneous net benefits $NB_0, \ldots, NB_3$, where

$$NB_t = NB_{A,t}, + NB_{B,t} + NB_{C,t} \qquad (5.27)$$

The NPV of the project is then the discounted sum of net benefits:

$$\text{NPV} = NB_0 + \frac{NB_1}{(1+\text{r})^{1}} + \frac{NB_2}{(1+\text{r})^{2}} + \frac{NB_3}{(1+\text{r})^{T}} \qquad (5.28)$$

Generally, for T periods, this yield $\sum_{t=0}^{t=T} \frac{NB_t}{(1+\text{r})^{t}}$ (5.29)

Notice that in this case, we use the **consumption** (rather than utility) **discount rate** (r rather than ρ).

The decision rule under this approach is to go ahead with the project if its NPV is positive. A positive NPV indicates that the project delivers a surplus of benefit over cost: consumption gains involved are greater than the consumption losses, taking account of the timing of gains and losses. The existence of a surplus means that those who gain from the project could compensate those who lose and still be better off.

5.3.3. CBA, Efficiency and Equity

Identifying the NPV test in in the above light, that is, as a potential compensation test, indicates that it is concerned with allocative efficiency (recall what we learnt in Module 2 with respect to Pareto improvement and Potential compensation test). However, compared with a private appraisal, CBA takes account of all impacts on consumption, irrespective of whether or not they show up, or are properly valued, in market transaction. In other words, it corrects for market failure. If there is a single market for loanable funds from which market failure is absent, the equilibrium rate of interest in that market, *i*, will be equal to the **consumption discount rate**, *r*, and the marginal rate of return to investment, δ. This would imply that if scarce resources were not used in the project under consideration, they could be invested elsewhere at a rate of return r per period. The NPV of the project will only exceed zero if its internal rate of return exceeds r. Scarce funds will only be allocated to the project by the NPV test if its rate of return is at least as good as the best alternative return available.

While some economists are content to treat CBA as a means for achieving efficiency objectives, leaving distributional objectives to be pursued by other means, others argue that CBA should be conducted so that projects that pass its test are welfare-enhancing. In other words, contemporaneous total net benefit should be defined as the weighted sum of individual net benefits, with marginal utilities of consumption as weights, rather than as the simple sum. This would suggest a definition of net benefits, such as

$$NB_t = U_C^A NB_{A,t} + U_C^B NB_{B,t} + U_C^C NB_{C,t} \qquad (5.30)$$

where U_C^i is the ith individual's marginal utility of consumption, instead of the one employed in equation (5.27).

But this suggestion is rarely followed in practice. Apart from assuming an ethical position on what social welfare should consist in, it requires identifying the individuals, or groups of individuals, affected by the project, and then ascertaining the marginal utilities for those individuals or groups. As in the utility-based approach, this is not realizable. Ignoring the ethical issues involved, a more realistic approach may be to attach arbitrary weights to the consumption of the individuals. But again, the arbitrariness also raises serious questions.

5.3.4. On Discounting and the Discount Rate

The discount rate allows analysts to compare economic effects occurring at different points in time: discounting converts each future dollar amount associated with the project into the equivalent present dollar amount that must be invested today in order to yield the same future amount. Environmental projects (such as Greenhouse gas emission control) may be viewed as an investment: money is spent today on emission controls to reduce the future costs of climate change. If the real rate of return on investment in emission reduction exceeds the rate on investment in machines and education, then future generations would be -better off if less were invested today in machines and education and more in controlling GHG emissions

Discounting of cash flows associated with projects and policies is necessary because individuals attach less weights to a benefit or cost in the future than they do to a benefit or cost now. Possible reasons for this include "pure impatience" or "time preference" (somebody will rather have a dollar today than wait to have it tomorrow) and the fact that the marginal productivity of capital (money)is positive (a dollar's worth of resources now will generate more than a dollar's worth of goods and services in future so that a rational agent will be willing to pay more than a dollar's worth in future to have a dollar's worth today). Questions of discounting are central to understanding economic growth theory and policy (Nordhaus, 2007).

Debates about discounting have a long history in economics and public policy. Identifying the appropriate discount rate has been discussed in the context of general cost-benefit analysis for many years (Dasgupta et al. 1972; Harberger 1976; Little and Mirrlees 1974; Sen 1967; Stiglitz 1982). Social scientists have debated the precise rate to use for environmental analysis, including global climate analysis (Broome 1992; Cline 1992; Nordhaus 1993). This is because, the choice of a discount rate powerfully affects the analytical results. There are disagreement among economists about the principles by which the discount rate to be used in CBA should be determined, as well as the actual number to use at any particular time in any particular economy. This is important because the decision reached on a project using the NPV test can be very sensitive to the number used for the discount rate. This is particularly relevant in the case of many projects involving environmental impacts: the time horizon for the NPV test as regards such projects reaches into many years into the future. In the practice of CBA there is the need for judgement and scope for legitimate disagreement. It is important that any exercise in CBA should include sensitivity analysis – examining the effect on the decision of variations around the central estimates/assumptions employed in the analysis.

On the appropriate discount rate to employ, two options are generally considered. The first involves simply taking the **real market rate.** This is premised on the belief that the interest paid on certain investment represents productivity of capital in the market equilibrium. However, there are serious problems with pursuing this line. In long time horizons, as is the case with many environmental projects, the market rate might not reflect preferences of society correctly for so many reasons, including market failures and imperfections (e.g. externalities, distortions, market power), the super-responsibility of government (the government might have to represent future generations as well as current generations, while only current generations are represented on the market), and the dual role of individuals (in their political role, individuals are more concerned about future generations than in their day to day activities, and it is the latter that determine market outcomes).

A second option for discount rate involves constructing a social discount rate (social discounting). This involves finding the determinants of the discount rate from economic or ethical considerations. Important factors in this regard include pure rate of time preference (time discounting, or utility discounting), pure impatience (rather consume/get utility now than later), economic growth (growth discounting, also called consumption smoothing: If someone is richer in ten years, a dollar today might be worth more than a dollar in ten years), uncertainty, and ethical concerns for environmental goods (should we deal with environmental impacts in the same way as 'ordinary' commodities for example). Also, how we think of these trade-offs between the present and future benefits involves issues of intertemporal equity. It is A matter of ethics and morals because it involves reaching judgments about what is fair or just. Depending on the direction the debate lies, more weight may be given to ethical considerations or to economic considerations.

5.3.5 Environmental Cost-Benefit Analysis (ECBA)

Some authors prefer to label a CBA that incorporates environmental impacts as environmental cost–benefit analysis, ECBA. In discussing ECBA it is convenient for expositional purposes to keep "ordinary" benefits and costs separate from environmental benefits and costs: even a project directed at achieving an environmental goal will have non-environmental benefits and costs. The NPV of a project can then be expressed as

$$NPV' = B_d - C_d - EC = NPV' - EC \qquad (5.31)$$

Where $B_d - C_d$ = discounted non-environmental benefits and cost respectively, expressed in **consumption-equivalent terms**, EC is the present value of the stream of the net value of the project's environmental impacts over its lifetime also expressed in **consumption equivalent terms,** and NPV' = $B_d - C_d =$ the present value of the projects outside consideration of environmental impact

In principle, EC (interpreted as the environmental cost of the project) could be negative, in which case, NPV will exceed NPV'. In this circumstance, the net value of the environmental consequences of the project strengthens, rather than weakens, the case for the project. Given that EC is positive, the ECBA decision rule is that the project should go ahead if

$$NPV' = B_d - C_d > EC \qquad (5.32)$$

while the project should not go-ahead if

$$EC \geq NPV' = B_d - C_d \qquad (5.33)$$

Thus,

$$EC^* = NPV' = B_d - C_d \qquad (5.34)$$

defines a threshold value for EC, such that. For EC ≥ EC* the project should not go ahead.

5.3.5.1. Hypothetical Example

Suppose that there are two towns linked by a four-lane highway built before both grew rapidly in population. The Highway is frequently affected by severe traffic jams, and the government is considering three options for dealing with this problem.

- Option A: simply build another four-lane highway between the two towns.
- Option B: to do same as in option one but to reserve one lane in each direction for specially built buses, with a view to reducing the emissions of $\boldsymbol{CO_2}$ per person-mile travelled on this route.
- Option C: build a new railway link rather than a new highway. It is thought that this could further reduce emissions and have less impact on wildlife and visual amenity.

The basic tasks involve assembling information about each option in terms of costs, impact on the perceived problem, and environmental impact. Such an exercise is called an **Impact Assessment** (see Module 5.4). In order to distinguish it from the final assessment that needs to be made in choosing between, the options, some prefer to call it an **Impact Estimation**. This would involve diverse professionals (engineers, environmental scientists etc.). (The final evaluation of the options will involve economists).

Assume that the impact assessment has been done and produces the data shown in Table 5.9. The impacts of the three options on the problem that is the origin of the various options (traffic jams and extended journey times), are measured in terms of (estimated) millions of hours saved per year. CO_2 emissions effects are measured as tonnes arising per year under each option (incurring more cost does more to reduce emissions). Whereas cost, time savings and emissions estimates can all be expressed quantitatively, we are assuming that the expert assessment of the wildlife and amenity impacts can only be expressed qualitatively (this is what happens in reality).

Table.5.9. Options for reducing traffic delays

	A: Highway	B: Highway & Buses	C:.Railway
Cost 106£	250	300	500
Time Saving 106 hours per year	10000	8000	6000
CO2 Emissions 103 tonnes per year	1000	800	200
Wildlife and Amenity Qualitative	Bad	Bad	Moderate

(**Source:** Perman, et al, 2003. p. 381)

Appraisal using ECBA suggest choosing the option with the highest NPV provided that that is positive. Implementing this rule means setting out the time profile of each option in terms of arising flows of costs and non-monetary impacts, assigning monetary values to those impacts, and using the agreed discount rate to arrive at an NPV figure for each option.

5.3.6. Objections to ECBA

One striking feature of ECBA is that the outcome is to be determined by the preferences of those affected by the project. But then, those preferences cannot be ascertained accurately. In addition, it can be argued that preferences are, in fact, the wrong way to evaluate policy options. Expectedly, there are disagreement on the appropriability and accuracy of valuation methods for environmental cost. Some argue that the methods do not produce reliable information for inclusion in ECBA. Some, economists and others, argue that the assumptions underlying theoretical foundations of valuation are not satisfied in practice, in that people do not, in fact, relate to the environment in this way. There are others who take the view that it is simply the wrong way, on ethical grounds, to inform social decision making where there are serious environmental impacts at issue.

Recall that welfare economics, on which ECBA is founded, is based on a particular form of utilitarianism, which is 'consequentialist' and 'subjectivist' in nature. It is consequentialist in that actions are to be judged in terms of their consequences for human individuals. It is only human individuals that are of interest – only humans have 'moral standing'. It is subjectivist in the sense that the measure of what is good for a human individual is that human individual's own assessment. The individual's assessment is to be ascertained from his or her preferences as revealed in behaviour (a notion summed up in the phrase, 'consumer sovereignty'). There are two classes of ethical objection to this way of proceeding. The first accepts that only human individuals have moral standing but rejects consumer sovereignty, arguing that individual preferences are a poor guide to individual human interests. Four particular arguments are put forward in support of this position. First, individuals may be inadequately informed as to the consequences for themselves of the alternatives they face. Second, individuals may be insufficiently deliberative in assessing the consequences of alternative choices. Thirdly, individuals may lack self-knowledge in the sense that they cannot properly relate the consequences of alternative choices to their preferences. Fourth, individuals' preferences may not reflect their true interests due to 'preference shaping' arising from socialization processes and advertising.

A second class of argument against the use of individual's preferences and consumer sovereignty is that the scope of ethical concern should not be restricted to humans, that animals and plants (and in some versions nonliving entities) should have 'moral standing'. According to this view, the ethically correct principle for social decision making is that 'destruction of the natural environment shall not be undertaken unless absolutely necessary to maintain the real incomes of all human individuals at a level required for the living of a decent human life'. This is an application of the Safe Minimum Standard (SMS) idea examined in Module 1. Observing sustainability constraints may involve overriding the outcomes that are consistent with consumer sovereignty (Common and Perrings, 1992). In particular, correcting market failure, which is what

ECBA and environmental valuation seek to deliver, is not sufficient for sustainability. A properly conducted ECBA may allow a project known to entail species extinction to go ahead if the present value of non-environmental benefits (NPV′ = $B_d - C_d$) is judged to exceed the positive environmental cost (EC > 0). In doing this, it effectively assumes that the services that the species provide can be substituted for by some other species and/or human-made capital. As we learnt in Module 1, this assumption does not find universal (and may not even get adequate) acceptance.

Those who object to ECBA as a technique for the social appraisal of projects would argue that the domain of ECBA should be limited to cases where it is known that the project in question will not have impacts that entail the loss of environmental services for which there is no substitute. Given the general assumption in some quarters that possibilities for substituting for environmental services are very limited, this argument would greatly limit the range of applicability of ECBA. What are the alternatives to ECBA? Various methods have been suggested, including**, c**ost effectiveness analysis, multi-criteria analysis, deliberate polling and citizens' jury.

Summary

- Cost–Benefit analysis (CBA) or Benefit-Cost analysis (BCA) involve social appraisal of investment projects (something that involves a current commitment with consequences stretching over future time) or, for example, the adoption now of a government policy intended to have future effects.

- CBA is different from private or commercial appraisal of a project in that it attempts to correct for externalities associated with projects. Projects where environmental market failure relates to incidental damage arise in both the private and public sectors.

- Private or commercial appraisal can be carried out using the Net present Value (NPV) or Internal Rate of return (IRR). Both methods use the commercial interest rate as the discount rate.

- Social appraisal (CBA) is based on utility or consumption and uses the utility or consumption discount rate. A project is deemed beneficial if it delivers net consumption gain to society. Even though there are concerns about the distributional consequences of projects, CBA is a potential compensation test and is focused on efficiency.

- Determining the appropriate discount rate to use in CBA is a controversial issue. The use of the commercial interest rate is not ideal because of the long-term nature of projects often considered under CBA. The alternative involves construction a social discount rate. This could be based on economic factors or ethical considerations.

- Some prefer to use the phrase environmental cost-benefit analysis (ECBA) to describe CBA that incorporates environmental impacts. The approach under ECBA separates between environmental and non-environmental costs and benefits. A project is deemed beneficial if the present value of net non-environmental benefit exceeds the environmental cost.

- The use of ECBA for appraising environmental projects have been criticized on the ground that it gives a green light to projects that involve irrecoverable environmental losses as long as non-environmental benefits are considered high enough. Some have also expressed concerns over the underlying theoretical basis of consumer sovereignty.

Review Questions

1. Distinguish between private/commercial appraisal and cost-benefit analysis (CBA).
2. What is the main difference, if any, between CBA and environmental cost-benefit analysis (ECBA)
3. Compare the utility-based and consumption-based approaches to CBA. Which do you prefer and why?
4. Comment on the argument for inclusion of distributive considerations in CBA
5. Assess the role of the discount rate in project evaluation.
6. What is the relationship, if any, between Impact assessment and CBA (project evaluation)?
7. What are the limitations of ECBA as a tool for appraising environmental projects?

Materials used to prepare this Module

1. Freeman III, A., Herriges, J.A. and C. L. Kling (2014), **Measurement of Environmental and Resource Values, Theory and Methods** Third Edition, RFF Press.
2. Perman, R., Ma Y., McGilvray J. and Common M. (2012). **Natural Resource and Environmental Economics**, 4th Edition, Edinburgh, Longman.

Module 5.4: Environmental Impact Assessment: An introduction (3 hours)

Learning Outcomes

After completing this Module, you will be able to

- ✓ understand what an Environmental Impact Assessment is and why the need for it.
- ✓ enumerate how undesirable impacts of developmental projects can be anticipated and also overcome through a well-prepared EIA
- ✓ know the various parties involved in an EIA
- ✓ describe the methods and aspects of a standard EIA
- ✓ outline the general procedures of EIA
- ✓ Know how EIA relates to Environmental Cost-Benefit Analysis (ECBA)

Outline

5.4.1 Introduction

5.4.2: Concept and Legal basis of Environmental Impact Assessment

 5.4.2.1: Concept of Environmental Impact Assessment (EIA)
 5.4.2.2: Legal bases of environmental impact assessment

5.4.3. Environmental components of EIA

5.4.4. EIA Process and Procedures

 5.4.4.1: Method of carrying out EIA
 5.4.4.2: Steps in the EIA Process
 5.4.4.3 Composition of the Expert Committees for EIA
 5.4.4.4. The Main Participants of EIA
 5.4.4.5. The Environmental Clearance

Summary

Discussion/Review Questions and Exercises

Materials used for the Lecture

5.4.1 Introduction

Every country strives to progress in economic development through manufacturing and trading. Countries build industries which provide employment, serve the consumers' needs and help to generate revenue. Development projects in the past were undertaken without any consideration for their environmental consequences. As a result, rivers and lakes got polluted, air pollution reached threatening levels and pilling of industrial wastes resulted in land degradation. Industrialization and economic growth provided material comforts and luxuries of life but unfortunately, it has also had adverse impact on the environment. Most of the developmental activities such as building of dams, roads, airports, industries, railway tracks, cities, etc. use enormous amounts of natural resources as raw material and they may generate waste, which is disposed into the environment. Waste disposal may cause damages to air, soil and water, and brings about depletion of natural resources. In view of the colossal damage to environment by developmental activities people are now concerned about the environmental impact of developmental projects. Environmental Impact assessment (EIA) enables decision-makers to analyze the effect of developmental activities on the environment, if any, well before the developmental project is implemented. Thus, it can be viewed as a tool for preventing adverse environmental impact of developmental activities.

5.4.2: Concept and Legal basis of Environmental Impact Assessment

5.4.2.1: Concept of Environmental Impact Assessment (EIA)

Sustainable development and environmental conservation are necessary for survival and wellbeing of future generations. Thus, Environmental Impact Assessment (EIA) is a tool which helps to evaluate environmental impact of proposed developmental projects or programs after mitigation strategies are included in the plan. EIA thus proves to be a tool which improves decision making and ensures that the project under construction is environmentally sound and within limits of the capacity of assimilation and regeneration capacities of the ecosystem. Environmental clearance of developmental projects is mandatory for the new project (Fig. 5.7).

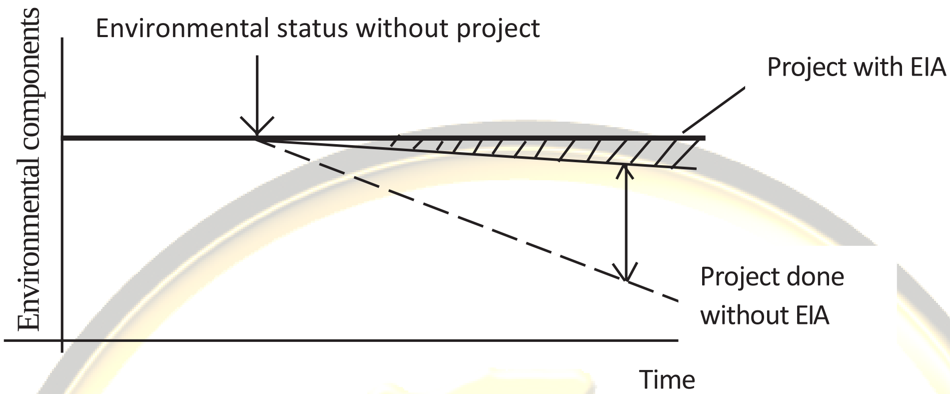


Fig. 5.7. Environmental impact rectification after EIA

EIA provides a cost-effective method to eliminate or minimize the adverse impact of development projects. The important aspects of EIA are risk assessment, environmental management and post product monitoring.

5.4.2.2: Legal bases of environmental impact assessment

The EIA process will be designed such that its guidelines follow basic legal and policy reequipments. For example: EIA is to

(i) serve as a primary environmental tool with clear provisions.
(ii) apply consistently to all proposals with potential environmental impacts.
(iii) use scientific practice and suggests strategies for mitigation.
(iv) address all possible factors such as short term, long term, small scale and large scale effects.
(v) consider sustainable aspects such as capacity for assimilation, carrying capacity, biodiversity protection.
(vi) lay down a flexible approach with and provides for public involvement.
(vii) have in built mechanism of follow up and feedback for comply into mandatory requirements.
(viii) include mechanisms for monitoring, auditing and evaluation.
(ix) consider sustainable aspects such as capacity for assimilation, carrying capacity, biodiversity protection.

EIA appraises the environmental health and social implications of planned developmental projects. It thus links environment with development. The goal of EIA is to ensure environmentally safe and sustainable development.

In many countries, it is a legal requirement for an EIA to be carried out on some projects. Projects that require clearance from central government can be broadly categorized into the following: industries, mining, thermal powerplants, river valleyprojects, infrastructure and CRZ (Coastal Regulation Zone), nuclear powerprojects. In order to carry out an EIA, the following are essential: assessment of existing environmental status, assessment of various factors of ecosystem (air, water, land, biological). analysis of adverse environmental impacts of the proposed project to be started, impact on people in the neighborhood.

5.4.3. Environmental components of EIA

The EIA process looks into the following components of the environment.

(i) Air environment
(ii) Quality of ambient air
(iii) Wind speed, direction, humidity etc.
(iv) Quantity of emission likely from project.
(v) Impact of the emission on the area.
(vi) Pollution control desires / air quality standards.
(vii) Noise, including levels of noise present and predicted and strategies for reducing noise pollution.
(viii) Water environment: existing ground and surface water resources, their quality and quantity within the zone, impact of proposed project on water resources.
(ix) Biological environment: flora and fauna in impact zone, potential damage (likely) due to project, due to effluents, emissions and landscaping, biological stress(prediction).
(x) Land environment: study of soil characteristics, land use, and drainage pattern, and the likely adverse impact of the project.
(xi) Impact on historical monuments and heritage site:

EIA involve assessment of the project in relation to all the above-mentioned factors. Thus, we can say that environmental concerns have to be made a part of the decision to set up a project.

5.4.4. EIA Process and Procedures

EIA process and procedure have several components. Each one is discussed below.

5.4.4.1: Method of carrying out EIA

Preparation of EIA report comprises the following steps:

(i) Collection of baseline data from primary and secondary sources;
(ii) Prediction of impacts based on past experience and mathematical modelling;

(iii) Evolution of impacts versus evaluation of net cost benefit; preparation of environmental management plans to reduce the impacts to the minimum;
(iv) Quantitative estimation of financial cost of monitoring plan and the mitigation measures;
(v) Preparation of environmental management plans to reduce the impacts to the minimum;

5.4.4.2: Steps in the EIA Process

EIA involves the steps mentioned below. However, EIA process is cyclical with interaction between the various steps.

(i) **Screening**: The project plan is screened for scale of investment, location and type of development and if the project needs statutory clearance.
(ii) **Scoping**: The project's potential impacts, zone of impacts, mitigation possibilities and need for monitoring. The EIA agency has to follow the published guidelines by the relevant Ministry or Environment Agency of the country.
(iii) **Collection of baseline data**: Baseline data is the environmental status of study area.
(iv) **Impact prediction**: Positive and negative, reversible and irreversible and temporary and permanent impacts need to be predicted which presupposes a good understanding of the project by the assessment agency.
(v) **Mitigation measures and EIA report**: The EIA report should include the actions and steps for preventing, minimizing or by passing the impacts or else the level of compensation for probable environmental damage or loss.
(vi) Public hearing: On completion of the EIA report, public and environmental groups living close to project site may be informed and consulted.
(vii) Decision making: Impact Assessment (IA) Authority along with the experts consult the project-in-charge along with consultant to take the final decision, keeping in mind EIA and EMP (Environment Management Plan).
(viii) Monitoring and implementation of environmental management plan: The various phases of implementation of the project are monitored.
(ix) Risk assessment: Inventory analysis and hazard probability and index also form part of EIA procedures.

5.4.4.3 Composition of the Expert Committees for EIA

The Committees should consist of experts in the following disciplines: Eco-system management, Air/ water pollution control, Water resource management, Flora/ fauna conservation and management, Land use planning, Social sciences/ Rehabilitation, Project appraisal, Ecology, Environmental Health, Subject Area Specialists, Representatives of NGOs/persons concerned with environmental issues. The Chairman will be an outstanding and experienced ecologist or environmentalist or technical professional with wide managerial experience in the relevant development. The representative of Impact Assessment Agency will act as a Member- Secretary. Chairman and members will serve in their individual capacities except those specifically nominated as representatives. The membership of a committee should not exceed 15 members.

5.4.4.4. The Main Participants of EIA

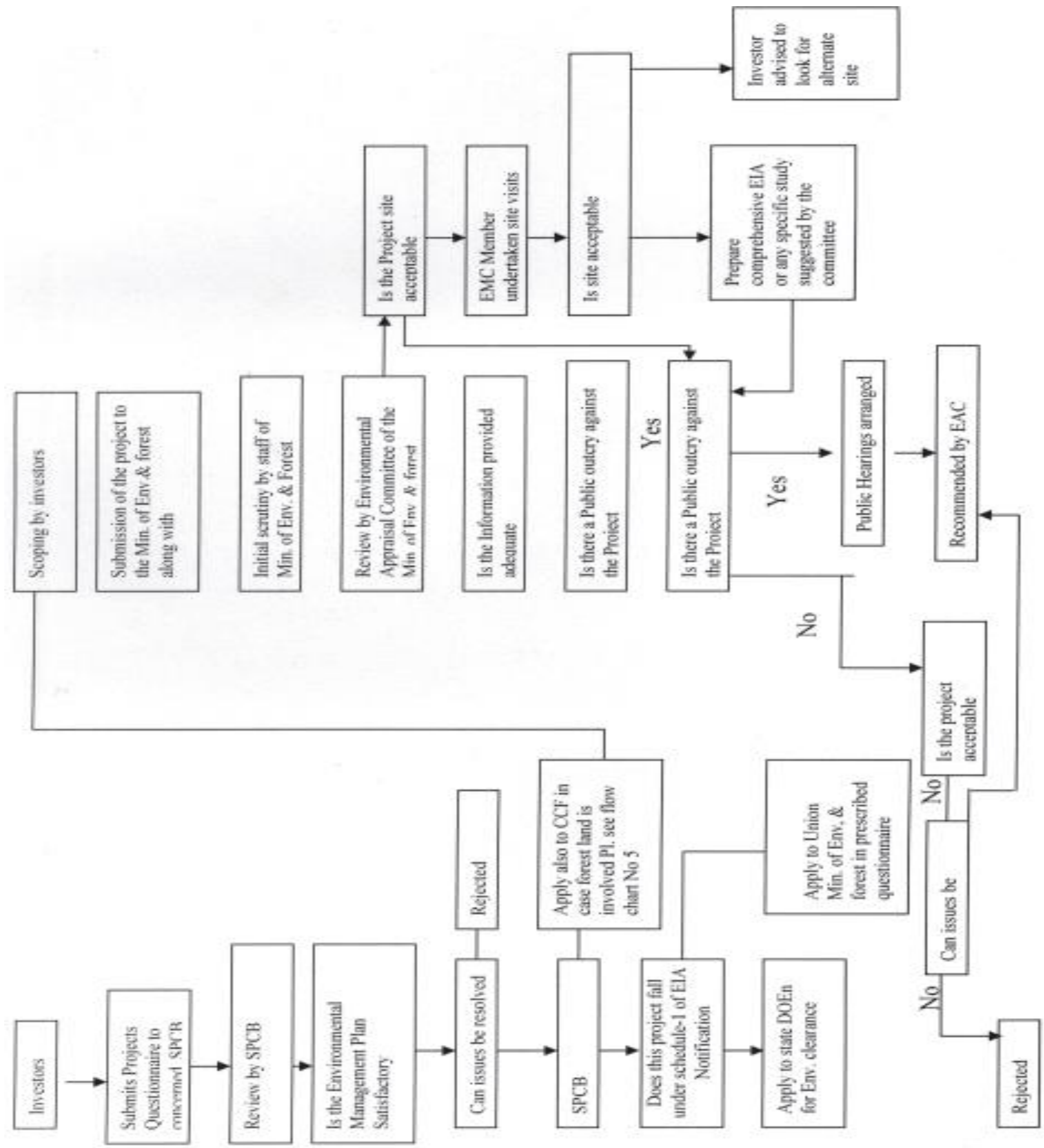
EIA applies to public and private sections. The six main players are:

(i) Those who propose the project
(ii) The environmental consultant who prepare EIA on behalf of project proponent.
(iii) Pollution Control Board (State or National).
(iv) The general public to be affected by the project.
(v) The Impact Assessment Agency.
(vi) Regional Centre of the Ministry of Environment.

5.4.4.5. The Environmental Clearance

The entire EIA process up to obtaining environmental clearance are summarized in the following flow chart (Fig. 5.8). An effective EIA exercise is focused, time bound, cost effective and makes assessment understandable. The sole objective is to erase any situations of environmental damage during construction and implementation of the developmental project. The general public and people in the local and neighborhood of the project should also be kept in mind. The evaluation of EIA is possible only when (a) there is public awareness of those responsible for protecting environmental quality and enforcement; (b) The EIA report and information contained therein is reliable.

Fig. 5.8. Process to obtaining environmental clearance under an EIA


Investors
Submits Projects Questionnaire to concerned SPCB
Review by SPCB
Is the Environmental Management Plan Satisfactory
Can issues be resolved
Rejected
SPCB
Apply also to CCF in case forest land is involved Pl. see flow chart No 5
Does this project fall under schedule-1 of EIA Notification
Apply to Union Min. of Env. & forest in prescribed questionnaire
Apply to state DOEn for Env. clearance
Scoping by investors
Submission of the project to the Min. of Env & forest along with
Initial scrutiny by staff of Min. of Env. & Forest
Review by Environmental Appraisal Committee of the Min of Env & forest
Is the Information provided adequate
Is there a Public outcry against the Project
Yes
Is there a Public outcry against the Project
Yes
No
Is the Project site acceptable
EMC Member undertaken site visits
Is site acceptable
Investor advised to look for alternate site
Prepare comprehensive EIA or any specific study suggested by the committee
Public Hearings arranged
Recommended by EAC
Is the project acceptable
No
Can issues be
No
Rejected

Summary

- Developmental projects are an essential component of economic development and progress of a country. To prevent adverse impacts of developmental projects and programmes an environment, Environmental Impact Assessment or EIA is carried out before the implementation. While development is important, more important is environmental protection so that there is sustainable development and the environmental resources remain available to future generations.

- EIA is tool for anticipating any harmful effects or developmental activities on the environment. As it clears the project plans only after mitigating all probable damaging effects on the environment. As a tool EIA improves decision making and ensures environmental safety. With EIA, a project is implemented with minimal damage to the environment.

- Important aspects of EIA are risk assessment, environmental management and post-product monitoring. Integrity, utility and sustainability are the core values of EIA. There are several legal bases of EIA as it not only appraises environmental health but also the social implications of planned developmental projects.

- In most countries, the projects that require clearance for the government are related to industries, mining power plants, river valley projects, nuclear power projects and coastal regulation zone (CRZ).

- The environmental components of EIA are associated with air, water, organisms, noise, and land. Preparation of the EIA report involves collection of baseline data, prediction of impact, evaluation of net cost benefit versus evolution of impacts, monitoring strategies and mitigation strategies and their quantities estimation, environmental monitoring plans

- EIA often involve experts from ecosystem management, pollution control, resource management, land use planning, rehabilitation project appraisal, ecology, and NGOs concerned with environmental issues

- The procedure for Environmental appraisal involve submission of documents by investor, scrutiny by multidisciplinary staff or relevant Environment Agency, placement before experts for evaluation, recommendations from Appraisal Committees to the Ministry of Environment or relevant Agency, acceptance or rejection of project by Ministry or Environmental Agency.

Review Questions

1. What is EIA? Why is EIA important?

2. Explain the core values of EIA
3. Describe the various components of process of EIA
4. Describe stepwise the procedure for environmental appraisal
5. Mention any four projects requiring environmental clearance and why.

Materials used for this Module

1. Environmental Impact Assessment Notes, https://www.academia.edu/29283773/Environmental_Impact_Assessment_Notes_7_Environmental_Management_24_ENVIRONMENTAL_IMPACT_ASSESSMENT

Module 6. 1 Environmental Accounting Theory (4 hours)

Learning Outcomes

- ✓ Understand the concepts of an optimal consumption path and sustainable income and wealth.
- ✓ Understand the role of prices (including the market interest rate) and the social discount rate in determining the choice of an individual or society's consumption path.
- ✓ Understand why conventional measures of income and wealth do not reflect sustainable income.
- ✓ Understand the predictions of capital theory on measures of sustainable income and wealth under various scenarios.
- ✓ Gain some knowledge as to why implementation of sustainable national income accounting can be problematic.

Outline

6.1.1 Resource use in a competitive world

6.1.2 Consumption, income and wealth

6.1.3 Measuring national income

6.1.3.1 Model with no natural resource as input
6.1.3.2 Model with nonrenewable natural resource as input and zero extraction cost
6.1.3.3 Costly resource extraction with new discovery
6.1.3.4 Model with renewable natural resource
6.1.3.5 Some limitations

Summary

Discussion/Review Questions and Exercises

Materials used for the Lecture

6.1.1 Resource use in a competitive world

Environmental accounting theory builds on the theory of natural resource use. The Hartwick rule examined in Module 1.2 and 3.3 suggests that sustainable behavior on the part of a resource owner in a competitive economy involves keeping wealth intact by consuming just the interest income on that wealth. We will illustrate with the case of an individual after which we apply the findings to an economy.

Consider an individual who owns an oil deposit, a non-renewable resource, and sells extraction permits to a company in the oil production business. The individual pays the proceeds from permit sales into his or her bank account, from which is paid his or her expenditure on consumption. Let

B = Size of the bank account (measured in monetary units, e.g., US $)

C = Consumption expenditure (in US$)

W =Total wealth, in US$

R = Total of permit sales (in tonnes)

X = Size of the remaining stock of mineral (in tonnes)

h = Price of a permit (in US$ £s per tonne)

V= Value of the mine (in US$, units £s

r = Interest rate, assumed constant over time

t − 1 = First day of the relevant period of time, say a year, and

t = Last day of the period.

For simplicity we assume that at t – 1, the mine owner sells permits and banks the revenue. At t he or she writes a cheque on the bank account to pay for his or her consumption during the period. Assume he/she lives forever (we treat his/her heir as an extension of him/her), the behaviour over time of B (size of the bank account) is given by

$$B_t = (1 + r)B_{t-1} + (1 + r)h_{t-1}R_{t-1} - C_t \qquad (6.1)$$

which can be written as

$$B_t - B_{t-1} = rB_{t-1} + (1 + r)h_{t-1}R_{t-1} - C_t \qquad (6.2)$$

At t, the value of the mine is given by the permit price at t multiplied by the amount of oil remaining, which is the amount remaining at the start of the period less the amount for which permits were sold at the start of the period. That is:

$$V_t = h_t(X_{t-1} - R_{t-1}) \qquad (6.3)$$

The price of an extraction permit in a competitive economy will be the difference between the marginal cost of extraction and the price for which extracted oil sells; that is, the *Hotelling rent*, represented here by *h*.

In Module 3. 1, we saw that Hotelling's Rule governs the behaviour of rent, and hence the price of extraction permits, over time so that

$$h_t = (1 + r)h_{t-1} \qquad (6.4)$$

Substituting (6.4) into (6.3) gives

$$V_t = (1 + r)h_{t-1}\,(X_{t-1} - R_{t-1}) = (1 + r)h_{t-1}X_{t-1} - h_{t-1}R_{t-1}$$

or

$$V_t = (1 + r)\,(V_{t-1} - h_{t-1}R_{t-1}) \qquad (6.5)$$

from which we get

$$V_t - V_{t-1} = rV_{t-1} - (1 + r)h_{t-1}R_{t-1} \qquad (6.6)$$

The individual's wealth is just the sum of the bank deposit and the value of the mine: $W_t = B_t + V_t$ so that the change in wealth over a period is:

$$W_t - W_{t-1} = B_t - B_{t-1} + V_t - V_{t-1} \qquad (6.7)$$

Substituting in equation (6.7) from equations (6.2) and (6.6) gives

$$W_t - W_{t-1} = rB_{t-1} + (1 + r)h_{t-1}R_{t-1} - C_t + rV_{t-1} - (1 + r)h_{t-1}R_{t-1} \quad \text{or}$$

$$W_t - W_{t-1} = rB_{t-1} + rV_{t-1} - C_t \qquad (6.8)$$

which can be written as

$$W_t - W_{t-1} = rW_{t-1} - C_t \qquad (6.9)$$

If wealth is constant, $W_t - W_{t-1} = 0$, and from equation (6.9), we have

$$C_t = rW_{t-1} \qquad (6.10)$$

so that if a period's consumption is equal to the interest earned on total wealth at the start of the period, wealth will be the same at the end of the period as at the start. Further, equation (6.10) holds for all t and t − 1, for all periods, so that if we use the subscript 0 for the start of some initial period, we have

$$C_t = = rW_0 \qquad (6.11)$$

Which is the maximum constant consumption level for all subsequent periods.

Given that for any X, the present value of x forever is *x/r*, the present value of the consumption stream rW_0 forever is

$$W_0^* = W_0 \qquad (6.12)$$

so that wealth as the current value of total assets and wealth as the present value of the largest future constant consumption level that is indefinitely sustainable are the same.

For this individual, a period's income, Y, is given by the interest payment on the bank deposit plus the revenue from permit sales and the interest earned thereon,

$$Y_t = \mathrm{r}B_{t-1} + (1 + \mathrm{r})h_{t-1}R_{t-1} \qquad (6.\ 13)$$

Equation (6.8) for W_t - W_{t-1}= 0, gives C_t = rB_{t-1} + rV_{t-1} and if we define investment, I, as the difference between income and consumption we have

$$I_t = Y_t - C_t = \mathrm{r}B_{t-1} + (1 + \mathrm{r})h_{t-1}R_{t-1} - \mathrm{r}B_{t-1} - \mathrm{r}V_{t-1} =$$

$$(1 + \mathrm{r})h_{t-1}R_{t-1} - \mathrm{r}V_{t-1} \qquad (6.14)$$

Using equation (6.6), this can be written as

$$I_t = -(V_t - V_{t-1}) \qquad (6.15)$$

which says that the individual is investing an amount equal to the depreciation of the mine. This is Hartwick's rule applied to this individual – investing in his or her reproducible capital, the bank account, in every period an amount equal to the depreciation of his or her resource stock, the oil deposit. The depreciation of the oil deposit is simply the reduction in its value over the period on account of the reduced size of the resource stock. Note that equation (6.15) can also be read as saying that net investment – that is, investment less depreciation – is zero when wealth is maintained intact.

If we view sustainable development in terms as that which maintains constant wealth, then 'sustainable income' can be considered as the amount that can be consumed during a period without reducing wealth. Thus, for the individual's sustainable income for the period starting on t − 1 and ending on t ($Y_{SUS,t}$) is the interest on wealth for the period and can be written as

$$Y_{SUS,t} = rW_{t-1} \qquad (6.16)$$

As argued by Solow, properly measured, net national product, or income, is both the interest on wealth and the level of consumption that can be maintained forever. For sustainable consumption, maintain wealth intact by consuming just the interest on the constant wealth.[36]

We have shown that by consuming just the interest on wealth an individual resource-stock owner achieves the highest sustainable level of consumption. However, the question may be asked

[36]Note that if the interest rate *r* is not constant, sustainable consumption would not maintain wealth intact. Wealth would have to move in the opposite direction to any change in the interest rate, so that the product *rW* remains constant.

whether the individual would choose such a consumption pattern. The answer, in fact, is that an individual would do so only in special circumstances. There is a substantial and technically sophisticated literature on the choice of intertemporal consumption plans by individuals, but for our purposes a very simple formulation of the problem will suffice. We assume that the problem of choosing a consumption plan can be represented as

$$\text{Max} \int_{t=0}^{t=\infty} U(C_t)\, e^{-\rho t} \mathrm{d}t \qquad (6.17)$$

subject to $dW/dt = rW_t - C_t$

where the notation is as before, but we have introduced the symbol ρ for the rate (assumed constant) at which the individual discounts future utility. For this problem, we get from the current-value Hamiltonian[37] necessary conditions which include

$$\partial H_t / \partial C_t = U_{C_t} - \lambda_t = 0 \qquad (6.18)$$

and

$$d\lambda/dt - \rho\lambda_t = -\,\partial H_t/\partial W_t = -\lambda_t r \qquad (6.19)$$

$$d\lambda/dt = (\rho - r)\lambda_t \qquad (6.20)$$

the following results follows, given the standard assumptions of diminishing marginal utility

- $\rho = r \rightarrow d\lambda/dt = 0 \rightarrow U_{C_t}$ constant, C_t constant
- $\rho > r \rightarrow d\lambda/dt > 0 \rightarrow U_{C_t}$ increasing, C_t decreasing
- $\rho < r \rightarrow d\lambda/dt < 0 \rightarrow U_{C_t}$ decreasing, C_t increasing

Thus, we see that the individual will choose constant consumption as his or her optimal plan only if his/her intertemporal utility discount rate (ρ) is equal to the interest rate (r).

Take note that if the individual started out with C_t increasing and then decided for some reason at the start of period T − 1 to T to switch to C_t constant, then from (6.20), it is clear that he/she would thereafter be acting to consume the interest on the wealth at T − 1 and maintaining that wealth intact and sustaining constant consumption forever, but that the wealth maintained intact would be less than the individual's initial wealth and the constant indefinitely sustainable consumption level would be lower than if such behaviour had been adopted at the outset.

The analysis also assists us to see the effect of a depletion in the natural resource. In this case, the exhaustion of the oil deposit will not affect consumption and wealth. By the time the oil is exhausted, given the behaviour from the outset that keeps wealth constant, the entire initial value of the oil stock will have been transferred to the bank deposit, and our individual can continue to have constant consumption forever as the interest on the bank deposit at the same level as initially. In the next module (6.2), we will extend the same analysis to an economy.

[37] We will not go into the mathematical details here.

6.1.2 Consumption, income and wealth

Consider an economy which uses reproducible capital and a non-renewable resource to produce output, which can be either consumed or saved and added to the capital stock. If we assume that the economy is a small open economy (implying that it takes world prices for traded goods as given), that there is complete freedom of international capital movements (with respect to which the economy is also 'small') and that all markets are competitive, then the situation for the economy is essentially as set out for an individual. For a small open economy which can export the resource and invest in overseas assets the situation is essentially as for an individual and the production function assumed in equation 6.13 will also apply in this case.

However, the global economy is a closed economy, and the sustainability problem is really a global problem. In this case, it is not appropriate to assume that the natural resource is inessential in production. In Module 1.2, we learnt that in such situation constant consumption over time requires a technology of production that allow for imperfect substitution (between the natural resource (R) and man-made capital (K) as inputs, is characterized by constant returns to scale, with the returns to man-made capital greater than the returns to natural capital. In other words,

$$Q_t = K_t^{\alpha} R_t^{\beta} \text{ such that } \alpha + \beta = 1 \text{ and } \alpha > \beta \qquad (6.21)$$

Where K_t is the stock of reproducible capital and R_t is the resource use at time t.

The second essential difference concerns the behavioural rule that will give sustainability, if it is feasible. Whereas for an individual in a competitive economy, or for a small open economy in a competitive world economy, prices are exogenous and unaffected by the behaviour of the individual, or of a small open economy, for a closed economy prices are endogenous and depend upon the economy's behaviour. Also, for the individual analyzed in the preceding section, the marginal product of the bank account in producing income is constant, and equal to *r,* the single interest rate ruling throughout the economy. For a closed economy with equation (6.21) as its production function, on the other hand, the behaviour of the marginal product of capital over time depends upon the time paths chosen for K_t and R_t as does the marginal product of resource use. The essential point here is that in this case of a closed economy, measuring sustainable income, and hence future constant consumption possibilities, requires using the prices that go with sustainability to measure total wealth. These are not, generally, the prices that obtain along the path that a competitive perfect-foresight economy would track, and are not the prices that we observe in actual economies.

In saying this, it is implied that there is a sustainable income to be measured, that constant consumption forever is feasible. However, this is not assured. There is an extensive literature on feasibility conditions in the simple model considered here, and on extensions to encompass multiple resource inputs (renewable and non-renewable), population growth and technical progress (see Perman et al., 2003, p658).

6.1.3 Measuring national income

The economic theory considered above (often referred to as **capital theory**) suggests the need for adjustments to standard measures of national income. In this subsection, we shall examine the measurement of sustainable income implied in the basic theory and variants that incorporate other assumptions.

6.1.3.1 Model with no natural resource as input

The simplest capital theory model used to address the question of the proper measurement of national income, or product, is a representative agent model of a closed economy where a single commodity is produced using just (non-depreciating) reproducible capital, which is accumulated by abstaining from consumption of the produced commodity. The basic result derived is that the proper measure of national income is

$$NDP_t = C_t + I_t \qquad (6.22)$$

where NDP stands for Net Domestic Product, C for consumption and I for investment in reproducible capital. Equation (6.22) is taken to be a measure of 'sustainable income'.

Other models extend this simple framework with regards to what is assumed about the way the economy relates to the environment in terms of arguments in the production and utility functions. Thus, they provide alternative theoretical arguments about how sustainable income should be measured.

6.1.3.2 Model with nonrenewable natural resource as input and zero extraction cost

A model where production requires inputs of a single nonrenewable resource as well as reproducible capital, and using EDP (**environmentally adjusted domestic product**) for sustainable income generally yields the result

$$EDP_t = NDP_t - QR_t R_t = NDP_t - h_t R_t \qquad (6.23)$$

where QR_t is the marginal product of the resource in production, R_t is the amount used, and h_t is the Hotelling rent. Note that in this model, resource extraction is costless, so that Hotelling rent is equal to marginal product. The second term on the right-hand side of equation (6.23) is the depreciation of the resource stock. Substituting (6.22) into (6.23) yields

$$EDP_t = C_t + I_t - h_t R_t \qquad (6.24)$$

so that if total net investment is zero – investment in reproducible capital equals resource depreciation, the Hartwick Rule – we have consumption equal to sustainable income and, given the caveats of the previous subsection, constant wealth.

The depreciation of the resource stock can also be interpreted in terms of Hotelling rent times resource use. Note that In the case of the individual, depreciation in the value of the mine is V_t

$-V_{t-1}$ = rV_{t-1} − (1 + r)$h_{t-1}R_{t-1}$ (equation 6.6). Rearranging we get depreciation as the change in the value of the mine as

$$V_t/(1 + r) - V_{t-1} = h_{t-1}R_{t-1} \qquad (6.25)$$

where the right-hand side refers to the start of a period, so that the value of the mine at the end of the period, V_t , has to be discounted by (1 + r) on the left-hand side for comparability. In both discrete and continuous time, depreciation of the resource stock/mine is equal to Hotelling rent times the amount extracted.

6.1.3.3 Costly resource extraction with new discovery

The model underlying equation 6.24 implies that resource extraction is costless, and there is no exploration activity that can increase the size of the known resource stock. In a model economy where resource extraction involves cost, and new known reserves can be established at some cost, we will have

$$EDP_t = NDP_t - (QR_t - GR_t)(R_t - N_t) = NDP_t - h_t(R_t - N_t) \qquad (6.26)$$

where QR_t is the marginal product of the resource, $GR_t$is marginal extraction cost, and N_t is additions to the known stock as the result of exploration. Note that where extraction is costly, Hotelling rent is the difference between the marginal product of the resource and its marginal cost of extraction.

6.1.3.4 Model with renewable natural resource

Suppose that a renewable resource rather than a non-renewable resource is used in production. Then we find that

$$EDP_t = NDP_t - (QR_t - GR_t)(R_t - F\{S_t\}) = NDP_t - h_t(R_t - F\{S_t\}) \qquad (6.27)$$

where GR_t is the marginal cost of harvesting, and $F\{S_t\}$) is the growth function for the resource stock, where $S_t$is the stock size. Note that equation (6.27) has exactly the same structure as equation (6.26), with F$\{S_t\}$ playing the role in (6.27) that N_t plays in (6.26). Note also that for sustainable yield exploitation of the renewable resource, $R_t = F\{S_t\}$, there is no depreciation to account for, and EDP_t = NDP_t.

While a renewable resource performs some service function in addition to its resource function (e.g., some tree species which is harvested and used in the production of commodities such as paper, and which as standing timber is a source of recreational services), we will have

$$EDP_t = NDP_t + (\frac{US_t}{UC_t})S_t - h_t(R_t - F\{S_t\}) \qquad (6.28)$$

where US_t is the marginal utility of standing trees (marginal utility of the resource as a source of service function) and UC_t is the marginal utility of produced commodity consumption (marginal utility of the resource as a source of resource function).

Compared with equation (6.27), equation (6.28) indicates an additional adjustment to make to net national income as conventionally measured: accounting for the amenity services of renewable resources (in this case the standing timber). Typically, unlike the resource value, there will be no market price that we can observe for the amenity services. In equation (6.28), the value is expressed in terms of the ratio of marginal utilities. It would be possible to get some kind of price to use based on valuation methods discussed in Module 5.

6.1.3.5 Some limitations

It is obvious from the above considerations that the prescriptions from capital theory for adjusting conventional income measurement to account for the environment are dependent on the assumptions embodied in the model. The same point also applies to adjustments on account of the environmental deterioration due to emissions arising in production. What capital theory tells us about how to do environmental accounting and measure sustainable income depends on the model of economy–environment interdependence that is used. Given the current state of knowledge, there is no unique and generally agreed model. Such a model, should one emerge, is also likely to be very complicated, and unlikely to generate simple prescriptions for national income accounting purposes. While capital theory can provide some general insights, it cannot provide generally-agreed definitive rules for practicing national income accountants to follow. Further, the pricing caveats discussed in the context of the simplest model with production using a nonrenewable resource extracted at zero cost carry through to all the more complex models. Finally, even where the theory offers clear and unambiguous prescriptions over a limited area of the total problem, as with non-renewable resource depletion, implementation remains problematic.

Summary

- Environmental accounting theory builds on the theory of natural resource use. Using the Hartwick Rule, sustainable behavior on the part of a resource owner in a competitive economy involves keeping wealth intact by consuming just the interest income on that wealth. Following this path leads to the highest sustainable level of consumption.

- However, a resource owner will choose constant consumption as his or her optimal plan only if his/her intertemporal utility discount rate (ρ) is equal to the interest rate (r).

- On the optimal consumption path, exhaustion of the natural resource will not affect consumption and wealth. By the time the resource is depleted the entire initial value of the resource would have been transferred to another form of asset, and the resource owner can continue to have constant consumption forever.

- For an economy constant consumption over time requires a technology of production that allow for imperfect substitution between the natural resource (R) and man-made capital (K) as inputs, is characterized by constant returns to scale, with the returns to man-made capital greater than the returns to natural capital.

- Measuring sustainable income, and hence future constant consumption possibilities, requires using the prices that go with sustainability to measure total wealth. These are not, generally, the prices that obtain along the path that a competitive perfect-foresight economy would track, and are not the prices that we observe in actual economies. Thus, capital theory suggests the need for adjustments to standard measures of national income to derive sustainable income.

- In saying this, it is implied that there is a sustainable income to be measured, that constant consumption forever is feasible. However, this is not assured.

- In a simple Model with no natural resource as input**,** sustainable income' is measured as Net Domestic Product (NDP) which is the sum of consumption and investment in reproducible capita.

- In a model with man-made capital and a nonrenewable natural resource as input with zero extraction cost, sustainable income requires adjusting for the depreciation of both assets**.** if total net investment is zero – investment in reproducible capital equals resource depreciation (the Hartwick Rule). The depreciation of the resource stock is equal to Hotelling rent times the amount extracted.

- Where resource extraction is costly and there is the possibility of new discovery, Hotelling rent is the difference between the marginal product of the resource and its marginal cost of extraction.

- In a Model with renewable natural resource, the growth function of the resource plays the same role as new discoveries in the non-renewable resource model. Sustainable yield exploitation of the renewable resource implies zero depreciation in the resource. Where the resource performs service functions, there will be additional adjustment to make to net national income as conventionally measured. Typically, unlike the resource value, there will be no market price that we can observe for the amenity or survival services.

- The prescriptions from capital theory for adjusting conventional income measurement to account for the environment (due to resource overexploitation or pollution) are dependent on the assumptions embodied in the model.

- Given the current state of knowledge, there is no unique and generally agreed model. Such a model, should one emerge, is also likely to be very complicated, and unlikely to generate simple prescriptions for national income accounting purposes

- Even where theory offers clear and unambiguous prescriptions over a limited area of the total problem, as with non-renewable resource depletion, implementation remains problematic.

Review Questions

1. Explain the concept of
   (a) An optimal consumption path
   (b) Sustainable wealth

2. Under what condition(s) will an individual with a portfolio containing some financial asset and a non-renewable resource choose an optimal consumption path?

3. Examine the condition(s) for sustainable income implied in the prescriptions of 'Capital Theory' under the scenarios presented below

(a) No natural resource is used as input in production
(b) Man-made capital and a nonrenewable natural resource with zero extraction cost are used as inputs in production
(c) The extraction of the resource is costly and there is the possibility of new discovery
(d) A renewable natural resource is used as input in production

4. What are the limitations of 'Capital Theory' as a guide for measuring sustainable income?

Materials used for this Module

Perman, R., Ma Y., McGilvray J. and Common M. (2012). Natural Resource and Environmental Economics, 4th Edition, Edinburgh, Longman.

Module 6.2 Environmental Accounting Practice (6 hours)

Learning Outcomes

This Module examines the practice of natural resource and environmental accounting. After going through, you should

- ✓ understand the limitations of conventional national income accounting in relation to the management of natural and environmental resources.
- ✓ know the methods that can be used to account for the depletion and degradation of natural and environmental resources and the associated difficulties.
- ✓ appreciate the progress that have been made in developing more realistic measures of sustainable income and wealth.
- ✓ have an understanding of some of the recent measures of sustainable income and wealth and how to apply them.
- ✓ Appreciate the need for further progress in this area.

Outline

6.2.1 The United Nation’s System of National Accounts (SNA) and its Limitations

6.2.2 Natural resource depletion, environmental degradation and defensive expenditures in the National Accounts

- 6.2.2.1 Measuring the depletion of natural resources
  - 6.2.2.1.2 User cost approach
  - 6.2.2.1.3 Application to non-renewable resources
  - 6.2.2.2 Addressing defensive expenditures

6.2.3 Progress in Developing More Realistic Measures of Sustainable Income and Wealth

- 6.2.3.1 The UNSTAT proposals: satellite accounting
- 6.2.3.2 Green GDP Measures
- 6.2.3.3 Adjusted Net Savings
- 6.2.3.4 Genuine Progress Indicator
- 6.2.3.5 Better Life Index
- 6.2.3.6. “Happiness” Indicators
- 6.2.3.7 Environmental Asset Accounts
- 6.2.3.8 The Future of Alternative Indicators

Summary

Discussion/Review Questions and Exercises

Materials used for the Lecture

6.2.1 The United Nation's System of National Accounts (SNA) and its Limitations

National Income Accounting (the process of accounting for goods and services produced, or the income and wealth generated) by society over a given period. Such an exercise serves several purposes. It gives a snapshot of revenue and expenditure flows to society over the period, helps to account for the sources of income (output/growth), and provides information on economic performance over the period. It can also provide a wide array of data (information) useful to households, businesses and governments, including information on the structure of economic activities which can be used for comparison of sectoral performance. At the International level, national income accounting can provide data for evaluation of cross-country performances.

The System of National Accounts (SNA) developed by the United Nation's during the second half of the twentieth century is the first attempt to provide an accounting framework that could be adopted globally. Effort started in 1950 with the compilation of national income estimates using data sources from 41 countries for the period 1938–48. The first official report, "*A System of National Accounts and Supporting Tables*", was produced in 1953 and adopted by the UN Statistical Commission. A revised and expanded version (aimed at systematizing various national efforts to extend and disaggregate national accounts for economic analysis of the SNA) was approved in 1968. This became the international standard for national accounting over the next two and a half decades. Reviews between 1975 and 1993, with major inputs from the Statistical Office of the European Communities (Eurostat) led to the approval of a revised SNA in 1993, which has since then remained the standard for conventional economic accounts.[38]

Current national income accounting conventions actually produce a variety of measures relating to national income. The most widely used are Gross National Product (GNP) and Gross Domestic Product (GDP). The difference between GNP and GDP is not great for most economies. We shall thus, limit our discussion by referring to GDP. Given that GDP measures total demand, it also measures the output produced to meet that demand, and GDP has come to be seen as a measure of economic performance, or welfare.

GDP can be measured in three ways. First, GDP is the total output sold by firms measured by value added. Second, GDP is the sum of the incomes earned by persons in the economy (this is the most obvious rationale for calling GDP 'national income'). The sum of incomes is equal to the value of total output produced by firms by virtue of the convention that output is measured in

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[38] The main objective of the 1993 SNA was to provide a comprehensive conceptual and accounting framework which can be used to create a macro-economic database suitable for analyzing and evaluating the performance of an economy as a prerequisite for informed, rational policy formulation and decision making. With it, countries could monitor the behavior of their economies, obtain data for macro-economic analysis and have a quantitative base for economic policy formulation and International comparison (World Wildlife Fund. 1995. *Real Value for Nature: An Overview of Global Efforts to Achieve True Measures of Economic Progress*. WWF International, Gland, Switzerland; see also Seve, 2002)

terms of value added. Third, GDP is total expenditure by individuals on consumption plus expenditure by firms on items of capital equipment (that is, investment).

Given these conventions, each way of measuring GDP should produce the same numerical result. The value-added measure of firms' total output equals the incomes generated in firms and equals total expenditure on non-intermediate goods. In practice, the three ways of measuring GDP do not produce the same numbers due to errors arising in the collection of data from the very large number of firms and individuals in an actual economy. To preserve the principle of the conventions, published national income accounts introduce a residual error term, and write the final output, expenditure and income numbers as the same after adding in that term. The expenditure measure of GDP is generally regarded as the most reliable. The size of the residual error term varies from year to year, but is often in excess of 0.5% of GDP.

It is universally agreed that to have a proper measure for monitoring national economic performance and welfare, we must account for the portion of capital that is used up in producing wealth (goods and services) during the period. The Net Domestic Product (NDP) is derived by deducting the allowance for capital depreciation over the period from the GDP. In principle, depreciation for a period is measured as the reduction in the value of the economy's existing stock of capital equipment over that period, on account of its use in production. However, in practice, GDP is much more widely used than NDP. The reason for this is that it is very difficult to measure the depreciation of capital equipment accurately (a point we shall meet again when we consider natural capital: the stock of natural and environmental resources). Indeed, for many commentators it has effectively become the performance/welfare indicator, notwithstanding that economists have long been aware of many ways in which it is a very poor performance/welfare indicator, even leaving aside environmental considerations.

Some of the common critiques of standard national accounting measures such as GDP include:

(i) Volunteer work is not accounted for. Standard measures don't count the benefits of volunteer work, even though such work can contribute to well-being as much as economic production.

(ii) Unpaid household production and informal economic activity is not included. While standard accounting measures include the paid labor from such household activities as childcare, housekeeping and gardening, these services are not counted when they are unpaid, or when wages are paid "under the table" through the informal economy.

(iii) No consideration is made for changes in leisure time. A nation's GDP will rise if total work hours increase, but no accounting is made for the loss of leisure time.

(iv) Defensive expenditures are included. Defensive expenditures are those needed to counteract problems. An example is expenditures on police protection. If police expenditures increase to counter a rise in crime levels, the increased spending raises GDP, but no consideration is made for the negative impacts of higher crime rates.

(v) The distribution of income is not considered. Two nations with the same GDP per capita may have significantly different income distributions and, consequently, different levels of overall well-being.

(vi) Non-economic contributors to well-being are excluded. GDP does not consider the health of a nation's citizens, education levels, political participation, or other social and political factors that may affect well-being levels.

Aside these factors, environmentally-driven criticism of current accounting conventions focuses on three areas: depletion of natural resources, environmental degradation and defensive expenditure. In general, while interactions between economic activity and the environment have become increasingly evident, SNA indicators completely ignore such interactions because of the non-market nature (either because property rights to the assets have not been established or because the "owner" of the property right, often the government, chooses not to act as a seller of the services. If a nation cuts down its forests, depletes its soil fertility, and pollutes its water supplies, this surely makes the nation poorer in some very real sense. But national income accounts will merely record the market value of the timber, agricultural produce, and industrial output as positive contributions to GDP, without taking account of the environmental damage.

As regards **natural-resource depletion**, the widely agreed principle is that stocks of natural resources such as oil and gas reserves, stocks of fish, etc., should be treated in the same way as stocks of human-made capital, so that a deduction should be made to allow for the depletion or consumption of these natural resources as they are used in production – that is, their depreciation. In this regard, and as we observed in Module 6.1, there is a distinction between resources that yield monetized flows (such as commercial forests, exploited oils and minerals, and so on) and those that yield non-monetized benefits (such as fresh air, lakes and oceans, and similar natural resources to which there are no exclusive property rights). In principle, the depreciation of the former ought to be observable in market data, while this will not be true of the latter. Where renewable resources are not traded in markets, or where they are exploited on an open-access basis, it is clearly going to be difficult to get firm data relating to depreciation. The latter case particularly sheds light on difficulties that may be associated with accounting for **environmental degradation**.

Closely associated with this is **defensive expenditures related to natural and environmental resources** (expenditures that are expressly designed to prevent degradation of the stock of natural capital or to counteract the effects of degradation that has already taken place). Like other forms of defensive expenditures, this kind of expenditures will be included in GDP as currently measured but they do not reflect a genuine increase in welfare. For example, if extra expenditure is incurred to maintain the level of environmental quality due to extra pollution over a period, the individual's welfare is not enhanced, but the measured Net Product under the SNA increases by the amount of the extra expenditure. If a river is polluted through a discharge of pollutants, and public expenditure is incurred to re-stock the river with fish to its original level, the national income rises. Other examples include health expenditures necessitated by poor air quality, or a clear-cut in a tropical rainforest area (DENR 1994). In these cases, GDP would register the clean-up effort, the increased health expenditures and the timber harvest as contributing to economic growth (i.e., they reflect market transactions), but would not reflect either the environmental damage from the oil spill, or the deteriorating air quality affecting the health of the citizens or the loss of environmental services from the degradation of the forest cover.

As noted, some commentators argue that such defensive expenditures should be deducted from GDP as now measured to arrive at a proper measure of national income. As a practical matter, quite apart from the difficulty of measuring defensive expenditure, it can be argued that there is no reason why defensive environmental expenditure should be treated differently from other forms of defensive expenditure, such as expenditure on armed forces, preventive medicine, policing and so on. It has also been suggested by some authors that all expenditure increases the welfare of those who have undertaken it, and the attribution of defensive expenditures to public sector action could lead to counter-intuitive outcomes (Bojö et al., 1990). If, for example, government expenditure on the maintenance of the stock of natural capital inherent in nature conservation was treated as defensive expenditure and subtracted from NNP, then the incentive for a government concerned with growth in NNP would be to either reduce this expenditure or to have it reclassified.

However, the counter-intuitive argument above simply illustrates an anomaly in the treatment of the public sector in national accounts. It does not disprove the more general assertion that deducting defensive expenditure results in a measure which more accurately reflects economic wellbeing. It is obvious that a consistent approach to defensive expenditure would require major changes in the measurement of national income. The over-riding problem is the delineation of the categories of expenditure to be deducted. It is generally agreed that the minimum expenditures which should logically be subtracted from Net Product are the costs of environmental protection and expenditures for damage compensation[39] In the next subsection, we will examine further theoretical discussions on how to treat the depletion of natural resources, environmental degradation and defensive expenditures in the national accounts.

[39] Additional categories suggested by Daly (1989) reflect concerns in post-industrial societies of decreased quality of mainly urban environments. They include the costs of transport congestion, including health service costs of accidents; increased costs of crime prevention (implicitly regarding high crime levels as a cost of higher levels of economic activity); and increased expenditures incurred due to unhealthy working and living conditions and addictions such as alcohol and tobacco. Clearly this presents a large agenda of issues and would widen the "environmental" modifications proposed (FHK, 2014).

6.2.2 Natural resource depletion, environmental degradation and defensive expenditures in the National Accounts

Recall, three issues are important to national income accounting from the standpoint of Environmental and natural resources economics and management: depletion of natural resources, environmental degradation and defensive expenditure. What are the theoretical suggestions on how these could be taken into consideration in accounting for income and wealth? We examine some few thoughts below.

6.2.2.1 Measuring the depletion of natural resources

There is evident asymmetry in the way man-made and natural capital are treated in the SNA: while accounting for loss in one; the loss in the other is ignored. It is implicit assumed that natural resources are so abundant that they are costless or have no marginal value, thus encouraging economic activities to the detriment of the ERB and of long-term economic growth itself.

It is more straight-forward to account for the depletion of non-renewable (depletable) resources, such as minerals in the national income accounting process because they are subject to private property rights and traded in markets so that it is not difficult to come up with numbers for depreciation (though even in this case, obtaining a single 'correct' number for the depreciation of a particular resource is problematic, notwithstanding the availability of market data).

There are two main approaches suggested in relation to accounting for the depletion of natural resources. They are (i) depreciation approach, and (ii) "user cost" approach

6.2.2.1.1 Depreciation approach

The principle here is already applied in the conventional SNA to reproducible (man-made) capital. It translating physical measurements of depreciation to monetary values. Valuation can be based either on the principle of replacement cost (where replacement is possible) or discounted values of willingness to pay. Application of the approach to the SNA will leave GNP/GDP unchanged but reduce NDP/NNP by the natural capital consumption allowance for the period.

As we have seen, the theoretically correct measure of the depreciation of an economy's stock of a non-renewable resource is the total Hotelling rent (THR) arising in its extraction. With P for the price of the extracted resource, c for the marginal cost of extraction, R for the amount extracted, N for new discoveries, and D for the depreciation of the resource stock:

$$D = THR = (P - c)(R - N) \qquad (6.29)$$

Given standard assumptions for a fully competitive economy, we would have

$$THR = CIV \qquad (6.30)$$

where CIV is the change in the value of the economy's stock of the non-renewable resource in question.

In principle, and given the standard assumptions, D could be measured as either THR given by equation (6.29) or as CIV, with the same result. In practice, neither of these measures of D appears to have been used, nor are they proposed for use in the literature concerning how environmental accounts might actually be constructed. The most obvious problem with equation (6.29) is that c, the marginal cost of extraction, is not observable in published, or readily available, data.

There are other problems with using equation (6.29) to measure D. If there existed competitive firms that were solely in the business of selling the rights to extract from the resource stock, which they owned, then stock market valuations of such firms could be used to measure CIV. Generally, such firms do not exist, resource ownership and extraction being vertically integrated in mining firms. Stock market valuations of mining firms are available, but these data confound the changes in other asset values with those of the mineral deposits owned, and reflect changes in overall stock market 'sentiment'. In any case, the minerals sector of an economy is rarely such that it can properly be characterized as 'competitive'.

An alternative approach (the **net price method**) uses average cost, C, instead of marginal cost to compute rent, which is taken as the measure of depreciation, so that:

$$D = (P - C)(R - N) \qquad (6.31)$$

Note that for c > C, (P − C) > (P − c) so that on this account there would arise an overestimation of THR using equation (6.31).

In many applications of the net price method, N is ignored. Given that actual accounts refer to periods of time, rather than to instants of time as in the theoretical literature, applications of equation (6.31), with or without N, also vary as to the treatment of P and C in terms of dating. Clearly, each could be measured at the start or the end of the period, or as some average over the period. These three measures will only coincide if P and C are unchanging throughout the period, which in the case of P is uncommon.

Another depreciation method involves **change in net present value**. For example, if we take 0 as indicating the start of the accounting period and 1 its close, this method states that

$$D = \sum_{t=0}^{T_0}[(P_t - C_t)R_t/(1+R)^t] - \sum_{t=1}^{T_1}[(P_t - C_t)R_t/(1+R)^t] \qquad (6.32)$$

where T_0 and T_1 are deposit lifetimes, and r is the interest rate. Apart from the use of C rather than c, this method can be seen as an alternative (to stock market valuations) method of measuring CIV. As actually used this method requires some specializing assumptions, as discussed below.

There are some concerns with the depreciation method of accounting for natural resource depletion. As observed, while it leaves GDP unchanged; it wipes out from NDP the entire proceeds from natural resource sales. It is thought that possession of natural resources should confer an advantage on society; it is not satisfactory and intuitive to have a zero net-income from its use.

6.2.2.1.2 User cost approach

This approach avoids the difficulties of putting values on natural resources and relies on the assessment of current extraction rates relative to total available stock. Depending on rate of depletion and discount rate, the revenue from sale of depletable resource, net of production cost, is broken into a capital element (the user cost) and a value-added element, representing true income. The capital element represents asset erosion and could be reinvested into other assets so that it continues to generate income after the resource has been exhausted (Ward, 1982)

User cost will alter both GDP and NDP, is in harmony with accounting principles and uses current market prices for valuation. But it requires a consensus discount rate to convert the capital sales into an income stream and is rooted in the economic meaning of "value added" and "rent".

A particular application due to El Serafy (1981) uses the following formula to calculate the user cost

$$D = R(P - C)/(1 + r)^T \qquad (6.33)$$

where r is the interest rate, and T is the deposit lifetime assuming a **constant rate of extraction** and R, and with P and C as earlier defined. For example, if the extraction rate is 20% of reserves, then T=5.

The principle underlying the rule for the calculation of a user cost measure of depreciation for a non-renewable resource is as follows. From the net receipts from sales a certain proportion is assumed to be set aside and invested at a constant rate of return in order to yield a constant level of income (X) indefinitely. User cost is then defined as the difference between net receipts (R) and that constant income, which is regarded as the true, or sustainable, income from resource depletion.

User cost (depreciation) as a proportion of net receipts is

$$\{R(P - C) - X\}/\{R(P - C)\} = 1/(1 + r)^T \qquad (6.34)$$

and depends only on the lifetime of the resource stock and the interest rate. Sustainable or true income as a share of net receipts is simply one minus the share of user cost.

$$X/R = 1 - \left\{\frac{1}{(1+r)^{T+1}}\right\} \qquad (6.35)$$

Table 6.1 gives the user cost share for different values for resource lifetime and the interest rate. With low interest rates and short lifetimes, user cost is nearly 100% of net receipts (the income share is close to zero). With long lifetimes and high interest rates, nearly all net receipts count as income. For any given asset lifetime, notice the importance of the choice of interest rate.

Table 6.1 User cost share of receipts from sales of nonrenewable natural resources

Lifetime of resource at current extraction rates (years)	Discount rate (%)				
	1	3	5	7	10
1	99	97	95	93	91
5	95	86	78	71	62
10	91	74	61	51	39
25	78	48	30	18	9
50	61	23	9	3	1
100	37	5	1	0	0

Source: Perman et al. 2003. P670

Note that the approach does not value total reserves but only the fraction of reserves being liquidated in the current period, which is valued at current prices. It is also flexible enough to handle changing levels of extractions, movements in the discount rates and alterations in reserve estimates, such as new discoveries which changes the reserve-extraction ratio.

6.2.2.1.3 Application to non-renewable resources

The process of accounting for depletion is more complicated when it comes to some types of renewable resources. As with other natural resources, land, air and water can be viewed as assets, the degradation of which should be treated as depreciation and accounted for in the same way as depletion of reproducible capital. An approach that has been suggested is to establish certain desirable quality standards, and then to measure degradation as the deviation from these quality levels. The value of the degradation can then be calculated as the cost of making good the degradation that has occurred or the cost of achieving the targeted quality standards. However, there is clearly the possibility of an arbitrary element in this since quality standards may be set which are higher than would occur in the 'natural' environment. It is unlikely that the quality standards established would be those which correspond to the efficient level of abatement (see Module 4).

If the use of the costs of achieving standards is considered inappropriate, alternative methods of valuing degradation must be sought. Willingness to pay (WTP) to avoid the degradation, or to make it good, has been proposed (see Module 5). Leaving aside the problems discussed there, from a national accounting standpoint there is the difficulty that WTP includes consumers' surplus whereas the standard components of the national accounts are valued using market prices.

6.2.2.2 Addressing defensive expenditures

Defensive expenditures could be large or small depending on where boundaries are drawn: basic line is expenditure against unwanted side-effects of production and consumption (costs of environmental protection and expenditures for damage compensation). There are various suggestions on how to handle such expenditures. Some have suggested treating such outlays as intermediate, and not final expenditures. Others suggest making allowance for natural capital and reflecting any drawdown as consumption. Another suggestion is the introduction of a "nature account" alongside the conventional accounts.

What is obvious from the above considerations is the need for a more realistic measures of income and wealth, taking into account the stock of natural capital. In the next (final) subsection of this Module, we will examine some of the various practical approaches that have been adopted towards achieving this goal.

6.2.3 Progress in Developing More Realistic Measures of Sustainable Income and Wealth

Over the past five decades or more, there has been increasing awareness of the interactions between societies and their natural environments. This has raised concerns about resource scarcity, environmental degradation and global environmental issues such as climate change and motivated attempts to expand the scope of the SNA to include environmental assets and services.

Efforts to develop "greener" accounting measures began in the 1970s and 1980s, when several European countries began to estimate physical accounts for natural resources such as forests, water, and land resources. In 1993 the United Nations published a comprehensive handbook on environmental accounting, which was revised in 2003, and again in 2014.

6.2.3.1 The UNSTAT proposals: satellite accounting

The U.N.'s 2014 System of Environmental-Economic Accounting (SEEA) report describes three basic approaches to environmental accounting

(i) Measuring the physical flows of materials and energy

(ii) Measuring the stock of environmental assets
(iii) Measuring economic activity related to the environment.

The essential idea is to measure the 'environmental cost' of economic activity in a period. Environmental cost (EC) is defined as the difference between the opening and closing value of the stock of environmental assets

$$EC_t \equiv \sum a_{it}v_{it} - \sum a_{it-1}v_{it-1} \qquad (6.36)$$

where the summation is over i = 1, 2, . . ., n assets, a_i represents the physical measure of the i^{th}environmental asset, v_i the unit value assigned to the i^{th} asset, and where t-1 refers to the start of the period and t to the end of the period.

For the i^{th} asset, $a_{it}v_{it}- a_{it-1}v_{it-1}$ is its depreciation over the period so that $EC_t$is the change in the balance sheet value of all n environmental assets over the period, the depreciation of the society's 'natural capital'. In line with the discussion of the previous section, environmentally adjusted net domestic product (EDP) could then be defined as

$$EDP_t \equiv NDP_t \text{ - } EC_t \equiv (GDP_t \text{ - } DM_t) \text{ - } DN_t \qquad (6.37)$$

where NDP stands for Net Domestic Product, DM for the depreciation of human-made reproducible capital, and DN ≡ EC for the depreciation of natural capital.

The UNSTAT (United Nations Statistical Division) proposals do not envisage replacing the publication of the standard GDP/NDP accounts with the publication of EDP accounts. They do envisage complementing the standard accounts with balance sheets for natural capital, from which users of the accounts could work out EDP. This would leave intact the current conventions for the measurement of GDP and NDP, so that adoption of the proposal would mean that figures on these constructs would continue to be available on a consistent basis with past data. The balance sheets for environmental assets are, therefore, referred to as '**satellite accounts**. The potential for large year-on-year changes in estimates of the depreciation of non-renewable resources is another reason why most of those concerned with the production of national income accounts favour the satellite accounting approach, rather than producing only figures for environmentally adjusted national income. The idea is to publish each year conventional national income accounts accompanied by opening and closing balance sheet accounts for environmental assets.

In principle, the satellite accounts could cover all environmental assets relevant to production and consumption. However, this would require physical data and valuations for all relevant assets (something that is practically difficult even in countries where the official statistical agencies have invested heavily in generating, collating and publishing environmental data). As mentioned in the preceding subsection, the problems are especially acute with respect to valuation data for those assets not subject to market transactions. Even for non-renewable natural resources subject to private property rights, there are quite serious problems about both physical data and valuation for depreciation. The UNSTAT proposals envisage that the range of assets used for the calculation of environmental cost be extended over time, starting with non-renewable resources and renewable resources involving market transactions.

The UNSTAT proposals do not involve treating defensive expenditures as an element of environmental cost for the adjustment of NDP to EDP (even though it involves identifying and separately reporting defensive environmental expenditures in the accounting system). The adduced reasons include the practical difficulty of definitively identifying and measuring such expenditures, and the belief that such subtraction might open the door to questioning the whole basis of measured national income as a welfare indicator. Leaving the natural environment aside, much of the expenditure counted in national income could be regarded as defensive – we eat and incur medical expenses to stay alive, we buy clothes to defend against the weather and social disapproval, and so on.

While many countries have adopted one or more of these accounts to some extent, no country has fully implemented the SEEA recommendations. In a general sense, we can divide the various national accounting measures that have been introduced to either revise or replace the conventional GDP into three broad categories:

(i) Approaches that adjust traditional accounting measures to account for resource depletion and environmental degradation, measured in monetary units. This yields an environmentally-adjusted net domestic product (EDP), which is also generally referred to as 'Green GDP'.[40]

(ii) Approaches that provide an alternative or supplement to traditional accounting measures, but are still measured in monetary units, and

(iii) Approaches that provide an alternative or supplement to traditional accounting measures, measured in one or more non-monetary units.

6.2.3.2 Green GDP Measures[41]

'Green GDP' approaches deduct monetary estimates for resource depletion and environmental degradation associated with economic production from the conventional GDP. One of the earliest attempts estimated the monetary value of the depreciation of three types of natural

[40] A different definition of Green GDP seeks to measure the positive economic value of ecosystem services and public goods that are not included in GDP (see Boyd, 2007). Some researchers also use the term Green GDP to refer more broadly to various other approaches that incorporate environmental factors into national accounting (Erin, Jonathan & Codur, 2019).

[41] This and the following subsections are based on Erin, Jonathan & Codur (2019)

capital in Indonesia from 1971-1984: oil, forests, and soil. Despite only considering three resources, the annual value of natural capital depreciation averaged about 20% of GDP. In contrast, a study in Sweden which included the value of depreciation of soils, recreation values, metal ores, and water quality, based on data from the 1990s, produced estimates of only 1-2 percent of GDP.

The most ambitious attempt at measuring Green GDP was in China in the mid-2000s (the project was sanctioned by Chinese President Hu Jintao in 2004 to foster a "scientific concept of development,") with data collection in 31 provinces and municipalities. Results published in 2006 indicated that national damages from pollution amounted to 3% of GDP. However, these results were clearly on the conservative side, and implied that a more complete assessment might conclude that Green GDP growth rates were actually negative (i.e., that natural capital depreciation was greater than the growth of traditional GDP), at least in some provinces. Due to political pressure from officials in provinces with high pollution, China's Green GDP project was officially cancelled in 2009, but in early 2015 China's Ministry of Environmental Protection announced that it would undertake "Green GDP 2.0," with a new methodology and data collection in several pilot cities starting in 2016. Also, beginning in 2018, India's government plans to undertake a five-year analysis to calculate Green GDP for each state in the nation with the goal of generating an increased understanding of environmental well-being to promote better informed policy making. If successful, this will be the most comprehensive accounting of Green GDP at the national level.

6.2.3.3 Adjusted Net Savings

Adjusted Net Saving (ANS) measure was developed by the World Bank. Like the Green GDP, it starts with a traditional national accounting metric and makes adjustments to account for the environment. The objective of ANS is to "measure the true rate of savings in an economy after taking into account investment in human capital, depletion of natural resources, and damage caused by pollution."[42] A country with a consistently negative rate of ANS would thus be considered on an unsustainable path.

Notice that instead of starting with GDP, ANS starts with a country's rate of gross saving, which essentially equals total income minus all consumption expenditures. It then proceeds to make the necessary deductions (see Figure 6.1). The ANS data include monetary values for the depletion of energy, mineral, and forest resources and also makes provisions for pollution from particulate matter and carbon dioxide.

[42] http://data.worldbank.org/data-catalog/environmental-accounting

A higher value of ANS, measured as a percentage of Gross National Income[43], indicates that a nation is saving more for the future. Notice that an ANS rate may be negative due to excessive manufactured capital depreciation, depletion of resources, or pollution. In other words, a nation's positive investments in manufactured capital can be more than offset by the depletion of its productive resources.

The World Bank has calculated ANS rates for most countries of the world. Table 6.2 shows the results for selected countries in 2016. For most countries, the environmental adjustments are relatively minor. For example, we see that the ANS rates of France and the United States are primarily a result of their respective net national saving rates and education expenditures. But the environmental adjustments can be quite significant in some countries. It is also important to note that the evaluation of carbon damages is controversial; the World Bank uses a relatively low estimate for the damages per ton of carbon emitted to the atmosphere. A higher estimate, advocated by some environmental economists, would lead to a more significant reduction in adjusted net savings.

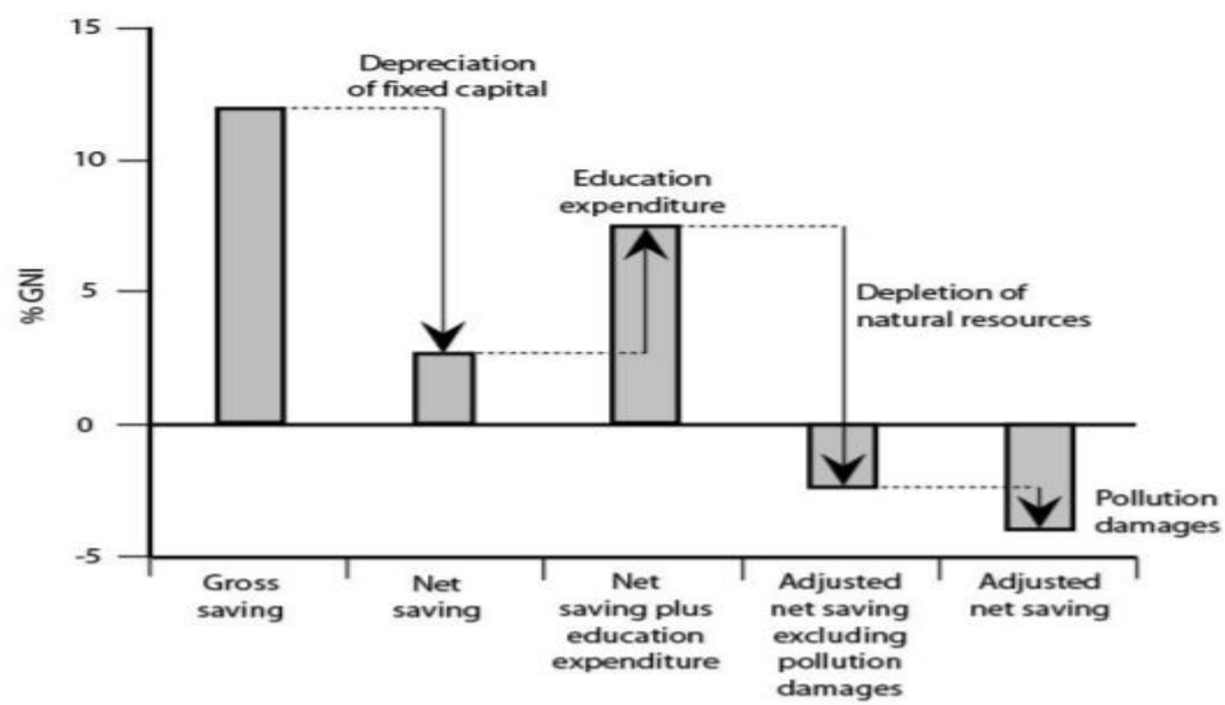


Fig. 6.1. Calculating Adjusted Net Saving. **Source:** Erin, Jonathan & Codur 2019. P.10

43 The ANS is calculated by the World Bank as a percentage of Gross National Income (GNI). GNI is the domestic and foreign output by residents of a country, and is normally relatively similar to GDP (Erin, Jonathan & Codur, 2019).

Table 6.2. Adjusted Net Saving Rates, Selected Countries, Percent of GNI, 2016

Country	Gross National Saving	Fixed Capital Deprec -iation	Education Expendi-ture	Energy Depletion	Mineral Deple-tion	Net Forest Deple-tion	Carbon Damage	Particulate Matter Damage	ANS
Chile	20.8	13.8	4.6	0.0	5.2	0.0	1.1	0.1	5.1
China	46.2	21.3	1.8	0.4	0.3	0.0	3.1	0.4	22.4
Congo, Dem. Rep.	12.6	1.1	2.1	0.3	9.8	13.4	0.5	1.9	-12.4
France	20.3	17.7	4.9	0.0	0.0	0.0	0.4	0.0	7.1
India	30.6	12.5	3.1	0.5	0.2	0.3	3.6	1.0	15.5
Indonesia	33.3	17.0	3.3	0.9	0.4	0.0	1.8	0.5	16.0
Russia	26.1	12.6	3.6	5.6	0.5	0.0	4.0	0.3	6.7
Saudi Arabia	26.8	9.3	7.2	9.2	0.0	0.0	3.1	0.2	12.2
Uganda	20.2	15.4	2.0	0.0	0.0	15.4	0.8	1.4	-10.8
United States	17.8	15.4	4.8	0.1	0.1	0.0	0.9	0.1	6.1

Source: World Bank, World Development Indicators database; Erin, Jonathan & Codur, 2019, p.10.

.Energy depletion is a significant deduction in Russia and Saudi Arabia. Mineral depletion significantly lowers the ANS rates in Chile and the Democratic Republic of Congo. Forest depletion exceeds 10% of GNI in the Democratic Republic of Congo and Uganda (Box 6.1 presents some insights into controversies that may surround accounting for deforestation). Based on traditional saving measures, countries such as Chile and Uganda appear to be investing somewhat heavily in their future. But once we account for the depletion of natural capital, their savings rates are significantly lower. Both the Democratic Republic of Congo and Uganda have positive savings rates according to traditional measures, but negative ANS rates.

BOX 6.1. Deforestation in Indonesia and China

The dollar valuation of natural capital in adjusted net savings accounts is controversial. Ecological values may not be fully taken into account. The World Bank, for example, indicates a "zero" estimate for net forest depletion in Indonesia (Table 6.2). But primary forest loss in Indonesia is a serious problem. According to a recent report, "the large majority of palm oil production occurs in just two countries, Malaysia and Indonesia, where huge swaths of tropical forests and peatlands (carbon-rich swamps) are being cleared to make way for oil palm plantations, releasing carbon into the atmosphere to drive global warming while shrinking habitats for a multitude of endangered species." So how can net forest loss be zero? Since destroyed tropical forest in Indonesia is frequently replaced by oil palm plantations, the land may be counted as still technically under forest cover. But this completely misses the vast ecological damage involved. Similarly, in the case of China, there has been substantial reforestation based on mono-species plantations, in what environmentalists call "green deserts" because they don't provide for the kind of habitat needed for biodiversity. Meanwhile, primary forests are continuing to be depleted in China, which is also evaluated as having zero net forest depletion by the World Bank measure.

Sources: Union of Concerned Scientists, Drivers of Deforestation: Palm Oil https://www.ucsusa.org/globalwarming/stop-deforestation/drivers-of-deforestation-2016-palm-oil#.W-C19XmouUk; Jon Luoma, China's Reforestation Programs: Big Success or Just an Illusion?" Yale Environment 360, https://e360.yale.edu/features/chinas_reforestation_programs_big_success_or_just_an_illusion. Erin, Jonathan & Codur, 2019, p.11.

6.2.3.4 Genuine Progress Indicator

Green GDP and ANS adjust traditional national accounting measures to incorporate natural capital depreciation and environmental damage. But just like GDP, neither of these alternatives purport to measure social welfare. Some other approaches to greening the national accounts start essentially from scratch to create a measure of social welfare. Perhaps the most ambitious attempt to-date to design a replacement to GDP is the Genuine Progress Indicator (GPI) An earlier version of the GPI was called the Index of Sustainable Economic Welfare (ISEW)

The GPI is designed to measure sustainable economic welfare rather than economic activity alone. As noted earlier one critique of GDP is that it includes all economic activity, including defensive expenditures, as a positive contribution to welfare. By this logic, the more pollution damage and resulting cleanup expense a nation experiences, the better off it is. Clearly this is irrational. The GPI differentiates between economic activity that diminishes both natural and social capital and activity that enhances such capital. In particular, if GPI is stable or increasing in a given year the implication is that stocks of natural and social capital on which all goods and services flows depend will be at least as great for the next generation. In contrast, if GPI is falling, it implies that the economic system is eroding those stocks and limiting the next generation's prospects.

Like the previous measures, the GPI is measured in monetary units. The starting point is personal consumption, based on the rationale that it is consumption that directly contributes to current welfare. Next, personal consumption is adjusted to reflect the degree of economic inequality in a society. Then monetary estimates of goods and services that contribute to social well-being are added. These positive factors include:

(i) The value of unpaid household labor
(ii) The external benefits society receives from higher education
(iii) The service value of public infrastructure such as highways
(iv) The value of volunteer work

Finally, the GPI deducts the monetary value of factors that reduce social welfare, including:

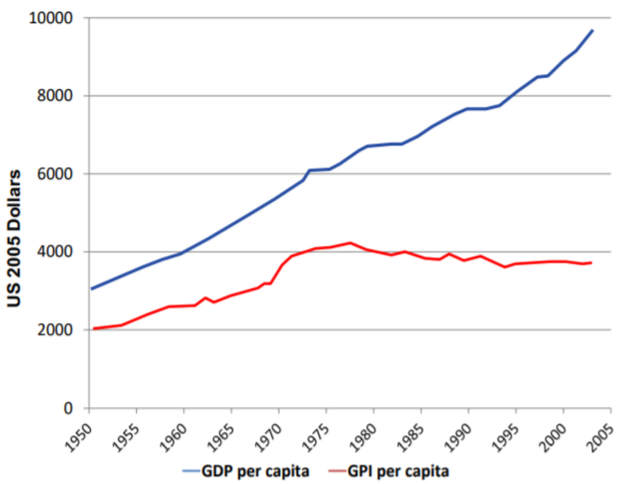
(i) The value of commuting and lost leisure time
(ii) Damages from crime
(iii) Climate change damages
(iv) Damages from air, water, and noise pollution
(v) The depletion of natural resources

The GPI has been estimated for many countries, including Chile, China, Germany, India, Thailand, and the United States. GPI estimates have also been compiled for several sub-national regions, including the U.S. states of Maryland, Hawaii, Colorado, Vermont, and Utah.

As we might expect considering all the adjustments above, the GPI may significantly differ from GDP in terms of magnitude and trends. This point is borne out in Figure 6.2a, which shows the trends in real GDP and real GPI per capita aggregated across 17 countries from the 1950s to the mid-2000s. While both GDP per capita and GPI per capita both approximately doubled in real terms from the 1950s to the 1970s, we see that since then GPI has leveled off while GDP has continued to increase. This led the authors to conclude that "although GDP growth is increasing benefits, they are being outweighed by rising inequality of income and increases in costs." (Kubiszewski et al., 2013, p.66. Also in Jonathan & Codur, 2019, p.12). The same trend is observed for the years 2012-2014 in the most recent version of GPI (termed GPI 2.0) which uses an updated, consistent and precise framework for measuring GPI (Figure 6.2b) (Talberth and Weisdorf, 2017).

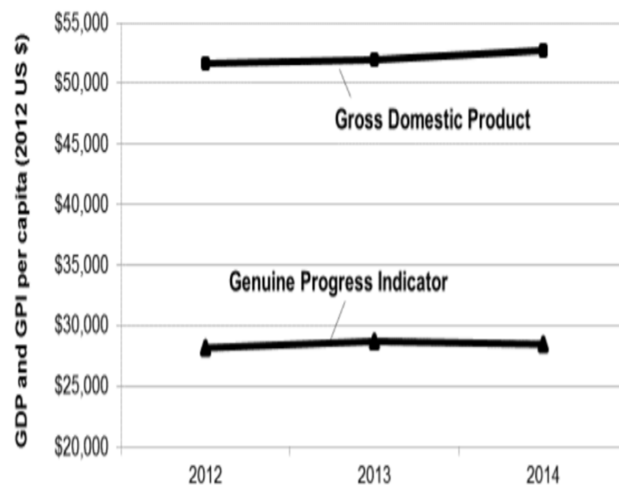
Like Green GDP and ANS, the GPI requires converting various environmental factors into a single metric—dollars. This raises numerous questions about the assumptions necessary to convert everything into dollars. There is also the question of whether disparate environmental resources and natural capital can be directly compared using a common unit. There are other approaches to measuring national well-being that have been developed which avoid the use of a monetary metric. One of this is the Better Life Index, which we consider next.

Fig. 6.2a GDP and GPI per Capita, Aggregate of 17 Countries.



Source: Kubiszewski et al., 2013. Also, in Erin, Jonathan & Codur, 2019, p.13.

Fig. 6.2b GPI vs. GDP per capita 2012-2014



Source: Source: Talberth and Weisdorf, 2017. Also, in Erin, Jonathan & Codur, 2019, p.13.

6.2.3.5 Better Life Index

Recognizing the limitations of GDP and the need to develop indicators that incorporate social and environmental factors, in 2008 French President Nicolas Sarkozy created the Commission on the Measurement of Economic Performance and Social Progress. The Commission included Nobel Prize-winning economists Joseph Stiglitz and Amartya Sen. The Commission's report, published in 2009, concluded that it is necessary to shift from an emphasis on measuring economic production to measuring well-being (Stiglitz, Sen, & Fitoussi, 2009. In Erin, Jonathan & Codur, 2019, p.14). It also distinguished between current well-being and sustainability, recognizing that the sustainability of current well-being depends upon the levels of capital (natural, physical, human, and social) passed on to future generations.

Largely in response to this report, the Organization for Economic Cooperation and Development (OECD) launched the Better Life Initiative in 2011. The most recent revision of the Report (titled "How's Life?") was published in 2017 describes the construction of the Better Life Index (BLI). The report recognizes that well-being is a complex function of numerous variables (similar to the three-pillar approach to sustainability). While material living conditions are important for well-being, so is quality of life and environmental sustainability. Further, the distribution of well-being across a society is important. The report argues that we need "better policies for better lives": Better policies need to be based on sound evidence and a broad focus: Not only on people's income and financial conditions, but also on their health, their competencies, on the quality of the environment, where they live and work, their overall life satisfaction. Not only on the total amount of the goods and services, but also on equality and the conditions of those at the bottom of the ladder. Not only on the conditions "here and now" but also those in other parts of the world and those that are likely to prevail in the future. In summary, we need to focus on well-being and progress.

Specifically, the BLI considers well-being to be a function of 11 dimensions, including income, housing conditions, health status, work-life balance, education, environmental quality, and subjective well-being. For each dimension, one or more statistical indicators provide empirical information about a country's performance on that dimension. For example, in the 2017 "How's Life?" report the environmental quality dimension is measured based on data on two variables: particulate matter concentrations and people's satisfaction with their water quality. The results for each dimension are standardized across countries resulting in a score from 0-10.

While the results for each of the 11 dimensions can remain disaggregated, they can also be combined to produce an overall well-being index. But how do we assign weights to the various dimensions? One basic approach is to simply weigh each of the 11 dimensions equally. But it may be possible that some dimensions contribute more to well-being than others. The BLI reports make no specific recommendations for weighing the different dimensions but it provides a website which allows users to select their own weights for each of the 11 dimensions.

The OECD has been assembling user input data to determine what is most important in different nations. Based on almost 22,000 responses from the United States (as of mid-2018) life satisfaction is ranked the most important dimension, followed by health. Environmental quality and income take the 5th and 7th position respectively. In France the most important dimension is health, in Brazil it is education, and in Australia it is work-life balance.

The BLI has been measured for 38 nations[44] Based on equal weighting of each dimension, Norway, Australia and Denmark are the top three countries. The United States ranks 7th, performing well in terms of housing and income but ranking lower in terms of health, work-life balance, and civic engagement. An equal weighing of each dimension reduces the importance of

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[44] Even for the OECD nations, some results have to be estimated because of a lack of consistent data. Improving the standardization of data collection and reporting is one of the objectives of the Better Life Initiative (Erin, Jonathan & Codur, 2019, p.14).

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income relative to most other national accounting approaches, such as the GPI and Green GDP. As far as the environmental rankings, the best scores are found in Iceland and Norway while pollution is ranked worst, among the countries evaluated, in Russia, Turkey, and Korea (Fig. 6.3). While the main focus of BLI is not on environment and resource issues, its measures of environmental quality could be expanded or given greater weight in future.

6.2.3.6. "Happiness" Indicators

These are indices that directly elicit people's well-being, or happiness, as a means of evaluating a society's progress. In 2012, the United Nations Sustainable Development Solutions Network published the first World Happiness Report, ranking 156 countries by their happiness levels.[45] In 2018 the Nordic countries scored highest in happiness rankings, with Finland coming in first followed by Norway and Denmark; while Syria, Tanzania and Burundi ranked lowest.

The Happy Planet Index (HPI), developed and calculated by the British New Economics Foundation, is perhaps the most novel attempt to devise an entirely new approach to measuring national welfare in the context of environmental sustainability.

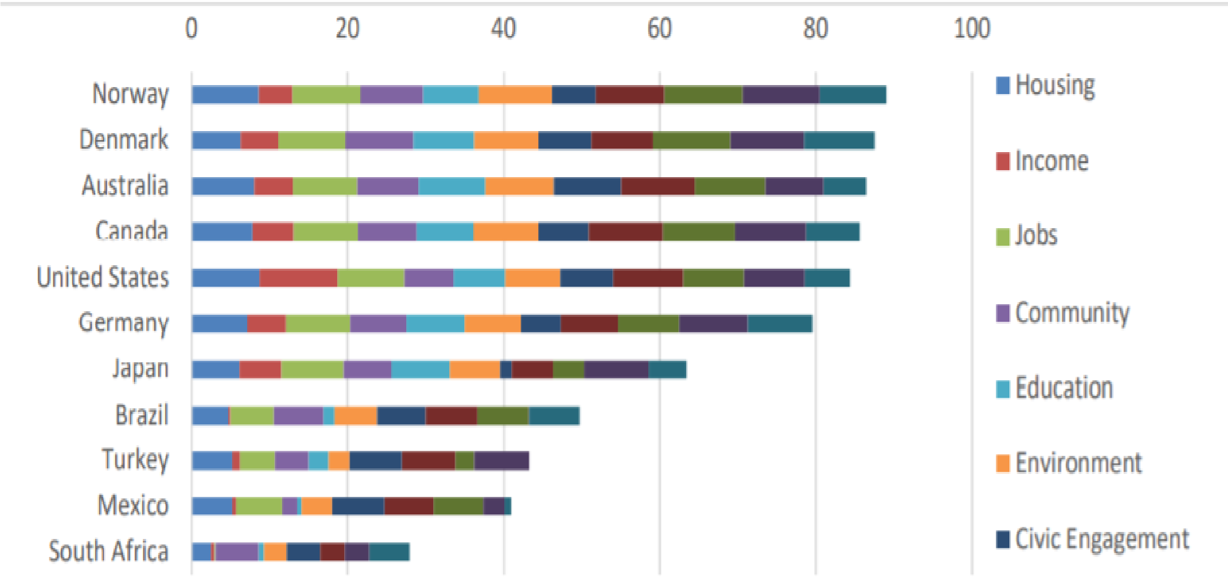

Fig. 6..3 Better Life Index, Selected Countries. **Source:** OECD Better Life Index website, [http://www.oecdbetterlifeindex.org/..](http://www.oecdbetterlifeindex.org/) Also in Erin, Jonathan & Codur, 2019, p.14).

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[45] This report is based primarily on data from the Gallup World Poll, which includes a number of measures of self-reported wellbeing, where individuals state how satisfied they are overall with their lives on a scale of 0 to 10 (Erin, Jonathan & Codur, 2019, p.15).

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The Index is calculated on a national scale based on four factors:

(i) Self-reported wellbeing (based on Gallup World Poll life satisfaction data)
(ii) Life expectancy
(iii) Inequality of outcomes (based on the distribution in each country's life expectancy and wellbeing data)
(iv) Ecological footprint, which is the average impact that each resident of a country places on the environment, calculated in global hectares per person.

The HPI has been calculated for 151 countries, using a combined measure of well-being and life expectancy divided by ecological footprint. The countries with the highest HPI scores are those whose citizens tend to be rather happy and long-lived but have a relatively modest ecological footprint, including Costa Rica, Vietnam, Belize, and Panama. One interesting aspect of the HPI is that a country's ranking tends to be unrelated to its gross domestic product (GDP). For example, the United States ranks 108th, only slightly better than Afghanistan (110th) and Syria (113th).

However, the interpretation and policy implications of the HPI are unclear. For example, India and Iraq have a higher HPI score than Germany or France, suggesting thus that the former countries are more desirable to live in, or more ecologically sustainable, than the latter, which is, of course, not likely. Another issue relates to whether a country's policies can affect happiness levels, which may be more a construction of inherent social and cultural factors rather than policy choices. Despite its limitations, the HPI has received attention as an alternative or supplement to GDP, especially in Europe.

What is considered by some as perhaps the best example of nationwide adoption of an alternative index as a primary well-being indicator over GDP comes from the country of Bhutan. Since 2008, the government of Bhutan has used Gross National Happiness (GNH) to measure their country's success and to inform policy making. This indicator is calculated based on factors including sustainable and equitable socioeconomic development, environmental conservation, preservation and promotion of culture, and good governance. Bhutan, for example, has achieved net neutrality in carbon emissions through hydropower and forest cover, though this status could be threatened by business-as-usual economic development. Other regions of the world including Seattle, Washington, Vermont, and Victoria, British Columbia have adopted measures of GNH modeled on the Bhutan indicator, but these have all been done on a much smaller scale.

6.2.3.7 Environmental Asset Accounts

These are also called natural resource accounts while the process of developing such accounts is called environmental and natural resource accounting (ENRA). These accounts are prepared by first defining various natural capital categories, such as timber resources, mineral resources, agricultural land, and groundwater. The accounts may have different degrees of aggregation. For example, the account for mineral resources might include a separate account for each mineral, or be further disaggregated based on mineral quality, degree of accessibility, or location. The units for each account would vary, based on the physical characteristics of the resource in question. So mineral accounts might be measured in tons, forest accounts in hectares of forest cover or board-feet of timber, groundwater accounts in acre-feet of water, and so on.

Environmental asset accounts can also be expressed in monetary units. In most cases, this simply involves multiplying a physical quantity by the market price per unit. For example, if a society has a standing timber stock of 500,000 board-feet of lumber and the market price is $5.00 per board-foot, then the asset value of their timber is $2.5 million. Environmental asset accounts in monetary terms offer the benefit of comparability, both among different types of natural capital and to traditional economic aggregates such as GDP. But the benefits of many types of natural capital, such as endangered species and nutrient cycling, are difficult to measure in monetary terms. Monetary estimates may also be misleading – if prices for a particular resource rise, the monetary value of that resource could increase even if the physical stock decreases. Thus, policy makers could get the wrong impression about the status of the physical resource.

Several countries have started to maintain environmental asset accounts, including the United Kingdom, Australia, Canada, Denmark, Norway, and Sweden.

6.2.3.8 The Future of Alternative Indicators

While the need for alternative indicators is becoming increasingly evident and accepted, no single preferred approach has emerged. It remains to be seen whether each country will rely upon their own chosen approach, or if one or more indicators will become universally accepted. An important research objective is to develop consistent methods for measuring different variables, such as measuring carbon emissions and administering surveys to collect subjective data. The measurement of a broader range of environmental impacts, such as biodiversity and ecosystem services, also requires further research.

Summary

- National Income Accounting is the process of accounting for goods and services produced, or the income and wealth generated by society over a given period. The System of National Accounts (SNA) developed by the United Nation's during the second half of the twentieth century is the first attempt to provide an accounting framework that could be adopted globally. It produces a variety of measures relating to national income. The most widely used are Gross National Product (GNP) and Gross Domestic Product (GDP).

- Environmentally-driven criticism of current accounting conventions focuses on three areas: depletion of natural resources, environmental degradation and defensive expenditure.

- As regards natural-resource depletion, the widely agreed principle is that stocks of natural resources should be treated in the same way as stocks of human-made capital, so that a deduction should be made to allow for the depletion or consumption. The process of accounting for depletion is more complicated when it comes to some types of renewable resources

- There are two main approaches suggested in relation to accounting for the depletion of natural resources. They are the depreciation approach, and “user cost” approach. Each approach has its strength and limitations but the user cost approach is generally preferred.

- Dealing with environmental degradation in national income accounting relates to making provisions to deduct the monetary cost of depletion in the environmental resource base, such as the effect of pollution etc.

- It is believed that defensive expenditure to avert an environmental damage or ameliorate the effect of such damages should be deducted from conventional national income since they do not constitute an increase in welfare.

- We can divide the various national accounting measures that have been introduced to either revise or replace the conventional GDP into three broad categories: The first consist of approaches that adjust traditional accounting measures to account for resource depletion and environmental degradation, measured in monetary units. This yields an environmentally-adjusted net domestic product (EDP), which is also generally referred to as ‘Green GDP’.

- The second consist of approaches that provide an alternative or supplement to traditional accounting measures, but are still measured in monetary units, such as the World Bank’s Adjusted Net Savings.

- The third category consists of approaches that provide an alternative or supplement to traditional accounting measures, measured in one or more non-monetary units, such as the Genuine Progress Indicator (GPI) and the Happiness Index.

Review Questions

1. What are the limitations of the conventional national income accounting as an indication of true wealth?
2. What are the practical issues involved in accounting for the use of natural resources in national income estimation?
3. Explain the depreciation approach to accounting for the use of depletable natural resources in national income estimation and its limitations.
4. Explain the user cost approach to accounting for the use of depletable natural resources in national income estimation and its limitations.
5. Why is it more difficult to account for the depletion of renewable natural resources?
6. Provide a summary of the progress in developing more realistic measures of sustainable income and wealth.
7. Why is it that under the World Bank's Adjusted Net Savings (ANS) method of assessing national wealth, many of the countries that are rich in natural resources have insignificant and sometimes, negative, adjusted net savings.

Materials used for this Module

Erin Lennox, Jonathan M. Harris, & Anne-Marie Codur (2019) **Macroeconomics and the Environment**, Global Development And Environment Institute, Tufts University. http://ase.tufts.edu/gdae

Perman, R., Ma Y., McGilvray J. and Common M. (2012). Natural Resource and Environmental Economics, 4th Edition, Edinburgh, Longman.

Module 6.3 Applications of Green National Accounts in Africa (2 hours)

6.3.1. Introduction

Sub-Saharan Africa is still heavily dependent on natural resources with natural capital accounting for a huge portion of wealth (World Bank, 2009). The need for environmental and natural resource accounting (ENRA) in the continent is even more pressing. **Available data shows that** In most years, adjusted net saving (ANS) for the region has been negative, and that natural resource depletion has been one of the key drivers (see Figure 6. 4). The situation compares unfavourably with that of East Asia and Pacific, as well as South Asia, for example. Lower natural resource depletion in these regions helps in generating high positive ANS (World Bank. 2018)

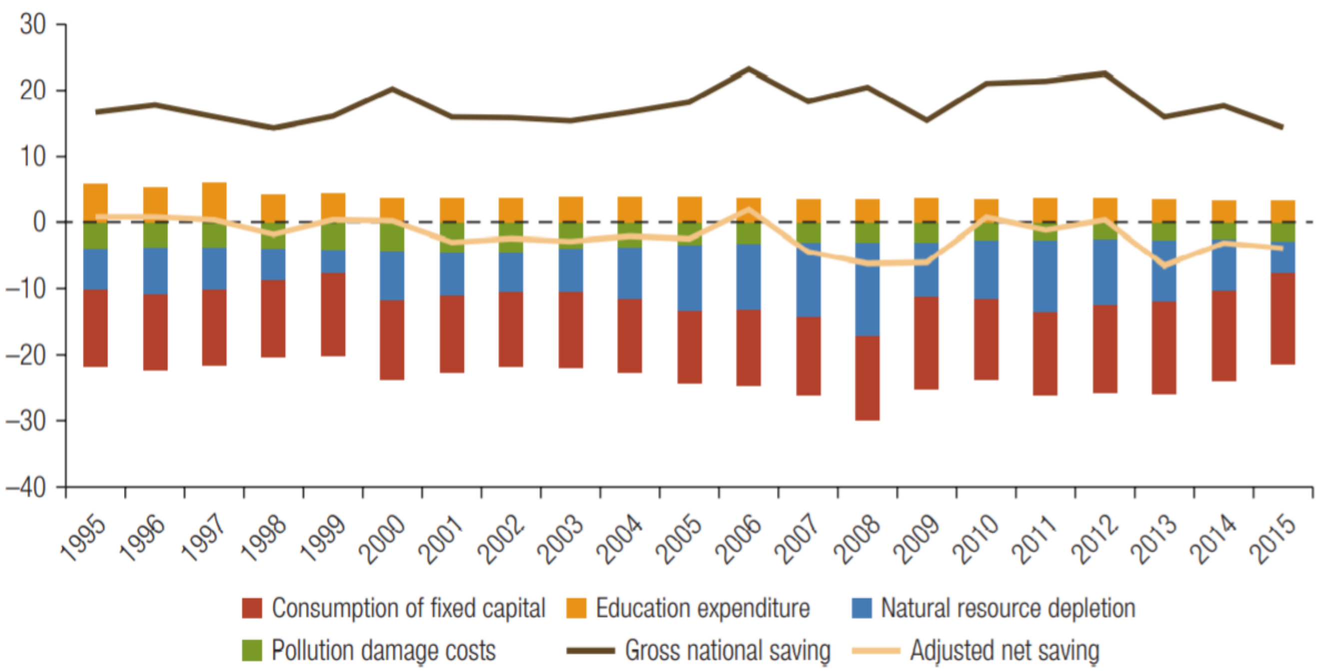

Fig. 6.4 Trends in Adjusted Net Saving for Sub-Saharan Africa, 1995–2015 percentage of gross national income. **Source:** World Bank 2018. p73

Within Sub-Saharan Africa, not all countries fare equally. Table 6.1 provides information on 43 countries classified by resource dependence and fragility. It shows that the proportion of countries falling into the category of higher dissaving is higher among the Continent's resource-rich countries than among non-resource-rich countries.[46]

[46] Countries are considered to have higher dissaving (negative saving) if ANS is less than 8 percent and higher saving if ANS is greater than 8 percent. The threshold of 8 percent is somewhat arbitrary, but conclusions would not fundamentally change with a slightly higher or lower threshold, and using this type of threshold helps illustrate and

Table 6.1. Typology of Countries and Average Adjusted Net Saving, 1990-2015

	Higher dissaving (less than –8%)	Some saving or dissaving (–8% to 8%)		Higher saving (greater than 8%)
Not resource-rich countries	Burundi (–30.3) The Gambia (–11.1) Malawi (–9.7)	Benin (1.4) Burkina Faso (2.1) Comoros (–2.1) Eritrea (4.0) Guinea-Bissau (–7.8) Kenya (–5.7) Lesotho (1.8)	Mauritius (6.9) Rwanda (–0.2) Senegal (3.3) Swaziland (3.8) Uganda (–5.8) South Africa (1.7) Zimbabwe (7.9)	Cabo Verde (18.8) Ethiopia (9.1) Namibia (10.3)
Resource-rich and stable countries	Angola (–67.8) Rep. of Congo (–49.3) Equatorial Guinea (–38.8) Guinea (–8.1)	Cameroon (–1.4) Ghana (0.8) Gabon (–4.3) Mauritania (4.8) Mozambique (0.5)	Niger (–0.8) Nigeria (–2.6) Tanzania (5.7) Zambia (5.3)	Botswana (28.5)
Resource-rich and fragile or conflict countries	Liberia (–8.2) Sierra Leone (–19.0) Sudan (–18.0) Togo (–11.0)	Central African Rep. (3.6) Chad (–3.8)	Madagascar (1.3) Mali (2.7)	Côte d'Ivoire (8.3)

Note: Data are not available for a few countries, including for the Democratic Republic of Congo, São Tomé and Príncipe, Somalia, and South Sudan. For some countries, data are available only for selected years during the period 1990–2015. **Source**: World Bank, 2018, p74

Several industrial countries (including Canada, France, Japan, Norway, and the United States) have developed ENRA tailored to their available resources and policy priorities. (France uses the term "patrimonial accounting" rather than "resource accounting" indicating accounting of the national environmental heritage"). From available records on early efforts in the African continent, only five countries (Angola, Botswana, Namibia, Tanzania and Zimbabwe) have considered or attempted ENRA efforts. Compares unfavorably with other developing nations in Asia (8 countries) and Latin America (17 countries). African ENRA efforts, on the whole, have been quite modest (for a review, see Seve, 2002).

Most country case studies find reduced growth rates over the traditionally calculated rates due to the depletion of natural resources, though consideration of some nonmarketed services of the land use sector and the role of "natural" greenhouse gas sinks, has produced positive net

categorize countries. The middle category includes countries with ANS between −8 percent and 8 percent. This is by no means good performance in comparison with countries in other regions, but it helps identify some of the outliers—the countries with higher saving or dissaving in comparison with the average level of saving for the region (which, again, is low overall).

adjustments for the land use sector in some countries, such as UK, when narrowly defined (Adger and Whitby, 1992). In the next subsection, we review an environmental accounting exercise for Zimbabwe undertaken in the early 1990s

6.3.2. Case Study: ENRA in Zimbabwe[47]

The value of reserves in the mining sector and erosion of the physical agricultural base through soil erosion and deforestation have been important considerations for the sustainability of income generation in the Zimbabwean economy. Inextricably linked to the ownership and control of those resources, especially land, and hence distribution of the income, in the post-colonial period, an issue outside the concerns of macroeconomic analyses and not directly related to estimation of sustainable income indicators.

Mining and quarrying account for 5.5 percent of GDP and agriculture 10.9 percent of GDP in 1987. The mining sector has decreased relative to the size of the economy in the previous 15 years, from 7.6 percent in 1974, and agriculture had also declined, though making a greater contribution to overall exports. The share of agriculture products and raw materials ranged between 53 and 61 percent in the decade up to 1987 (Zimbabwe CSO, 1989b). The value of reserves in the mining sector and erosion of the physical agricultural base through soil erosion and deforestation have been important considerations for the sustainability of income generation in the Zimbabwean economy.

Data requirements for a meaningful analysis of the revisions to aggregate income are large. Macroeconomic indicators do not reflect distributional issues (a thorny issue in post-colonial Zimbabwe) but rely on data formulated to give policy prescriptions at the sectoral level, and hence, must be used with caution. Annual changes in environmental indicators, such as soil erosion and deforestation, are also difficult to assess.

Sustainable Social Net National Product is given by the formula

$$SSNNP = C + KM - CD - K\ N \qquad (6.38)$$

Where C = aggregate consumption

KM = reproducible capital stock

[47] Based on Adger, W. N (1992) *Sustainable National Income and Natural Resource Degradation: Initial Results for Zimbabwe*, GEC Working Paper 92-32, CSERGE, University of East Anglia and University of London.

CD = defensive expenditure or consumption by households and governments

KN = natural capital stock

Adjusted or modified Net National Product (NNP) can be summarized as follows:

$$Modified\ NNP = C + KM - (PE - MCE)KE + (PR - MCR)KR + (PX - MCX)X \quad (6.39)$$

where:

KR = reproducible capital; C = consumption;

PE = price of exhaustible resources; MCE = marginal cost of extraction of exhaustible resources

KE = QE - DE ; QE = extraction; DE = discoveries

PR = price of renewables; MCR = marginal cost of renewable

KR = MAI –QR; MAI = growth of renewables (mean annual increment); QR = harvest

PX = price of pollution; MCX = marginal cost of pollution abatement, X = Stock of pollution

The adjustments are for exhaustible and renewable resources and for changes in the pollution stock, valued at the difference between price and marginal cost of the physical change in quantity. The signs on the adjustments are different, for example between exhaustibles and pollution because where a change in the stock of exhaustibles is negative (extraction > discoveries), and (P-MC) > 0 (positive rent), then this leads to a downward adjustment in NNP. For pollution, however, according to Hartwick (1990, 1991) increases in X, the pollution stock, have (P-MC) < 0. The pollution adjustment is then positive, so that an increase in the stock of pollution leads to a decrease in NNP.

Zimbabwe forestry sector

An energy accounting project in Zimbabwe in the 1980s (Hosier, 1986) concludes that a shortfall is likely to occur between the supply and demand for fuelwood, given the then present population and relative price levels in Zimbabwe, by 2000. The reduction of the total stocks of forests each year is the difference between the mean annual increment (MAI), which is the increase due to the growth of the existing stock, and the harvest.

The estimated aggregate figures are given in Table 6.3 for 1987, showing a reduction in stock change of 2.66 million tonnes of dry weight matter equivalent in the time period. This reduction in the stock of natural capital would not appear in the Net Product of Zimbabwe as traditionally measured, though the consequences of the use of other purchased fuels would appear.

Table 6.3 Stock and changes of Forests in Zimbabwe, 1987

	Million tones
Opening stock	654.49
Mean Annual Increment (MAI)	6.81
Harvest (Q)	-9.47
Closing Stock	651.83
Stock reduction (MAI - Q)	2.66

Source: Adger, 1992; Based on Hosier, 1986.

If this reduction were to be reflected in a modified Net Product figure, by subtracting the depreciation of the physical stock valued at the rental value (following Hartwick, 1990)) then for the forestry sector this would be calculated by:

$$NNP = C + K - (P - MC).(MAI - Q) \qquad (6.40)$$

Where PR = market price for fuelwood; pr = marginal cost of extraction

Market price of fuelwood per tonne in 1987 (PR) was estimated to be ZM$68, taking a weighted average of urban and rural fuelwood prices based on various reported surveys (Hosier, 1988; Du Toit et al., 1984). Imputed cost of extraction of fuelwood per tonne is derived from the estimated time to collect fuelwood in different regions, the shadow price being the minimum agricultural wage:

$$MC\,R = T.W\mathrm{min}/C \qquad (6.41)$$

where T = estimated mean labour input in fuelwood collection per household; Wmin = minimum agricultural wage; C = mean household fuelwood consumption.

Estimates are of average costs of extraction, data on marginal extraction costs were not available. (Other authors, e.g. Repetto et al; 1989 also use the average extraction cost in their estimates for Indonesia for depreciation in the fuelwood sector for lack of marginal estimates). It was envisaged that average extraction costs are rising, hence this estimate understates marginal extraction costs and overstates the value of the physical depreciation of the capital stock.

Resulting estimates suggest that net product should be reduced by the value of the physical depreciation of ZM$ 93.77 million in 1987. If this is borne by the agricultural sector of the Zimbabwean economy, this represents a 9% reduction in the net product of the combined commercial and communal areas agricultural net product as traditionally measured. This forms part of the KN adjustment in Table 6.4 along with the adjustment for soil erosion.

Soil Erosion

Author adopted the productivity loss approach to calculating value though the productivity studies do not cover the range of agricultural activity and give only initial estimates. The replacement cost approach assumes that fertilizers can replicate lost soils which have different nutrient and structure depth profiles; that thresholds occur above which the soil cannot be recuperated; and that net erosion and natural replacement are difficult to estimate. This makes it of limited use (Solórzano et al. 1991). Productivity loss method is closely related to the capital loss as estimated for forest depreciation. The physical resource loss is valued at the real economic costs over time.

Estimates of the aggregate production loss of cotton and maize are taken by taking the sample area's proportions of land use to be typical across natural regions

$$C = A . F . (GMm . Pm + GMc . Pc) \quad (6.41)$$

Where C = cost of soil erosion ($ million)

A = available area for crop production (approx. 15.25 m ha)

F = proportion under threat of erosion (13.2 percent severely threatened (Whitlow, 1988 and Whitlow and Campbell, 1989).

P = proportion under maize (m) and cotton (c) (m = 0.56, c = 0.05)

GM = proportion of difference in gross margin under soil conservation and no soil conservation for maize (m) and cotton (c). (m = $155.5/ha c = $555.8/ha)

The aggregate estimates for the productivity costs of soil erosion in natural regions I and II in Zimbabwe then are $175.3 million in lost maize production and $55.94 million in cotton production, summing to $231.2 million (1990). Author acknowledged this is likely to be an overestimate as attributing the difference in gross margin between areas under soil conservation and not under soil conservation assumes no difference in management techniques and inputs. The areas of greatest threat to soil erosion would also not necessarily be under the same cropping regimes as the sample area, or expect the same yield differences. Analysis can only be taken as an indicator of the methodology to estimate the costs of soil erosion on a basis closer to the standard accounting for depletion of renewable resources (rent on the physical asset depletion) rather than the replacement cost method which does not conform to this concept. The problems of finding an economic cost which is "recreatable" in each accounting period are dependent on a large database of land use and observed erosion rates

Agricultural sector accounts

The degradation of the resource base of soil and forest stock should modify the net product as traditionally measured. The agricultural sector accounts were adjusted in the first instance to reflect the role of that sector as the major location for primary natural resources. The accounts also illustrate difficulties which also occur in national accounts. The communal area account, for example, for lack of data, imputes value to production based on estimates of yields and areas which are not updated each year.

The role of subsistence and informal economic activity tends to be ignored in market-based indicators due to paucity of data. The communal area net product in Table 6.4 is not disaggregated into returns to the factors.

Depreciation of natural capital (KN), then from the estimates of soil erosion (taking the 1990 estimates as 1987 via a GDP deflator) and depletion of the forest stock in 1987 sums to $297 million, over 30 percent of the net product as usually measured.

Note that the Modified Net Product as estimated here would increase under circumstances where policies to conserve forest or soil reserves led to decreased depletion. Similarly, greater resource depletion as a result of distorting agricultural or land use policies would reduce the Modified Net Product measure, but would not be apparent in the traditional measure.

Table 6.4 Modified Net Product for Commercial and Communal Agriculture sector of Zimbabwe, 1987

	ZM$ million (1987)
Output	2024
Input	987
Gross Product	1037
Depreciation KM	-62
Net Product	975
Less Depreciation KN	-297
Modified Net Product	643
of which Labour (commercial sector)	333
Farming Income	372
Communal Sector	332
Depreciation KM	-62
Depreciation KN	-297

Note: Part of KR forms part of farming income but is not reported separately. Communal sector accounts are not broken down into disbursement of net product. **Source:** Zimbabwe Central Statistical Office

Table 6.5 Zimbabwean minerals sector output (gold equivalent), 1991(Q1).

ZM$ m (current)	Traditional NP	% change	Modified NP	% change
1990(Q4)	391.5		313.2	
		+18%		+7.2%
1991(Q1)	462.0		335.7	

Notes: Figures are based on a US$ price of gold of $350 assumed constant across the period; zero changes in reproducible capital stock and zero discoveries; and the average cost of extraction being 0.8*PE over the sector. Estimates presented convert the output from the sector to gold equivalent for simplicity and for lack of data. This then imposes the assumptions that the market prices for zinc, copper and coal acted in the same way over the period, and production reacted at the same rate. **Source:** Adger (1992)..

Mineral resources sector

Similar initial analysis undertaken for the mineral resources sector for Quarter 1 of 1991, shows the effects of external shocks to the sector, and how these are not reflected in the GDP estimates. The devaluation of the Zimbabwe dollar (ZM$) under the macroeconomic adjustment programme initiated in 1990, led to a boom in mineral production. Revenue from the minerals sector rose by 18 percent, mainly due to depreciation of the dollar: the quantity of output rose by 7 percent and, although the US dollar price of gold was steady, revenue rose by 18 percent.

Traditionally calculated Net Product from the sector would show a rise of 18 percent (calculated by output less depreciation of the reproducible capital stock), assuming no change in this stock over the quarter (or a 7 percent rise in real terms). But at the end of the period there are less reserves of gold (and other minerals) so the Net Product of the sector can be recalculated by:

$$NP = C - KM - (PE - MCE).(QE - DE) \quad (6.42)$$

again assuming no change in reproducible capital stock and no discoveries in the period (D =0). (In the long run if the market price rises, we would expect D to be positive).

Results from the minerals sector are given in Table 6.5. The estimates show a revision of the growth in net product from the sector from 18.0 percent to 7.2 percent in nominal terms, when adjustments for the depletion of the reserves are taken. The reduction is not as great when calculated in real terms, being from 7 to 5 percent. Nevertheless, the use of traditionally calculated net product from natural resources sectors overestimates the growth in the macroeconomy when compared to accounting for depletions in the resource base.

So, what have we learnt from the Zimbabwean case study? ENRA is crucial for both developed and developing countries: both could be under false illusion of income growth (industrial countries, mainly through wrongly imputed defensive expenditures; resource-dependent countries through failure to account for depletion and degradation). Despite data and methodological limitations, efforts could provide very useful information.

6.3.3. Some thoughts on what can be done to encourage ENRA in SSA[48]

A properly conducted ENRA effort, i.e., one that will be comprehensive, focus on the *management* function of environmental accounting, lead to policy formulation, and end up as an institutionalized function, will require critical doses of data, analytical capability, staffing, funding, and time. This appears intimidating at first glance! SNA in many African countries are even of poor quality, with sizable informal sectors omitted from the accounts. However, some of the country-experiences suggest that ENRA programs can start as modest efforts focusing on a limited number of priority sectors.

If an ENRA effort is to go beyond the level of a one-time academic study, an initial focus on institutionalization is essential. This implies the endorsement and support of the national government, and the fact that most of the work must be done by country nationals in order to develop a core of capable in-country professionals. More importantly, given the substantial commitment of human and financial resources required, the policy formulation purposes of the effort must be clear, the feasibility of constructing an ENRA system must be assessed, and the policy making users must be identified before proceeding with data collection

"Learning by doing" aspect of building an ENRA effort is also fundamental. A major lesson of experience, particularly from the Philippines, is that the best way of developing accounting techniques is by implementing the accounts. The "learning by doing process" can begin by assembling rather crude data for the construction of initial accounts. This initial exercise will point the way towards those sectors where data refinement will substantially improve the accounting structure (Peskin 1993). The purpose of "learning by doing" should be the training of a critical mass of national professionals capable of undertaking and maintaining ENRA systems without the need for foreign involvement.

Iterative development of the accounts is also a basic consideration. The economies and environmental conditions of several (and probably most) African countries are sufficiently complex that it would be unrealistic to believe that a complete set of accurate environmental and resource accounts could be established in the near term.

Another important consideration has to do with the "home" of an ENRA effort. This is basic to the institution-building dimension. There is the need to overcome the natural tendency to place a project of this type within environmental and resource administrations (departments of government), at least, at the initial stages! These administrations usually focus on sectoral

[48] Based on Seve (2002)

interests that are not always consistent with the comprehensive view provided by the augmented accounts. Additionally, any official government agency may be reluctant to publish accounts derived from crude data, or any data that might suggest problems with past policies. It is best, at least in the initial stages, to place an ENRA project in some non-governmental research institution with close ties to the government (Peskin 1993).

Exposure of government officials to both the process and the results is essential over the long run, if an ENRA project is to have any policy impact. The official institutionalization of an ENRA effort will need close collaboration with (and perhaps control by) a central government administration such as a statistical bureau or a planning agency. This will require training of the officials in such agencies on a "learning by doing basis" under the guidance of project staff in moving towards the final stages of institutionalization.

Finally, successful national-level environmental accounting will require changes to accounting practices at the level of companies

Additional Materials used for this Module

1. Adger, W. N (1992) *Sustainable National Income and Natural Resource Degradation: Initial Results for Zimbabwe*, GEC Working Paper 92-32, CSERGE, University of East Anglia and University of London.
2. World Bank (2018) The Changing Wealth of Nations, Building a Sustainable Future, Washington D.C.: World Bank.

Module 7.1: International Environmental Externalities (3.5 hours)

Learning Outcomes

This Module introduces the reader to the nature of international environmental problems and the complexities associated with solving them. After going through the Module, the reader should

- ✓ understand what international environmental problems are.
- ✓ know what are transnational commons and their characteristics.
- ✓ understand the peculiar challenge associated with addressing international environment problems.
- ✓ understand and be able to apply the basic framework used to analyze solutions to international environmental problems.
- ✓ appreciate why international environmental problems are rarely fully solved.
- ✓ know what options are available towards enhancing the likelihood of getting a cooperative solution to international environmental problems.

Outline

7.1.1. Introduction

7.1.2. Framework for Analyses

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Summary

Review/Discussion Questions and Exercises

7.1.1. Introduction

Recall that natural and environmental resources are often public goods and are also subject to externalities. Consequently, the market system fails to allocate such goods optimally. When all generators and victims of an externality or all individuals affected by a public good reside within a single country, the government can adopt mechanisms to induce or enforce an efficient allocation if it has sufficient information and means to do so. However, many important environmental and natural resources problems concern public goods or external effects where affected individuals live (or are yet to live) in many or all nation states. The goods in this case are transnational commons. *Transnational commons* (TNCs) are resources of the world that do not belong to any individual, organization or nation. Examples include the ozone layer, oceans (international fishing, navigation), the deep ocean floor (with its manganese nodules and polymetallic sulphides), the Antarctica, outer space.

International and global environmental problems associated with transnational commons include global warming, ozone-layer depletion, acid rain and biodiversity loss**.** One property common to these problems is that the level of an environmental cost borne, or benefit received, by citizens of one country does not depend only on that country's actions but also depends on the actions of other countries. This introduces additional complications into the problem of controlling human abuses of the environment and adds an important dimension to environmental analyses. The complication arises from the fact that the world is divided into entities which are 'sovereign nations', each of which could use, or misuse, the TNCs in whatever way it considers advantageous, unless it agrees voluntarily to forgo some or all of these rights. Since no one's nation abstention is enough to protect the TNCs, nothing can be done without an enforceable international agreement. Meanwhile the damages can accumulate and the TNCs deteriorate.

Where environmental impacts spill over national boundaries, there is typically no international organization with the power to induce or enforce a collectively efficient outcome. Whether countries will behave selfishly or not in these circumstances depends on the incentives or disincentives they face. The problem of protecting the transnational commons is considered to be less of a natural scientific problem of understanding the physical and biological processes that disrupts the environment or of developing appropriate protective techniques, than it is a social scientific problem of devising procedures to expedite international cooperation. 'We generally know what should be done (or not done); we do not know how to agree to do it (or not do it)' (Dorfman, 1997; cited in Titenberg and Lewis, 2012).

7.1.2. Framework for Analyses

Game theory provides a theoretical framework to understanding international environmental problems, the potential for cooperation in addressing such problems, and the likely outcomes from cooperation or non-cooperation. Recall that game theory is used to analyze choices where the outcome of a decision by one player depends on the decisions of the other players, and where decisions of others are not known in advance. This is often the case with environmental problems. In the case of international environmental problems, for example, where pollution spills over national boundaries, expenditures by any one country on pollution abatement yields benefits not only to the abating country but to others as well. Similarly, spending on pollution control by one country gives benefits not only to that country but also to other affected countries who did not spend. Thus, the pay-off to doing pollution control (or not doing it) depends not only on one's own choice, but also on the choices of others.

The 'Prisoner's Dilemma' game is the most appropriate game characterization of most environmental problems. In such games there is always a dominant strategy (a most preferred choice, one that yield the highest benefit to the country irrespective of whatever choice the other country or other countries make). Consider two countries, X and Y jointly affected by pollution emanating from their individual activities. Each country must choose whether or not to abate pollution. Abatement by either country benefits both parties so that pollution abatement is a public good. Assume each unit of pollution abatement cost 7 to the abater, but confers benefits of 5 to each country. If both abate, we have two units of pollution abatement and the benefits to each country increases to 10. The pay-offs from the four possible outcomes are indicated in the game matrix in Fig 7.1 where we have assumed that Pollute is the *status quo strategy*.

Y's strategy / X's strategy	Pollute	Abate
Pollute	(0, 0)	(5, -2)
Abate	(-2, 5)	(3, 3)

Fig. 7. 1 Two-player-two-strategy pollution abatement game

7.1.2.1 Non-cooperative solution

It is obvious from the game matrix that in the absence of some form of cooperation to abate, the dominant strategy for each country is to abate. From game theory, whenever the players in a game each has a dominant strategy, the joint dominant strategies of the players constitute the unique equilibrium of the game. Thus, the *non-cooperative (equilibrium) solution* to the game is for both countries not abating pollution.

There are three important characteristics of this outcome that is worthy of note. First, the dominant strategy equilibrium (DSE) is also a Nash equilibrium (NE) because it is the best response of each country to the choice of the other. Thus, there is no incentive for each country to deviate from the outcome because deviation (given that the other country sticks to its choice) will lower the payoff to the deviating country. Second, the outcome is inefficient in the sense that it yields a lower payoff to each country than what each could have gotten if they both abated (a payoff of 3 each rather 0). Third, because neither country chooses to abate pollution, the outcome implies that the state of the environment will be worse than it could be. Thus, the outcome is not only inefficient from the viewpoint of the private actors (the two countries) but also from society's viewpoint.

Two factors account for this outcome. The first is that the game has been played non-cooperatively. The second concerns the pay-offs used. The pay-offs in a game determines the structure of incentives facing the agents and reflect the assumptions made about the costs and benefits of various joint actions that can be taken by the players. In this particular game, the incentives are not conducive to the choice of abatement.

7.1.2.2 Cooperative solution

If we assume that both countries are able to collaborate and make binding agreements about their strategic choices, the resulting outcome would be a cooperative solution (equilibrium) to the game. In this particular case cooperation can lead to the abate-bate outcome thus offering the prospect of greater rewards for both countries, and superior environmental quality. However, this outcome cannot be sustained if actors (the countries in this case) are governed by self-interest. The reason is because the cooperative outcome is not a Nash equilibrium: if one country chooses to abate, then abate is not the best response of the other country. Rather, a country can raise its payoff by polluting given that the other abates. Thus, there is a compelling incentive for each country to cheat (defect or renege on the agreement) if it knows that the other will keep the agreement. Except there is a way to enforce the agreement, this tendency to 'free-ride' on the other's pollution abatement will make the cooperative outcome unstable.

Is it possible to make the agreement binding by introducing some form of punishment (built-in penalty clauses) for defecting? The answer is that there will still be problems. First, defection may still be the compelling choice even in the face of punishment. In other words, the payoff from polluting and receiving punishment may still be higher than the payoff from abating given that the other country abated. This will be the case when the time horizon is finite (when the game is played for a limited time; in this case when the interactions between the countries is going to end at a point in time). The shorter the time horizon, the more unlikely that punishment clauses will deter defection.

Second, sometimes it may not be in a player's best interest to punish the other for defecting on an agreement because doing so may make the punishing party even worse off. In such cases, the threat of punishment, being not credible (the defecting party knows the other party will not carry it out because it is not in her interest to so do) will not be able to deter defection. Sometimes, lack of credibility may arise because the punishment cannot be enforced and the players know it. At other times, cheating may not be easily detectable so that the threat of punishment becomes less potent.

It may be possible for countries to be forced to keep their promises (or pay their fines) if there were a third party who could enforce the agreement. But in a world of sovereign states, no such enforcer exists. So, agreements between nations must be self-enforcing if they are to be sustained. And the only self-enforcing equilibrium here seems to be the non-cooperation outcome. It is for this reason that this type of games goes under the generic name of Prisoner Dilemma. Players acting in an individually rational way end up in a bad state. If they attempt to collaborate, the incentives to cheat on the deal expose each to the risk of finishing up in the worst of all possible states. Thus, mutual defection becomes the inevitable option even though it makes both parties worse off than they would have been if they cooperated.

7.1.2.3 Extension to large number of countries

Most international environmental problems involve several countries, not just two. However, the results from our two-country model generalizes readily to problems involving more than two countries: nations following their self-interest each finish up with worse outcomes (than if all were to cooperate and abate pollution). But the cooperative solution remains unstable. Given an agreement to Abate, any individual country does better by reneging on the agreement and polluting. If all countries are symmetrical, three kinds of outcome are possible. The first is that none abate (*non-cooperation*). The second is that all abate (*full cooperation*), and the third is that some abate but others do not (*partial cooperation*).

7.1.2.4 Non-binary choices

In practice, the relevant decision facing countries in the case of international environmental problems is not in the nature of a binary (all-or-nothing) choice, such as abate or pollute. Even if a country agrees to cooperate, there is often a further choice of what level of abatement to undertake. Thus, in addition to agreeing on cooperation to tackle international environmental problems, countries must decide (often through negotiations) on abatement levels.

Assume that there are N identical countries, indexed by *i = 1, . . ., N*. Each country maximizes some net benefit (or pay-off) function, Π_i such that

$$\Pi_i = B(Z) - C(z_i), \text{ for } i = 1, \ldots, N \qquad (7.1)$$

Where

z_i denote pollution abatement by country *i* so that $Z = \sum_{i=1}^{N} z_i$ is the total abatement of the pollution;

B(Z) is the benefit of abatement to country *i* and is dependent on the total amount of abatement by all countries; and

$C(z_i)$ is the cost of abatement by country *i* and is dependent on its own level of abatement).

Thus, (1) shows the net benefit to a country from abatement.

If each country chooses its level of abatement to maximize its pay-off, independently of, and without regard to the consequences for, other countries (*non-cooperative behaviour*), each will choose z to maximize (7.1) for given levels of z in other countries (conditional on z being fixed in all other countries), the optimal abatement choice for country *i* is

$$\frac{dB(Z)}{dZ}\frac{dZ}{dz_i} = \frac{dC(z_i),}{dz_i} \qquad (7.2)$$

$\frac{dZ}{dz_i}$ = 1 (since all z for all other countries other than *i* is constant). Since all countries are symmetrical, the efficient abatement level will be identical, so that we can write (7.2) as

$$\frac{dB(Z^U)}{dZ} = \frac{dC(Z^U),}{dz} \qquad (7.3)$$

where the superscript U denotes the unilateral (noncooperative) solution.

Intuitively, each country abates up to the point where its own marginal benefit of abatement is equal to its marginal cost of abatement.

If we assume instead that countries cooperate fully on levels of abatement, the *full cooperative behaviour* will consists of the N countries jointly choosing levels of abatement to maximize their collective pay-off. This is equivalent to what would happen if the N countries were unified as a single country that behaved rationally (The joint decision process may also involve negotiations about how the additional benefits from cooperation are to be distributed between the parties). The solution requires that abatement in each country be chosen jointly to maximize the collective pay-off

$$\Pi = NB(Z) - \sum_{i=1}^{N} C(z_i) \qquad (7.4)$$

The necessary conditions for a maximum are

$$N \frac{dB(Z)}{dZ} \frac{dZ}{dz_i} = \frac{dC(z_i),}{dz_i} \text{ for all } i. \qquad (7.5)$$

These can be written as

$$N \frac{dB(Z^C)}{dZ} = \frac{dC(Z^C),}{dz}; \; Z^C = \sum_{i=1}^{N} z^C \qquad (7.6)$$

where the superscript C denotes the full cooperative solution.

This is the usual condition for efficient provision of a public good. In each country, the marginal abatement cost should be equal to the sum of marginal benefits over all recipients of the public good. Figure7. 2 presents a graphical illustration of the analyses. Z denotes pollution abatement. The non-cooperative equilibrium abatement level is Z_N where each country's marginal benefit of abatement (MB_i) and marginal cost of abatement (MC_i) are equal. In contrast, the full cooperation equilibrium abatement level Z_C has each country equating the sum of the marginal benefit of abatement across all countries (MB) with its own marginal cost of abatement. ($Z_C - Z_N$) shows the amount by which the full cooperation abatement level exceeds the non-cooperative abatement level while the shaded triangular area shows the magnitude of the efficiency gain from full cooperation. Both are determined by two factors. The first is the relative slopes of the MB_i and MC_i curves. The second is the number of competing countries, N (which determines the relative slopes of the $MB_i$and MB curves). We can use these factors to draw inferences about the conditions under which international cooperation is likely to deliver large decreases in emissions**.**

The *full cooperative solution* can be described as collectively rational: it is welfare-maximizing for all N countries treated as a single entity. It is the same outcome that would be chosen by some supranational governmental body acting to maximize total net benefits on behalf of the group with sufficient authority to impose its decision.

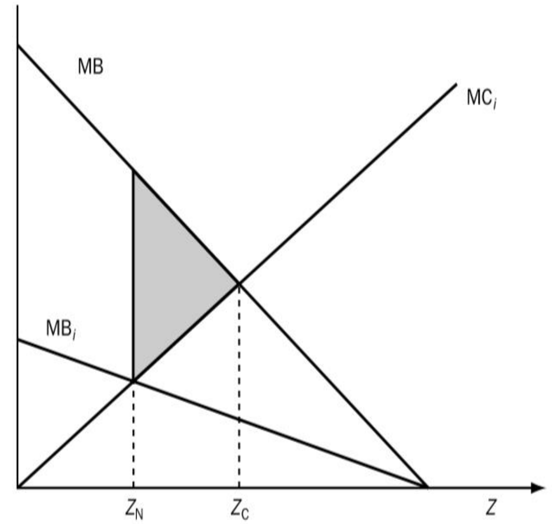


Fig. 7.2. A comparison of the non-cooperative and full cooperative solutions to an international environmental problem involving non-binary choice. **Source**: Perman et al, p.209

7.1.3. Changing Incentive structures

As we saw in Module 4, economists generally believe that the goal of environmental policies should be to alter the incentives agents face in relation to an environmental factor in ways that will make them voluntarily choose socially desirable outcomes. If we can alter the relative costs and benefits of choices available to agents, this will reflect in the associated pay-offs and we may be able to influence choices along desired line. Indeed, there may be ways in which a Prisoner's Dilemma game could be successfully transformed to a type that is conducive to cooperation. Two forms of game that can emerge from such transformation and which are useful in exploring international environmental problems are the *Assurance Game* and the *Chicken Game.*

7.1.3. 1 The 'Chicken Game'

Let us revisit the Prisoner Dilemma game in Figure 7.1. Suppose that all else remains the same but now doing nothing exposes both countries to serious pollution damage instead of leaving them at the status quo. Assume, for example, that continuing to pollute will impose a cost of 4 on each country. The pay-off matrix for the new game is presented in Figure 7.3. The new reality has fundamentally changed the nature of the game. We now have a 'Chicken game'. A 'Chicken game' is a game in which the pay-off matrix can be used to illustrate a potentially fatal confrontation between two players. One player will have to stoop down for the other (chicken out) in order to avoid the confrontation and thus avert the damages that would have occurred to both players. The player that chickens out suffers some loss but less than she would have suffered if the confrontation occurred, while the player that adopted the belligerent posture gains. In this case pollute will be the daring strategy while abate implies a chickening out.

X's strategy \ **Y's strategy**	Pollute	Abate
Pollute	(-4, -4)	**(5, -2)**
Abate	**(-2, 5)**	(3, 3)

Figure 7.3. A two-player Chicken game

Unlike in the Prisoner Dilemma, in the 'Chicken game', neither player has a dominant strategy. There are also two Nash equilibria (the bottom left and top right cells with pay-offs in bold numerals). They show the best response of each player to the other's choices. Assuming noncooperative behaviour, in the absence of a dominant strategy equilibrium, a Nash equilibrium will be played (if one exists). However, in this case there are multiple Nash equilibria and we do not know which of the two will prevail.

How can this indeterminacy be resolved? One possibility arises from commitment or reputation. Suppose that X commits herself to pollute (the daring strategy). If Y considers this commitment to be credible, she will choose to abate (chicken out) because it is in her best interest to get a pay-off of −2 instead of −4. The same outcome will occur if Y knows that X has a reputation of being daring. Another possibility arises if the game is played sequentially rather than simultaneously. This could happen if, for example, some circumstance exists so that country X chooses first. Y then observes X's choice and decides on its own action.

Sequential-move games are best analyzed in *extensive forms* which enables us to account for all possible moves in the game. Figure 7.4 presents an extensive form characterization of the 'chicken game'. Sequential move games are solved using the solution method of backwards induction (a technique whereby players anticipate the solution at the end of the game and use that knowledge to make their choices going forward). Applying this technique to the particular game, In this particular game, X who is the one that makes the first move knows that

- if she chooses *Pollute*, Y will chose *Abate* when it is her turn to move and she (X) will get a payoff of 5
- If she chooses *Abate*, Y will chose *Pollute* when it is her turn to move and she (X) will get a payoff of -2

With this knowledge of how the game will end, in the first move of the game, X will choose *Pollute* rather than *Abate*.

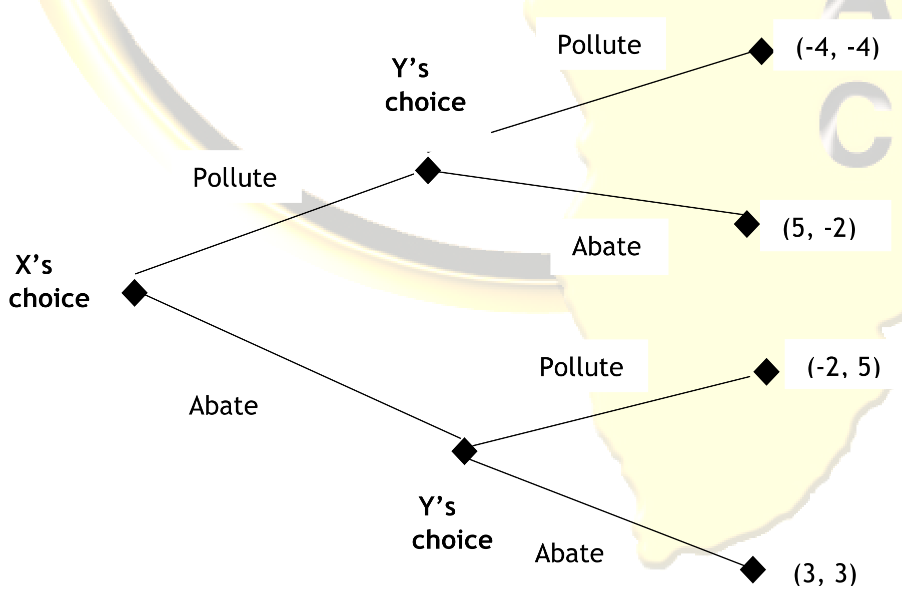


Figure 7.4. Extensive form characterization of the 'Chicken game'

We can interpret a prior commitment to a given action on the path of X or reputation in terms of a first move. That is, the other player (in this case Y) regards X as already having made her choice of strategy through the commitment made or reputation that had been created. In this game, as in many other sequential move games, there is a ‘first-mover advantage’. However, it is not always advantageous for a player to take the first move in a sequential-move game. Depending on the structure of the game, it may be better to let the other player move first and then take advantage of that other player.

7.1.3. 2 Asymmetry in damages

Now consider another possibility. Suppose that there is *asymmetry* in the impact of pollution on the two countries. Assume for example that country Y suffers more from a pollute-pollute strategy than country X (country X suffers a loss of 1 while country Y a loss of 4 for example) while all else remains the same. This will significantly alter the game. The resultant game, illustrated in Figure 7. 5, is no longer a Chicken game. The outcome of the game is also determinate: X now has a dominant strategy of *Pollute*. And given X’s strategy, Y’s best response is to abate. This equilibrium could prevail for some time until X finds it also in her interest to abate. It is believed that the game illustrated in Figure 7.5 captures the global experience in reducing ozone-layer depletion at least for some time (see Box 7.1).

Y’s strategy / **X’s strategy**	Pollute	Abate
	(-1, -4)	**(5, -2)**
Abate	(-2, 5)	(3, 3)

Fig 7.5. A two-player game in which one player has a dominant strategy

We will be looking more closely at international agreement at reducing ozone-layer depletion in Module 7.4. As we shall see also in the Module and in Module 7.2, asymmetry in damages associated with climate change is a major constraint to securing and implementing an effective cooperative solution

Box 7.1. Asymmetric damages and Free-riding in reducing ozone-layer depletion

For a while, some countries (represented as X in Figure 5) expected the USA (represented as Y in figure 5) to reduce ozone-depleting emissions, and were content to free-ride on this. Indeed, the USA did play a major role in leading the way towards reducing their usage of ozone-depleting substances. This was also a strategic choice. Studies carried out by the US Environmental protection Agency (EPA) suggests that the health benefits to the country from ozone depletion exceeded the cost of control. So, the country derived a net benefit from emission control. In addition, chemical businesses in the USA were confident of being able to achieve competitive advantage in the production of substitute products to CFC substances. The USA would be in a very strong position were a CFC ban to be introduced. Thus, overall, the USA perceived that the benefits to her of abatement were high relative to the benefits of not abating. This was not true for all countries, however, and it is this that creates an asymmetry in the pay-off matrix. Those countries which were, initially at least, free-riders had less relative advantage in abating.
Source: Perman et al, p.304

7.1.3.3 Assurance games

Assume a situation where countries are required to contribute to the sustenance of a TNC or the provision of a global public good. Assume also that it is only when the provision reaches a certain level does any benefit flow from the public good. Thus, there is a form of *threshold effect*. Situations like this can arise, for example, in the control of infectious disease, conservation of biodiversity, and the reintroduction of species variety into common-property resource systems. Let us assume that the threshold level for the public good in this case is 2 units and that there are two countries. The cost to each country of contributing is 8. Benefits of 12 accrue to each country only if both countries contribute. If one or neither country contributes there is no benefit to either country. The resulting pay-off matrix is given in Figure 7.6.

X's strategy \ Y's strategy	Do not contribute	Contribute
Do not contribute	**(0, 0)**	(0, -8)
Contribute	(-8, 0)	**(4, 4)**

Fig. 7.6. A two-player game involving contribution to a global (environmental) public good.

Again, as in the 'Chicken game' neither country has a dominant strategy and there are two Nash equilibria (shown in bold in the matrix). If one country chooses not to contribute, the best response of the other is also not to contribute. If the country chooses to contribute, the other country's best response is also to contribute. The best response of each country to the other's choice is to choose what the other chose. In the absence of co-operation, which of the two Nash equilibrium is more likely to occur? The answer is that we cannot know for certain if the game is played once. However, if the game were to be played repeatedly, there is a strong presumption that both countries would contribute. Moreover, the greater is the difference between the payoffs in the two Nash equilibria, the more likely is it that the both-countries-contribute outcome will prevail.

The cooperative solution can also prevail even if the game is played once, if one country can in a way give an assurance to the other of a commitment to contribute. We have seen that this can be represented in a first-move. Indeed, if we convert the game in Figure 7.6 to a sequential-move game, it is easy to see that, unlike in the Chicken game, here the cooperative solution emerges as the equilibrium. In this case, the cooperative equilibrium is stable because it is self-enforcing: if one player cooperates, it is in the interest of the other to also contribute. And once the equilibrium is achieved, neither would wish to renege or renegotiate. Thus, the incentive structure in this case is supportive of cooperation.

Summary

- International and global environmental problems associated with transnational commons include global warming, ozone-layer depletion, acid rain and biodiversity loss**.** One property common to these problems is that the level of an environmental cost borne, or benefit received, by citizens of one country does not depend only on that country's actions but also depends on the actions of other countries.

- Since no one's nation abstention is enough to protect the environmental an natural resources affected by these kind of problems (transnational commons), nothing can be done without an enforceable international agreement.

- But where environmental impacts spill over national boundaries, there is typically no international organization with the power to induce or enforce a collectively agreement for the common good. Whether countries will behave selfishly or not in these circumstances depends on the incentives or disincentives they face.

- Engagements to solve International environmental problems often take the form of 'Prisoner Dilemma' games. Each country would wish to cooperate but knows that doing so places her at a strategic disadvantage and also knows that she could improve her lot by cheating if the other cooperates. Thus, each has a compelling incentive to cheat. This either leaves international environmental problems unsolved or brings them to an even worse state.

- Cooperation offers the prospect of greater rewards for all parties involved and superior environmental quality. However, this outcome cannot be sustained if actors are governed by self-interest.

- The extent of cooperation can be enhanced if there is repeated interaction between nations. This scenario is more realistic because most environmental problems are long-lasting and require that decisions be made repeatedly. However, if the incentive structure facing countries creates a pay-off matrix that is of the Prisoner Dilemma type, repeated interactions will still not lead to the cooperative outcome except when the game is *repeated infinitely* (the environmental challenge is such that lasts forever and countries will always have to relate to it. In other words, interaction is never-ending, or its end point is unknown).

- If interaction among countries with respect to the international environmental problem is lasts 'forever', a suitable punishment strategy will be required to sustain the cooperative outcome given that countries are also concerned about the future (the discount rate is small). However, as the number of countries becomes large, cooperation tends to be more difficult to sustain, even in infinitely repeated game scenarios.

- Where there is a large number of countries affected by an international environmental problem and all countries are symmetrical, three kinds of outcome are possible. The first is that none abate (*non-cooperation*). The second is that all abate (*full cooperation*), and the third is that some abate but others do not (*partial cooperation*).

- In practice, the relevant decision facing countries in the case of international environmental problems is not in the nature of a binary (all-or-nothing) choice, such as abate or pollute. Even if a country agrees to cooperate, there is often a further choice of what level of abatement to undertake. Thus, in addition to agreeing on cooperation to tackle international environmental problems, countries must decide (often through negotiations) on abatement levels

- Transnational commons taking the form of global public good, such as the control of infectious disease, conservation of biodiversity, and the reintroduction of species variety into common-property resource systems, often display a form of *threshold effect,* that is it is only when the provision reaches a certain level does any benefit from it. In this case, it will typically be difficult to secure cooperation. However, there is a strong presumption that countries would cooperate if the problem is long-lasting.

- The cooperative solution can also prevail in a short-lived situation if one (some) country (countries) can in a way give an assurance to the other (others) of a commitment to contribute. Cooperation in this case will be self-enforcing.
- In general, we may be able to achieve a better outcome in solving international environmental problems if we can alter the incentive structure of the game (change private benefit and costs structures) in favour of cooperation. Two of the ways this can be done are the use of commitment, and the creation of reputation. Here also, policy could play a role.

Review/Discussion Questions and Exercises

1. What are transnational commons. What problems are associated with their management. Illustrate using a game theoretic framework.

2. What factors determine the possibility of a cooperative solution to an international environmental problem involving a large number of countries.

3. In what ways can we alter incentives to increase the likelihood of cooperation to solve international environmental problems?

4. Consider the game matrix below which relates to cooperation to end a pandemic.

X's strategy / Y's strategy	Do not contribute	Contribute
Do not contribute	(0, 0)	(-6, 0)
Contribute	(0, -6)	(3, 3)

(a) Identify the Nash equilibrium (equilibria) and comment.
(b) What is likely to be the outcome if the game is played once (the pandemic will soon disappear).
(c) Will the outcome be different if the pandemic is going to be around for 'as long as we can see'? Why or why not?
(d) What will be the outcome if one country knows that the other will always pull out of agreements? Explain
(e) What will be the outcome if one country makes a financial commitment? Explain.

Materials used for this section

1. Perman, R., Ma Y., McGilvray J. and Common M. (2012). Natural Resource and Environmental Economics, 4th Edition, Edinburgh, Longman.
2. Durfman Dorfman, R. (1997), "Protecting the Transnational Commons", for application of the "benefit principle" to multinational bargaining for the protection of global commons.
3. Dasgupta, P. K.-G Maler and A. Vercelli (2000) The Economics of Transnational Commons, Clarendon Press: Oxford.

Module 7.2 Economics of Climate Change (5 hours)

Learning outcomes

Climate change is one of the most topical issue in the world today. This Module examines the economics of climate change. After going through this Module, the reader should

- ✓ be familiar with the concept of climate change and the causes.
- ✓ understand how economic activities contribute to climate change.
- ✓ know the impact of climate change and the socioeconomic burden on societies.
- ✓ know the broad strategies available to address climate change and its impacts.
- ✓ have a basic understanding of climate change assessment models and their uses

Outline

7.2.1 The Science of Climate Change: Introduction and Basic concepts
- 7.2.1.1 The Basic Science of Climate Change
- 7. 2.1.2. Evidence on climate change

7.2.2 Climate change Impacts
- 7.2.2.1 Impacts on natural systems
- 7.2.2.2. Impacts on human systems

7. 2.3. Damage Valuation

7.2.4 Strategies to stabilize greenhouse-gas atmospheric concentrations
- 7.2.4.1. Climate change adaptation
- 7.2.4.2. Climate change mitigation

7.2.5. Integrated (Climate change) Assessment Models (IAMs)
- 7.2.5.1. IAMs and Climate Policy Controversy and debates: Targets and Pathways
- 7.2.5.2 The pathway to two degrees

Summary

Discussion/Review Questions/Exercises

Materials used for the Lecture

7.2.1 The Science of Climate Change: Introduction and Basic concepts

Climate change is used in the scientific literature to refer to *a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer*. It refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC, 2007, p30).[49] Climate science is a rapidly evolving field. Every few years, the body of knowledge in the field is pulled together and published in Intergovernmental Panel on Climate Change (IPCC) Assessment Reports.[50] The latest of these – the Fifth Assessment Report (AR5) – was released in 2014 (See Box 7.2 for an illustration of the activities of the IPCC since inception). Climate change economics provides a bridge between science and policy, translating scientific predictions about physical systems into projections about economic growth and human welfare that decision makers can most readily use. Climate analysis thus requires both economics and science.

The process of predicting future economic impacts from climate change and deciding how best to react to those impacts begins with predictions about the **baseline**, or "**business as usual**," future world economy and the greenhouse gas emissions that it is likely to be releases. Climate scientists build on these economic projections, combining them with records of past climatic changes and the most up-to-date knowledge about the climate system, to predict future atmospheric concentrations of greenhouse gases, temperature increases, and other climatic changes. These projections of our future climate system are used to estimate the type and magnitude of impacts expected in terms of physical and biological processes, such as changes to water availability, sea levels, or ecosystem viability.

7.2.1.1 The Basic Science of Climate Change[51]

[49] This definition differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to *a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time period*s (ibid)

[50] The Intergovernmental Panel on Climate Change (IPCC) is the UN body for assessing the science related to climate change. It was set up in 1988 by the World Meteorological Organization and United Nations Environment Programme to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation.

[51] This section is based on *The Economics of Climate Change: A Prime*r April 2003, The Congress of the United States # Congressional Budget Office, chapter two.

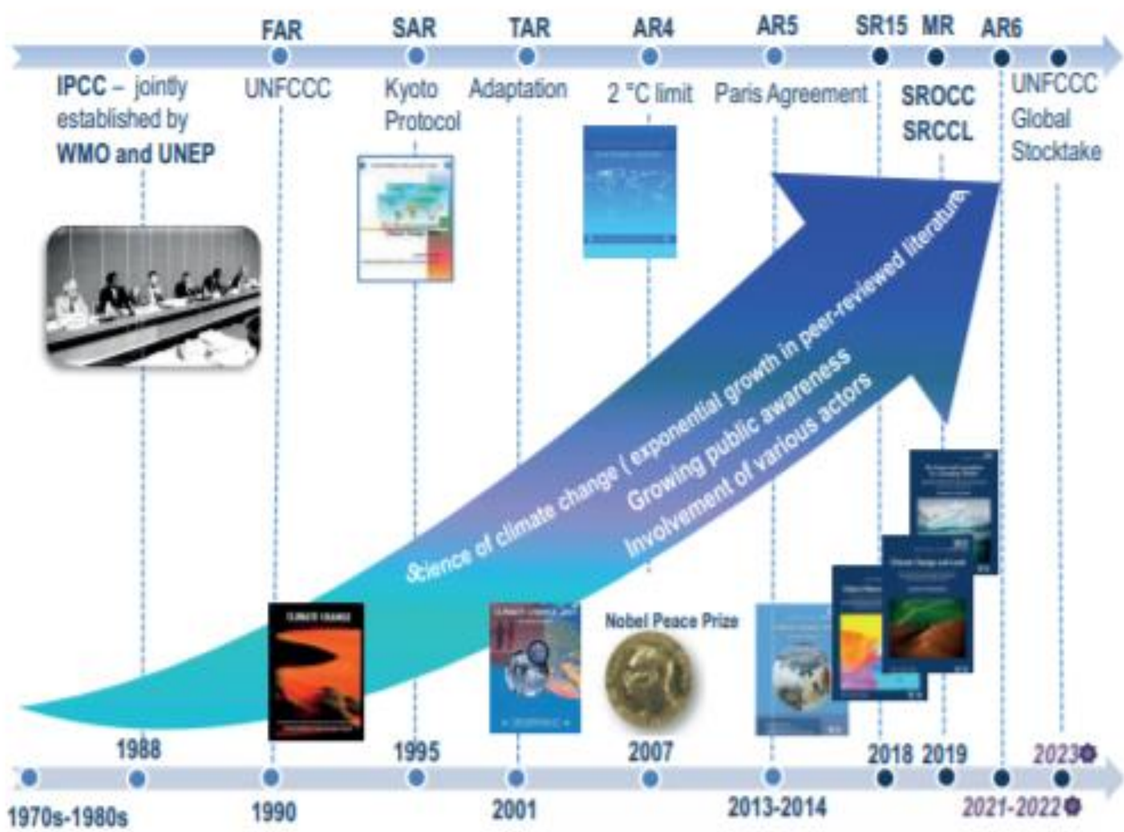
As the Earth absorbs shortwave radiation from the Sun and sends it back into space as longwave radiation, naturally occurring gases in the atmosphere absorb some of the outgoing energy and radiate it back toward the surface. This phenomenon, called the **“greenhouse” effect**, currently warms the Earth’s surface by an average of about 60^oFahrenheit (F), or 33^o Celsius (C), creating the conditions for life as it exists on Earth (see Figure 7.7).

Water vapor is by far the most abundant greenhouse gas (GHG) and accounts for most of the warming effect. However, several other trace gases also play a pivotal role in maintaining the current climate because they not only act as GHGs themselves but also enhance the amount of water vapor in the atmosphere and thus amplify the effect. Those trace gases include carbon dioxide, methane (which also contains carbon), and nitrous oxide, as well as the man-made halocarbons, which contribute to the breakdown of stratospheric ozone. GHGs differ in their ability to trap energy; they interact with each other, and they stay in the atmosphere for different and varying lengths of time.[52]

The link between GHG and climate is greatly complicated by a variety of physical processes that obscure the direction of cause and effect. Variations in the Sun’s brightness and the Earth’s orbit affect the climate by changing the amount of radiation that reaches the Earth. Clouds, dust, sulfates, and other particles from natural and industrial sources affect the way radiation filters in and out of the atmosphere. Snow, ice, vegetation, and soils control the amount of solar radiation that is directly reflected from the Earth’s surface. And the Earth’s vast ocean currents, themselves partly driven by solar radiation, greatly influence climate dynamics. Moreover, the climate system exhibits so-called threshold behavior: just as a minor change in balance can flip a canoe, relatively small changes sometimes can abruptly trigger a shift from one stable global pattern to a noticeably different one (Alley and others, 2003). Fluctuations in those physical processes affect the complex balance among the reservoirs of carbon dioxide and methane in the atmosphere and the larger reservoirs of carbon in the biosphere—which comprises soils, vegetation, and creatures—and in the oceans. Large quantities of carbon flow back and forth between those reservoirs, regulated by the seasons, winds, and ocean currents.

[52]By convention, scientists apply a standard metric to the gases by comparing their 100-year global warming potentials (GWPs: the amount of warming that an incremental quantity of a given gas would cause over the course of a century), with that of carbon dioxide However, in practice, the GWP of each gas is affected by the quantity of other gases, but this approach is used in international negotiations because of its simplicity. GWPs range from 1 for carbon dioxide to many thousands for halocarbons. Using 100-year GWPs, scientists convert quantities of other greenhouse gases to metric tons of carbon equivalent (mtce).

Box 7.2 IPCC s activities since inception



Abbreviations

FAR: First Assessment Report; **SAR:** Second Assessment Report; **TAR:** Third Assessment Report; **AR4:** Fourth Assessment Report; **AR5:** Fifth Assessment Report; **AR6:** Sixth Assessment Report.
UNEP: United Nations Environment Programme; **UNFCCC**: United Nations Framework Convention on Climate Change; **WMO**: World Meteorological Organization; **MR**: Methodology Report. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories,
SR15: Global Warming of 1.5°C, an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.
SRCCL: Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems
SROCC: Special Report on the Ocean and Cryosphere in a Changing Climate.
Source: The IPCC and the Sixth Assessment cycle, http://www.ipcc.ch/.

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The flows maintain a rough equilibrium among the reservoirs, which all gradually adjust to other influences—and to influxes of carbon—over periods of decades to centuries. Other GHGs, such as nitrous oxide, are part of similarly complex cycles.

The geologic record reveals dramatic fluctuations in GHG concentrations and in the Earth's climate, on scales as long as millions of years and as short as just a few years. The record suggests a complicated relationship between GHG concentrations and the Earth's climate. Warmer climates have usually been associated with higher atmospheric concentrations of greenhouse gases and cooler climates with lower concentrations. However, the climate has occasionally been relatively warm while concentrations were relatively low and cool while they were high. Moreover, climate change has occurred without alterations in GHG concentrations. Nevertheless, significant changes in concentrations appear to be nearly always accompanied by changes in climate. Climate change is driven mainly by the atmospheric concentration of GHGs, and by the rate of change of those concentrations through time.

At any point in time, GHG concentrations depend on the levels of emissions at all previous points in time, and on the extent to which sinks have sequestered atmospheric GHGs, or the amounts that have decayed into harmless forms, at all previous points in time. How much global climate change will occur over the next century and beyond is partly predetermined (because of its dependence on previous net emissions), but also depends on future GHG emissions and actions that affect the size of various carbon sinks. Box 7.3 presents definitions/explanations of some of the terms/concepts often used in climate change economics.

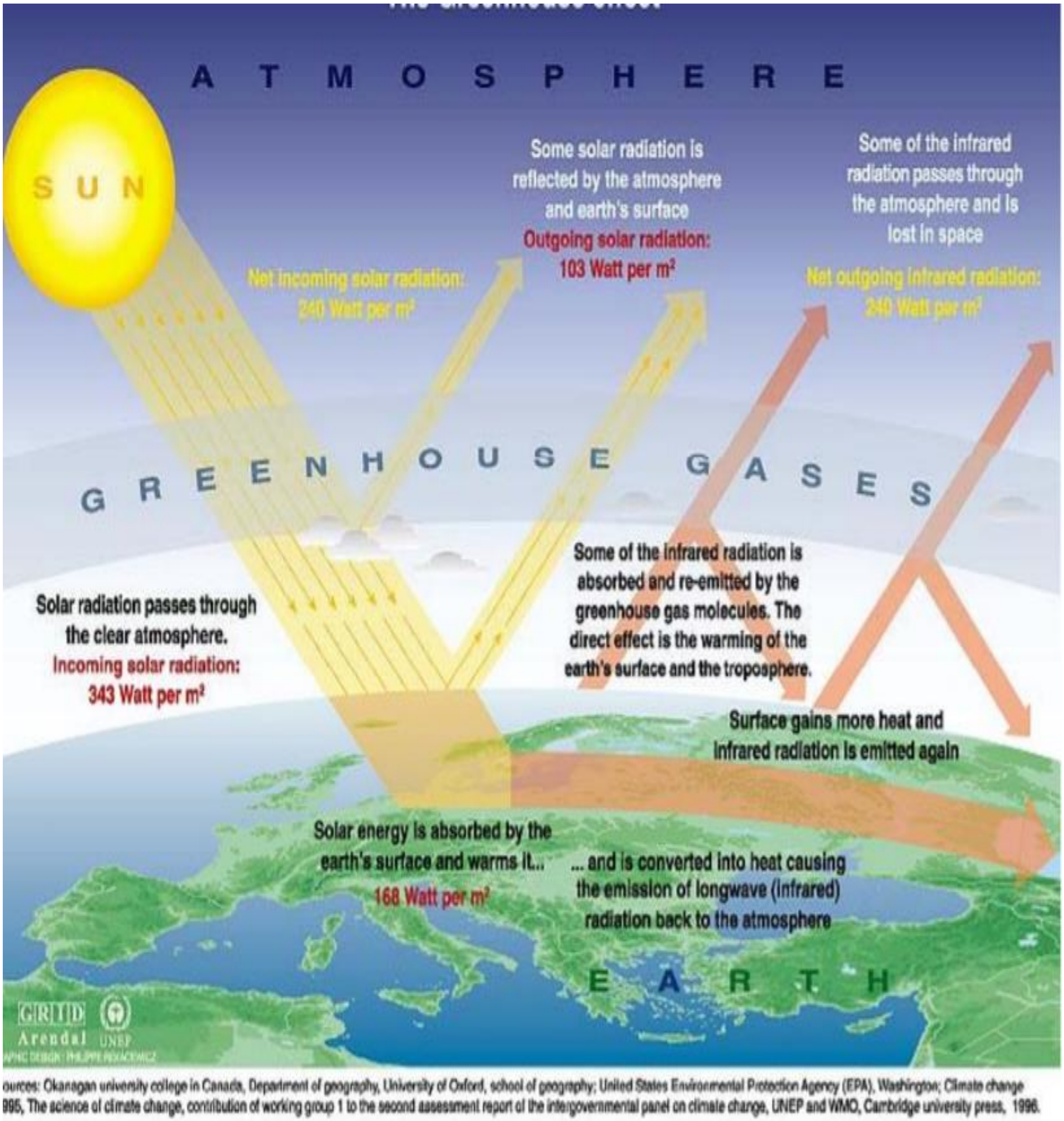

Fig.7.7 Science of Climate change. **Source:** http://www.grida.no/climate/vital/03.htm; Traeger C. (2009) Lecture Slides, Economics of Climate Change, UC Berkeley. Chapter 1

Box 7.3 Some terminologies related to climate change

Global mean surface temperature (GMST): Estimated global average of near-surface air temperatures over land and sea ice, and sea surface temperatures over ice-free ocean regions, with changes normally expressed as departures from a value over a specified reference period.

Detection of climate change: the process of demonstrating that an observed change is significantly different (in a statistical sense) from what can be explained by natural variability.

Attribution: process of linking climate change to anthropogenic causes. Involves statistical analysis and the assessment of multiple lines of evidence to demonstrate that the observed changes are (i) unlikely to be due entirely to natural internal climate variability, (ii) consistent with estimated or modelled responses to the given combination of anthropogenic and natural forcing, and (iii) not consistent with alternative, plausible explanations.

Anthropogenic forcing: changes in climate due to human, rather than natural, factors. Such factors include increased greenhouse gas concentrations associated with fossil fuel burning, sulphate aerosols produced as an industrial by-product, human-induced changes in land surface properties among other things.

Radiative forcing: measure of the influence that a factor has in altering the balance of incoming and outgoing energy in the earth's atmosphere (usually expressed in watts per square metre, wm^{-2}). It is an index of the importance of the factor as a potential climate change mechanism. Positive forcing tends to warm the earth's surface while negative forcing tends to cool it.

Precipitation: any product of the condensation of atmospheric water vapor that falls under gravity. Main forms include drizzle, rain, sleet, snow, and hail

Flows, Stocks and Greenhouse (GH) Effect: there is difference between one unit of a GHG, such as CO_2 emitted (a flow) and one unit in the atmosphere (as a stock). Not every unit of a GHG emitted stays up in the atmosphere (at least not for long). The time up in the atmosphere (half-life) varies for different GHGs.

Global warming potential (GWP): the ratio of the time-integrated radiative forcing from the instantaneous release of a kg of a trace substance relative to that of a kg of a reference gas. It is used to compare different gases with respect to their greenhouse effect contribution.

Box 7.3 contd.

Climate Sensitivity Parameter The temperature increase caused by a doubling of CO_2 concentration with respect to pre-industrial 1750, The IPCC (2007) estimates it to be in the range of [2°C,4.5°C] with a best estimate of 3°C =5.4̊ F.

Climatic change models: models designed to simulate the climate consequences of particular paths of GHG concentrations over time. Researchers using these models are interested not only in global mean temperature changes, but also in their variation across space. This is typically done through the use of *global circulation models* (also called *carbon cycle models*), which simulate atmospheric and oceanic dynamic processes. Global circulation model simulations generate information about what the global mean temperature – and its spatial variation – would be at various points in time if GHG concentrations were to increase along particular paths and stabilize at particular levels.

Carbon dioxide removal (CDR): Anthropogenic activities removing CO2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO2 uptake not directly caused by human activities.

Net zero CO_2 emissions: Net zero carbon dioxide (CO_2) emissions are achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period.

Total carbon budget: Estimated cumulative net global anthropogenic CO_2 emissions from the pre-industrial period to the time that anthropogenic CO_2 emissions reach net zero that would result, at some probability, in limiting global warming to a given level, accounting for the impact of other anthropogenic emissions.

Emission pathways: modelled trajectories of global anthropogenic emissions over the 21st century.

Climate-resilient development pathways (CRDPs): Trajectories that strengthen sustainable development at multiple scales and efforts to eradicate poverty through equitable societal and systems transitions and transformations while reducing the threat of climate change through ambitious

7. 2.1.2. Evidence on climate change

Climate change reflects primarily in changes in global temperature. Global temperatures have risen by more than 1 degree Centigrade since the Industrial Revolution with a sharp upward trend since about 1970 (Fig. 7.8a). Projections of future temperature trends vary across a wide range, but all show temperatures continuing to rise. The lower range projections show global average increase of about 2 degrees Centigrade (3.6 degrees Fahrenheit) above pre-industrial levels by 2100, but high range projections show an increase of as much as 8 degrees Fahrenheit (Figure 7.8b).

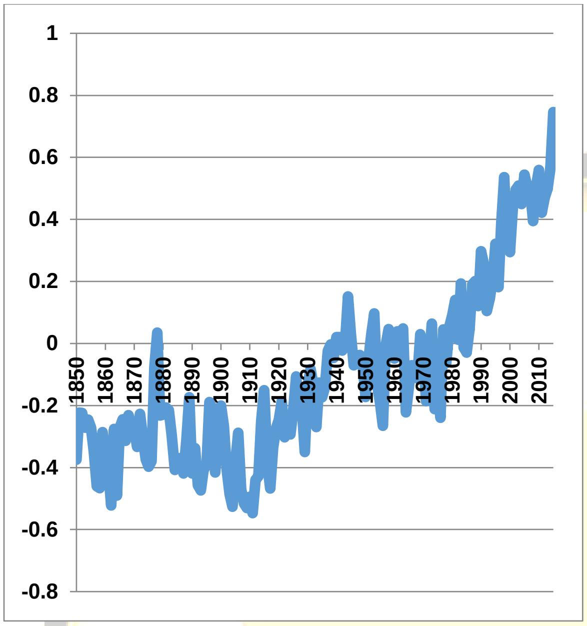

Fig.7.8a Global Annual Temperature Anomalies (°C), 1850–2015

Source: CDIAC, Global Monthly and Annual Temperature Anomalies (degrees C), 1850-2015, relative to the 1961-1990 mean, May 2016. http://cdiac.ornl.gov/ftp/trends/temp/jonescru/global.txt. *Note:* The zero baseline represents the average global temperature from 1961 to 1990. (Also, in Jonathan and Roach, 2017).

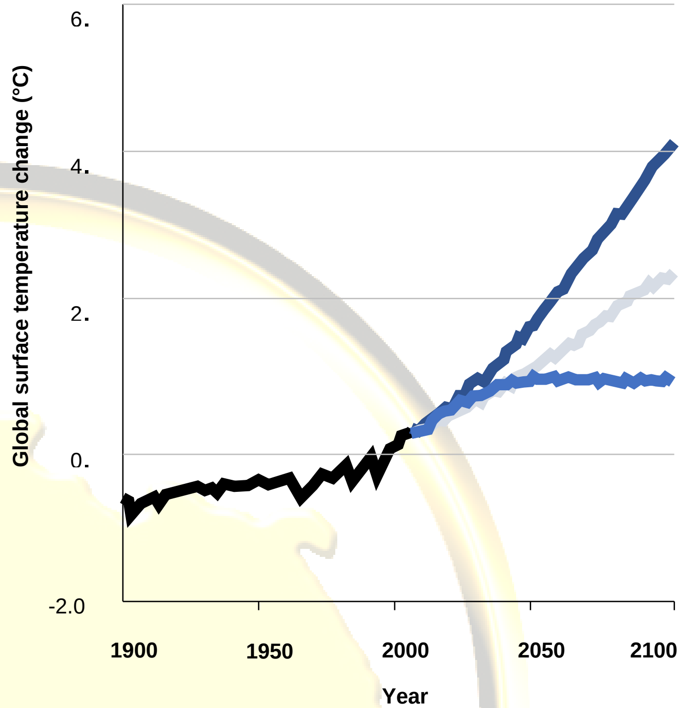

Fig. 7.8b Global Temperature Trends, 1900–2100

Source: IPCC 2014c, Summary for Policymakers, p. 13. (Also, in Jonathan and Roach, 2017).

Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever (IPCC, 2007). This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century. The principal GHG – CO_2 – derives mainly from fossil-fuel use, but an important contribution is also made by deforestation. In addition, agricultural activity and the decomposition and disposal of waste are important emitters of methane. The temperature increase caused by a doubling of CO_2 concentration with respect to pre-industrial 1750 is estimated to be in the range of 2°C - 4.5°C with a best estimate of 3°C =5.4°F (Jonathan and Roach, 2017). Emissions of these gases are increasing over time, changing their mix in the atmosphere. Evidence is mounting that by burning fossil fuels, leveling tropical forests, and injecting more of the other GHGs into the atmosphere, humans are creating a thermal blanket capable of trapping enough heat to raise the temperature of the earth's surface. There are reasons to suggest that the warming process may be moving faster than was anticipated in the IPCC report (Stern, 2008) and that climate change may occur rather more abruptly than previously thought. In October 2018, the IPCC at a meeting in South Korea issued what it called a 'final call to save the world from climate catastrophe' as it believes the world is now heading towards temperature increase of 3°C. In its submission, keeping to the preferred target of 1.5°C above pre-industrial levels will mean 'rapid, far-reaching and unprecedented changes in all aspects of society'.[53]

Box 7. 4 and the associated figures (Figure 7.9 a-d) present some recent trends in relation to GHG emission. Since all nations are emitters and each is affected by the emissions of all others, GHG emissions constitute both a reciprocal spillover problem as well as a global public 'bad' (IPCC 2014).

Box 7.4 Recent trends in GHG emission: Some observations

- Concentrations of CO_2 in the atmosphere have risen steadily, recently crossing the benchmark of 400 parts per million (ppm) atmospheric concentration (Figure 7.9a).
- Carbon emissions from fossil fuels have risen steadily since the Industrial Revolution, with a much more rapid rate of increase after 1950. The rate of increase has accelerated further since 2000, with an especially notable growth in emissions from coal, largely due to increased emissions from China and other rapidly developing countries (Figure 7.9b).
- The increase in CO_2 emissions since 2000 has been almost entirely in the developing world. Developed country emissions rose slightly through about 2006, but have since declined. It is not clear if a recent apparent levelling off in total global emissions (2014-2015) will be sustained. This reflects slower growth in China, as well as expansion in use of renewables and greater energy efficiency (Figure 7.9c).
- China is currently the world's largest CO_2 emitter, with the United States being second. Most of the future growth in carbon emissions is expected to come from rapidly expanding developing countries such as China and India.
- However, current per capita carbon emissions show a huge disparity across nations. U.S. per capita emissions are about twice those of Japan and Germany, while developing nations have much lower emissions per person. Some developing nations, such as China and Mexico, have reached per capita emissions levels similar to those of developed nations such as France. Considering the large populations of developing nations such as India, the potential for increased total emissions from these nations is very great Figure 7.9d).

[53] https://www.bbc.com/news/science-environment-45775309. However, not all (even among economists) share in this view (See "The Skeptical Environmentalist" by Lomborg, 2001. See also www.climate-skeptic.com). Some have suggested that neither the rate nor magnitude of recent warming is exceptional and that the IPCC models may have overestimated the climate sensitivity for greenhouse gases, underestimated natural variability, or both.

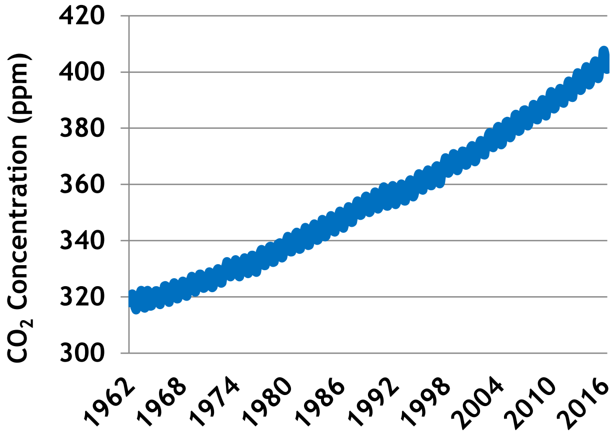

Fig. 7.9a Atmospheric Carbon Dioxide Levels

Source: National Oceanic and Atmospheric Administration, Earth System Research laboratory, Global Monitoring Division http://www.esrl.noaa.gov/gmd/ccgg/trends/data.html. (In Jonathan and Roaches, 2017)

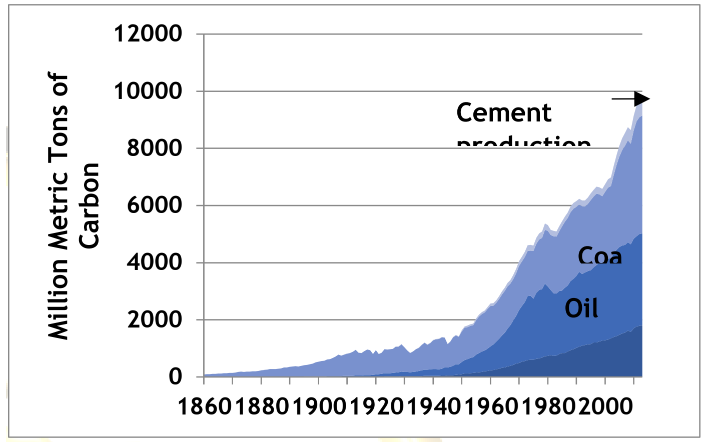

Fig. 7.9b Carbon Emissions from Fossil Fuel

Source*:* Carbon Dioxide Information Analysis Center (CDIAC)
http://cdiac.ornl.gov/ftp/ndp030/global.1751_2013.ems,
Note: Emissions in million tons (MMt) of carbon. To convert to MMt of CO_2, multiply by 3.67. (In Jonathan and Roaches, 2017)

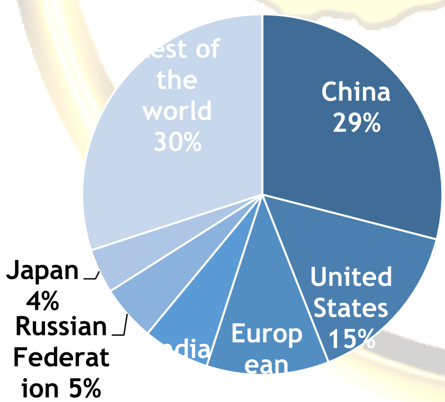

Fig. 7.9c Percentage of Global CO_2 Emissions by Country/Region

Source: Jos G.J. Olivier et al., European Commission's Joint Research Centre, 2014. "Trends in global CO2 emissions: 2014 Report" http://edgar.jrc.ec.europa.eu/news_docs/jrc-2014-trends-in-global-co2-emissions-2014-report-93171.pdf (In Jonathan and Roaches, 2017).

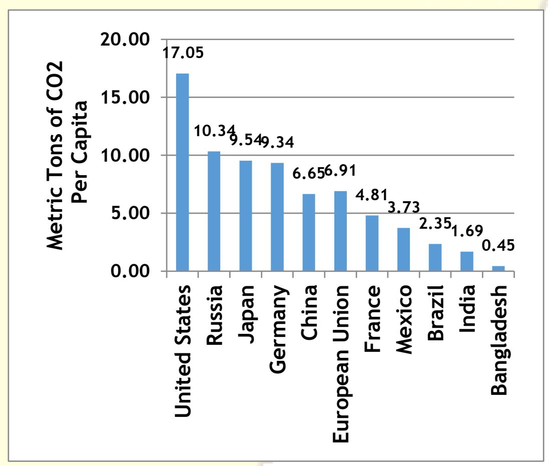

Fig. 7.9d Per-Capita Carbon Dioxide Emissions, by Country

Source: Source: British Petroleum, Energy charting tool 2015. (In Jonathan and Roaches, 2017).

7.2.2 Climate change Impacts

Temperature changes in the higher range could have massive impacts especially in hotter, drier, and coastal areas. According to the IPCC (IPCC, 2007. Working Group II, Chapter 4), a 2 to 3°C warming could put about 20 to 30 percent of plant and animal species at high risk of extinction and cause changes in the structure and functioning of terrestrial and aquatic ecosystems, while warming of 4°C could lead to major extinctions around the world. In this subsection, we examine the impacts of climate change. These include impacts on natural and human systems.

7.2.2.1 Impacts on natural systems

Impact of climate change on natural systems includes impacts on forestry and fisheries.

(a) Forests

Vast amounts of carbon are stored in forests, both in vegetation and in the soil. Changes in this carbon reservoir are of great importance for climate dynamics. Moreover, forests have other important interactions with the earth's climate. There is a complex cyclical pattern of feedbacks: climate change affects forests, and forests affect climate change, and there are positive and negative effects in both directions.

Positive effects of climate change on forests include potential for higher growth due to carbon fertilization (process whereby an increase in atmospheric CO_2 causes acceleration of plant growth and of the resulting removal of carbon from the atmosphere) and longer growing seasons at high latitudes or elevations. Negative effects of climate change on forests include a likely increased risk of forest fire (IPCC 2007, Working Group II). This effect however varies across regions. Others include death of tress due to increased vulnerability to disease; increased survival of pests; decreased moisture availability leading to desiccation; and physiological temperature stress that induces mortality and/or makes other species more competitive, forcing out the weaker species (Kliejunas et al. 2009). There is also the potential for catastrophic collapse in tropical forests, resulting from deforestation and climate-related changes in temperature and precipitation. For example, it is believed that the Amazon rainforest (the most important forest reserve in the world), may be approaching a threshold beyond which an irreversible dieback will be set in motion (Brovkin et al. 2009).[54]

[54] Studies suggest that only large-scale intervention to control deforestation and wildfire can prevent the Amazon from passing a tipping point for its demise and that the dieback could occur during the 21st century (Malhi et al. 2008; Malhi et al. 2009).

While climate change has multiple positive and negative effects on forests, there are complex effects of forests on climate change. The net impact differs by region (Bonan 2008). Positive effects of forests that reduce the impact of climate change include *sequestration of carbon*, which lowers atmospheric CO_2 concentrations; and *evaporative cooling*, which lowers temperatures. Forest carbon sequestration, particularly in tropical countries, is often identified as one of the lowest-cost options for reducing net global emissions. On the other hand, forests have lower albedo (they are darker and therefore absorb more solar radiation) than do alternative land uses, which tends to increase radiative forcing and raise temperatures.[55]

(b) Fisheries

Global fisheries are both an important economic sector and a key source of nutrition. Climate change is expected to have profound effects on marine ecosystems, driving many species of coral to extinction, decreasing crustacean and mollusk populations, and causing large-scale disturbances to the distribution of numerous commercial fish species. The two main pathways for climatic disruption of marine biological systems are *ocean warming* and *ocean acidification*.

(i) Ocean warming

Ocean temperatures have increased along with atmospheric temperatures. Ocean warming shifts the distribution of many ocean species poleward, including fish species of utmost importance to commercial fisheries. It also leads to expansion of ocean water volume and, together with melting icecaps, causes sea-level rise (Figure 7.10).

[55] Carbon lost from Amazon vegetation and soil has the potential to cause significant climate feedback effects; a 2005 Amazon drought has been estimated to have caused the loss of 1.6 Gt C in that single year (Phillips et al. 2009).

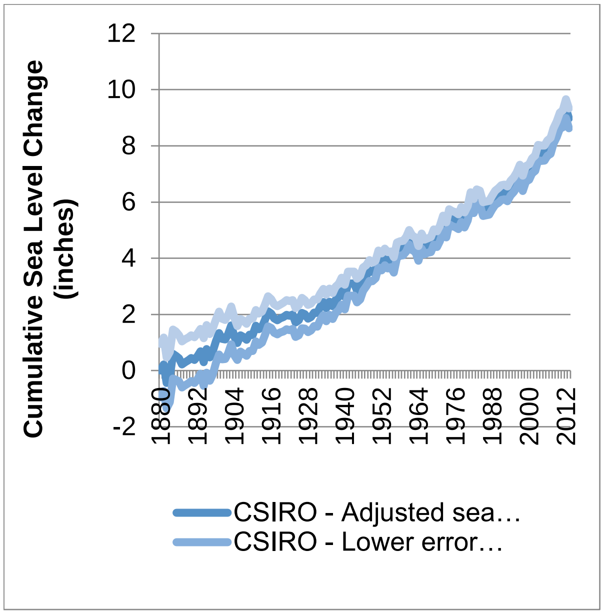

Fig. 7.10. Sea-Level Rise, 1880–2012. *Source:* IPCC, 2014a. Also, in Jonathan and Roaches, 2017.

At the higher ranges of projected temperature increases, sea-level rise could be several meters, swamping major coastal cities and low-lying regions of the earth.

(ii) Ocean acidification:

GHG emissions cause ocean ecosystems (marine waters) to absorb CO_2 at a higher rate, causing ocean pH to fall. At lower pH levels, concentrations of calcium carbonate decrease, and as a result, calcifying organisms such as coral, mollusks, and crustaceans may have difficulty forming their shells and skeletons, causing populations to decline. Lower ocean pH levels and undersaturation of calcium carbonate have the potential to affect a wide range of commercially important species. IPCC scenarios imply that by 2050, global mean surface pH is likely to be lower than at any time in the last 24 million years (Turley et al. 2010).

7.2.2.2. Impacts on human systems

As temperatures and sea levels rise and precipitation patterns change, human systems are expected to suffer damages. Agriculture, coastal settlements, and human health are expected to experience the most direct impacts from climate change. In the coolest regions, agriculture output may show modest gains from the first few degrees of climate change, but in most temperate and almost all tropical regions, changes to temperature and precipitation are expected to lower yields in the coming century.

Low-lying coastal settlements are extremely vulnerable to rising sea levels, from both permanent inundation and greater storm damage. With nearly two-fifths of the world population living in coastal zones, flooding from sea-level rise and storm surges has the potential to prompt large-scale migration of human populations, together with political instability, and could cause devastating losses of homes, businesses, infrastructure, and coastal shallow-water ecosystems. Some estimates suggest that 150 - 200 million people may become permanently displaced by the middle of the century due to rising sea levels, more frequent floods, and more intense droughts.

Damage to infrastructure from storms will increase substantially from only small increases in event intensity while changes in soil conditions (from droughts or permafrost melting) will influence the stability of buildings.

Human health is affected not just by high temperatures but also by climate-induced changes in disease vectors and by decreasing water availability, which is expected to have the biggest impact on already-dry regions. Likely impacts on human health from climate change include increased incidence of malnutrition; increased incidence of disease, injury, and death from heat waves, floods, storms, fires, and droughts; and changes in the range of some infectious diseases, including malaria (IPCC 2007, Working Group II, Chapter 8). The increasing incidence of asthma and other diseases triggered by airborne allergens is thought by some researchers to be related to climate change (Haines et al. 2010; Markandya et al. 2009; Tagaris et al. 2009). Some evidence suggests that 88 percent of the current disease burden from climate change falls on children, compared to the overall pediatric burden of disease (Sheffield and Landrigan 2011; Tillett 2011; Bernstein and Myers 2011).

Table 7.1 presents the potential impact of climate change for various projected levels of temperature increase.

Table 7.1: Possible Effects of Climate Change

	Eventual Temperature Rise Relative to Pre-Industrial Temperatures				
Type of Impact	**1°C**	**2°C**	**3°C**	**4°C**	**5°C**
Freshwater Supplies	Small glaciers in the Andes disappear, threatening water supplies for 50 million people	Potential water supply decrease of 20–30% in some regions (Southern Africa and Mediterranean)	Serious droughts in southern Europe every 10 years 1–4 billion more people suffer water shortages	Potential water supply decrease of 30–50% in southern Africa and Mediterranean	Large glaciers in Himalayas possibly disappear, affecting ¼ of China's population
Food and Agriculture	Modest increase in yields in temperate regions	Declines in crop yields in tropical regions (5–10% in Africa)	150–550 million more people at risk of hunger Yields likely to peak at higher latitudes	Yields decline by 15–35% in Africa Some entire regions out of agricultural production	Increase in ocean acidity possibly reduces fish stocks

Human Health	At least 300,000 die each year from climate–related diseases Reduction in winter mortality in high latitudes	40–60 million more exposed to malaria in Africa	1–3 million more potentially people die annually from malnutrition	Up to 80 million more people exposed to malaria in Africa	Further disease increase and substantial burdens on health care services
Coastal Areas	Increased damage from coastal flooding	Up to 10 million more people exposed to coastal flooding	Up to 170 million more people exposed to coastal flooding	Up to 300 million more people exposed to coastal flooding	Sea-level rise threatens major cities such as New York, Tokyo, and London
Ecosystems	At least 10% of land species facing extinction Increased wildfire risk	15–40% of species potentially face extinction	20–50% of species potentially face extinction Possible onset of collapse of Amazon forest	Loss of half of Arctic tundra Widespread loss of coral reefs	Significant extinctions across the globe

Sources: IPCC, 2007b; Stern, 2007.Also in Jonathan and Roaches, 2017.

7. 2.3. Damage Valuation

There have been attempts to put monetary values to the effect (costs and benefits) of climate change, or equivalently on the costs and benefits of control measures to reduce climate change, so as to guide policy-making. This requires use of appropriate valuation methods (see Module 6). While this approach has generated controversies, it is generally believed that impacts may well be very large and will bear down unequally between countries in a world in which the wealth distribution is extremely skewed. As far as the regional distribution of damages arising from climate change is concerned, the current consensus view is that there will be few, if any, 'big winners' but there will almost certainly be some very large losers. (See Nordhaus, 1990a; Hansen, 1990, Nordhaus and Boyer, 1999). On average, damage is expected to be inversely related to per capita income. Furthermore, those economies with the greatest incentive to cut emissions (or otherwise limit climate change) tend to have the poorest resource base to implement policies that adapt to climate change and minimize the most serious forms of damage.

Table 7.2 shows estimated GDP gains or losses arising from a rise in global mean temperature of 2.5 °C by the year 2100. Higher ranges of temperature change lead to dramatically increased damage estimates at the global level. Different models yield different estimates for future damages, ranging from 2 percent to 10 percent or more of global GDP per year, depending on the global mean temperature rise (see also Figure 7.11). In general, the evidence suggest that the most severe impacts of climate change will occur in developing countries. The number of people suffering loss of water resources, as well as coastal flood victims and population at risk of hunger by 2080 will be relatively larger in Africa, South America, and Asia, where most developing countries are located (Table 7.3).

Table 7.2 Estimated GDP gains or losses arising from a rise in global mean temperature of 2.5 °C by the year 2100

Country/Region	Net output gain/loss	Comments
Russia	+0.65	Significant agricultural benefits Gains from non-market time use
Eastern Europe	−0.71	
USA	−0.45	Temperate climate Low dependence on agriculture Advanced health system Positive amenity of warmer climate
China	−0.22	
Japan	−0.50	
Middle-income	−2.44	
High-income OPEC	−1.95	
Lower-middle-income	−1.81	Potential of catastrophic climate change due to shifts in ocean currents Significant coastal and agricultural impacts
OECD Europe	−2.83	Canada: Significant agricultural benefits Gains from non-market time use Potential for adverse health impacts
Other high-income	+0.39	Extreme vulnerability to climate change due to importance of monsoons on agriculture

Africa	−3.91	Disamenity of higher temperatures on non-market time
India	−4.93	Potential for adverse health impacts
Other low-income	−2.64	
Global average	−1.50 (output-weighted) −1.88 (population-weighted)	

Source: Adapted from Nordhaus and Boyer (1999). Also, in Perman et al., 2003.p 330.

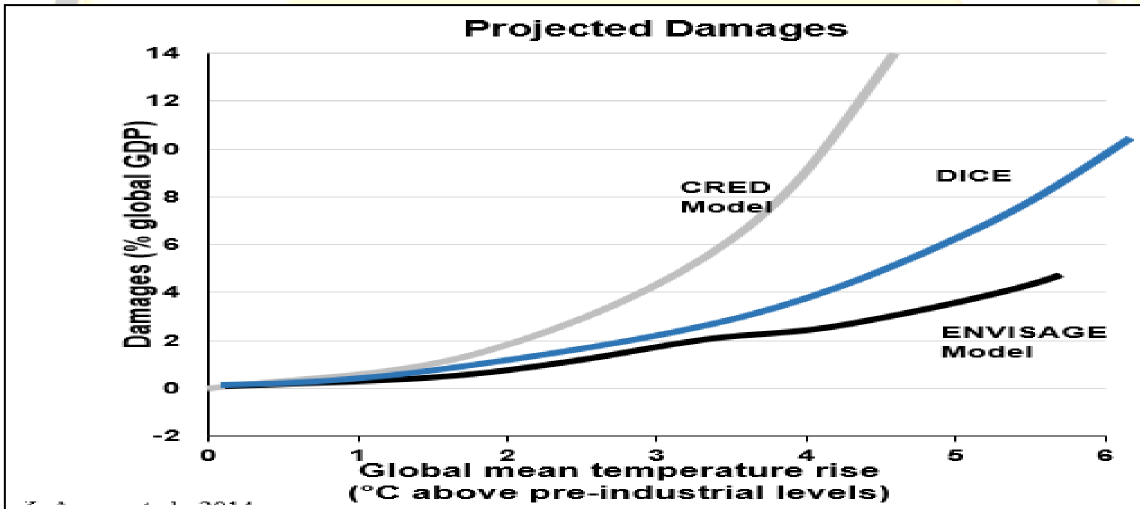

Fig. 7.11. Increasing Damages from Rising Global Temperatures. *Source*: R. Revesz, K. Arrow et al., 2014. http://www.nature.com/news/global-warming-improve-economic-models-of-climate-change-1.14991. Also, in Jonathan and Roach, 2017.
Note: The three different models (ENVISAGE, DICE, and CRED) shown in this figure give damage estimates that are similar at low to moderate levels of temperature change, but diverge at higher levels, reflecting different assumptions used in modeling.

Table 7.3 Regional-Scale Impacts of Climate Change by 2080 (millions of people)

Region	Population living in watersheds with an increase in water-resources stress	Increase in average annual number of coastal flood victims	Additional population at risk of hunger (figures in parentheses assume maximum CO_2 enrichment effect)

Europe	382–493	0.3	0
Asia	892–1197	14.7	266 (–21)
North America	110–145	0.1	0
South America	430–469	0.4	85 (–4)
Africa	691–909	12.8	200(-2)

Source*:* Adapted from IPCC, 2007b. Also in Jonathan and Roach, 2017. *Note:* These estimates are based on a business-as-usual scenario (IPCC A2 scenario). The CO_2 enrichment effect is increased plant productivity, which at maximum estimates could actually decrease the number at risk of hunger. (The figures in parentheses showing decline in risk of hunger are outlying estimates based on increased crop yields due to higher CO_2 levels; most projections indicate declines in crop yields especially in tropical and sub-tropical areas.)

7.2.4 Strategies to stabilize greenhouse-gas atmospheric concentrations

The Intergovernmental Panel on Climate Change (IPCC) has called for stabilization of atmospheric CO_2 at levels no greater than 430 – 580 parts per million (current levels are over 400 ppm). To achieve the lower target, global emissions would have to decline sharply starting around 2020 (Figure 7.12). Even the less ambitious target of 530-580 ppm requires an immediate slowing in the rate of increase of emissions, with rapid decline starting by 2050. We will be taking an introductory look at climate targeting and the underlying modelling and issues in the next subsection. In this section, our focus is on strategies by which set climate targets can be pursued. They include

- climate adaptation strategies and
- climate mitigation strategies.

According to the IPCC (2014), future climate-related risks would be reduced by the upscaling and acceleration of far-reaching, multilevel and cross-sectoral climate mitigation and by both incremental and transformational adaptation.

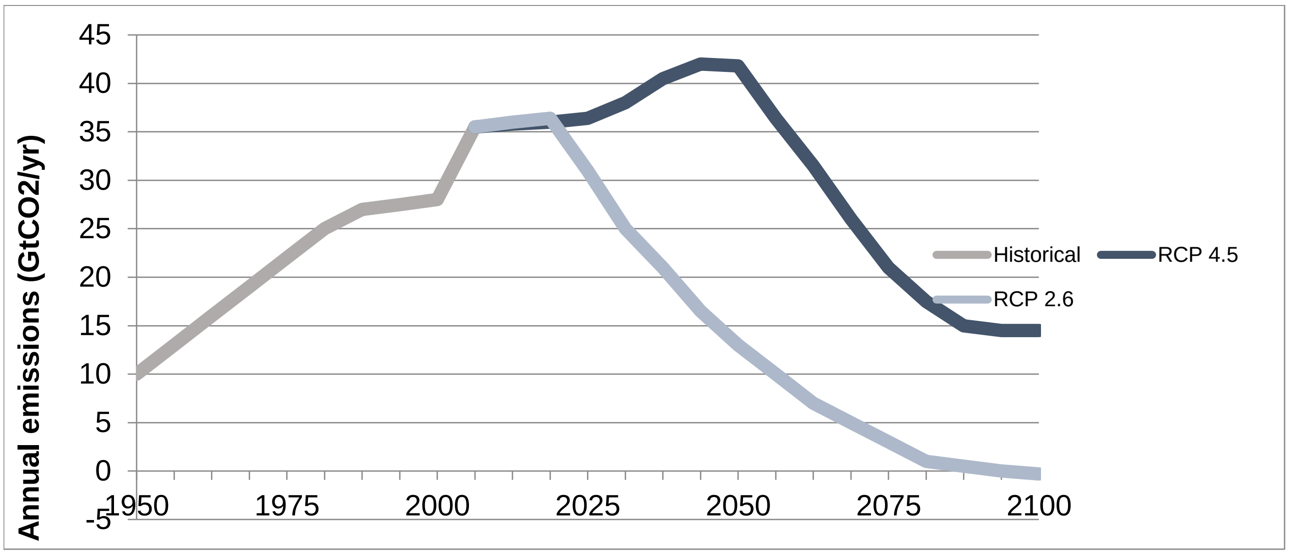

Fig. 7.12: Carbon Stabilization Scenarios: Required Emissions Reductions. **Source:** IPCC, 2014d, p. 11. Also, in Jonathan. *Note:* Upper line represents IPCC RCP 4.5 scenario (moderate stabilization in the range of 530 – 580 ppm CO_2 accumulation) and lower line represents IPCC RCP 2.6 scenario (stronger stabilization at 430 – 480 ppm CO_2 accumulation).

7.2.4.1. Climate change adaptation

Past GHG emissions have already altered the earth's climate, "locking in" some amount of additional change to temperatures, sea levels, and precipitation patterns that can no longer be avoided. Thus, any strategy to limit global mean warming to manageable level would still accommodate the fact of significant future emissions and damages. Climate change adaptation strategies involve large and diverse set of measures aimed at reducing vulnerability to damages occasioned by climate change and enhancing resilience with regard to changing climatic conditions. They involve efforts to modify natural or human systems in order to minimize harm from climate change impacts resulting from the warming that is already unavoidable due to past emissions. Examples include, but are not limited to, modifying development planning to include the impacts of sea-level rise and preparing public health facilities to handle the consequences of the changing disease impacts of a warmer climate.

Table 7.4 shows examples of sectors where climate adaptation strategies are likely to be required and the kind of strategies that are called for. Adaptation to climate change is essential, and will have significant costs in the areas of water, agriculture, infrastructure, health, transportation, and energy. Technology of adaptation will also vary from across settings and includes a broad swath of building, infrastructure, and energy technologies, as well as numerous public health and even poverty reduction measures. Types of expected damages are different in each locality, as are the solutions considered most technically sound and culturally appropriate.

Table 7.4: Climate Change Adaptation Needs, by Sector

Sector	Adaptation strategies
Water	Expand water storage and desalination Improve watershed and reservoir management Increase water-use and irrigation efficiency and water re-use Urban and rural flood management
Agriculture	Adjust planting dates and crop locations. Develop crop varieties adapted to drought, higher temperatures Improved land management to deal with floods/droughts Strengthen indigenous/traditional knowledge and practice
Infrastructure	Relocate vulnerable communities Build and strengthen seawalls and other barriers Create and restore wetlands for flood control Dune reinforcement
Human health	Health plans for extreme heat Increase tracking, early-warning systems for heat-related diseases Address threats to safe drinking water supplies Extend basic public health service
Transport	Relocation or adapt transport infrastructure New design standards to cope with climate change Strengthen distribution infrastructure
Energy	Address increased demand for cooling Increase efficiency, increase use of renewables
Ecosystems	Reduce other ecosystem stresses and human use pressures Improve scientific understanding, enhanced monitoring Reduce deforestation, increase reforestation Increase mangrove, coral reef, and seagrass protection

Source: **IPCC, 2007; IPCC, 2014b.**

Several recent studies have attempted to estimate the costs of near-term adaptation measures. Table 7.5 presents a summary. These estimates should be taken with caution for many reasons, including lack of direct attribution to specific adaptation activities, the lack of consideration of the benefits of adaptation investments, and issues of double counting and scaling up to global levels.

Table 7.5 Estimates of adaptation costs

Authors	US$ billion
World Bank	9-41
Stern	4-37
Oxfam	≥50
UNDP	86-109 (by 2015)
United Nations Framework Convention on Climate Change (UNFCCC)	annual global adaptation costs: 44-166 (including 28-67 for developing countries) (infrastructure investments: 8-130; agriculture: 14; water systems: 11; coastal zones: 11; human health: 5)

Source: Agrawala et al. 2008

7.2.4.2. Climate change mitigation

Mitigation strategies are actions to reduce the rate of growth of atmospheric GHG concentrations in the atmosphere. They fall into two broad categories

1. Increase the capacity of 'carbon pools' that sequester carbon dioxide and other greenhouse gases from the atmosphere (increasing the planet's natural capacity to absorb GHGs)
2. Decrease the rate of emissions of GHGs (thereby reducing GHG inflows into the atmosphere).

An ultimate objective of stabilizing GHG atmospheric concentrations could be achieved by the second of these alone, or by some combination of the two methods.

The first involves increasing the capacity of forests, agricultural lands and other terrestrial ecosystems which offer significant carbon reduction potential. This potential operates through several channels. For example

(i) increased planting rates and volumes would increase the amount of biomass that accumulates through natural growth; it is this biomass which sequesters carbon.

(ii) Some changes in the species or varieties mix of crops and biological material mass can enhance the amount of biomass that is stored.

(iii) Changes in agricultural practice and land use patterns can conserve existing stocks of carbon more effectively (preventing its discharge into the atmosphere).

The IPCC estimates that the potential here is large but nevertheless limited due to the feasible size of the pools and the fact that larger biomass stocks today imply greater flows to the atmosphere in the future.[56] A permanent reduction of atmospheric carbon stocks would require, loosely speaking, a permanent increase in the stock of the biomass in question. Even if this option is feasible, it may not be economically sensible. That depends on the costs of sequestering carbon in this way compared, for example, to the costs of reducing equivalent amounts of carbon emissions. Those cost comparisons need also to take into consideration opportunity costs of the land on which biomass is accumulated. Doing this may incur opportunity costs in the form of lost alternative uses of that land. A sensible approach might be to look for sequestration projects that generate synergies, by being complementary to other activities or land uses, such as wildlife or biodiversity reserves, or recreational activities. Box 7.5 sums up the debate on carbon sequestration in current climate change negotiations.

Associated with the first option is 'climate engineering' or geoengineering covering deliberate efforts to remove carbon dioxide from the atmosphere and solar-radiation management. While approaches in the former category, such as direct air capture or ocean fertilization, seek to reduce the greenhouse gases, approaches in the second category, such as injecting stratospheric aerosols, aim to cool the planet by reflecting a fraction of the incoming sunlight away from Earth. Some propose that one or more of these strategies could provide a cost-effective alternative to mitigation, but recent other reviews have emphasized that such approaches are fraught with uncertainties and may have potential adverse effects and, thus, cannot currently be considered

[56] For example, a once-for-all forestation project would store carbon for the lifetime of the timber, but once that timber decays or burns, its carbon is returned to other pools, including the atmosphere.

a substitute for comprehensive mitigation. Research continues, while the ultimate role for geoengineering remains to be determined.

Box 7.5. Should Carbon sequestration in the terrestrial biosphere be credited?

Both forests and soils sequester (store) a significant amount of carbon. Research suggests that with appropriate changes in practices, they could store much more. Increased carbon sequestration in turn would mean less carbon in the atmosphere. Recognition of this potential has created a strong push in the climate change negotiations to give credit for actions that result in more carbon uptake by soils and forests. Whether this should be allowed, and, if so, how it would be done are currently heavily debated. Proponents argue that this form of carbon sequestration is typically quite cost-effective. Cost-effectiveness not only implies that the given goal can be achieved at lower cost, but also it may increase the willingness to accept more stringent goals with closer deadlines. Allowing credit for carbon absorption may also add economic value to sustainable practices (such as limiting deforestation or preventing soil erosion), thereby providing additional incentives for those practices. Proponents further point out that many of the prime beneficiaries of this increase in value would be the poorest people in the poorest countries. Opponents say that our knowledge of the science of carbon sequestration in the terrestrial biosphere is in its infancy, so the amount of credit that should be granted is not at all clear. Obtaining estimates of the amount of carbon sequestered could be both expensive (if done right) and subject to considerable uncertainty. Because carbon absorption could be easily reversed at any time (by cutting down trees or changing agricultural practices), continual monitoring and enforcement would be required, adding even more cost. Even in carefully enforced systems, the sequestration is likely to be temporary (even the carbon in completely preserved forests, for example, may ultimately be released into the atmosphere by decay). And finally, the practices that may be encouraged by crediting sequestration will not necessarily be desirable, as when slow-growing old-growth forests are cut down and replaced with fast-growing plantation forests in order to increase the amount of carbon uptake. **(Source:** Titenberg and Lewis, 2012, p.428).

Given the limited scope for larger terrestrial sinks, a large component of any programme must involve GHG emissions reductions. This has implications for our use of fossil-fuel energy.[57] Combustion of fossil fuels results in the creation of CO_2.. CO_2 emissions can be reduced either by using less energy or by using alternative energy sources (such as wind, photovoltaics, or hydro) that produce no CO_2. To think about how they might be achieved, it is worth looking at the following accounting identity (which assumes that carbon emissions arise entirely in energy use)

[57] Coal contains the most carbon for a given amount of energy supplied. Oil has about ¾ of the carbon content and natural gas about half the carbon content as compared to coal (Jonathan et al, 2017).

$$M = \frac{m}{e} . \frac{e}{q} . \frac{q}{v} . v. N \qquad (7.7)$$

where M is total emissions, N is total population, m = M/N is emissions per person, e is the energy used per person (in producing material output), q is material output per person, and v is the value of output per person. The first three components on the right-hand side are expressed as ratios of per capita terms, and reflect various kinds of 'intensities. The fourth and fifth components, v and N, measure the scale of the economy in different ways.

The identity shows that total emissions will fall if any term on the right-hand side falls, other things being equal, leading to the following conclusions (assuming that other things stay constant in each case):

- Emissions will fall if m/e – which reflects the emissions intensity of energy production – can be reduced. This could be achieved by changes in fuel mix (from fossil to renewable energy, for example).
- Emissions will fall if e/q – the energy intensity of material output – falls. This could be achieved by changes in material output mix, or by producing output in more energy-conserving ways.
- Emissions will fall if q/v falls. This concept is subtle, but possibly of some significance. As we have seen, q is an index of (per capita) material output. It is best thought of in volume terms. In contrast, v is a (per capita) measure of the value of output, where value reflects the contribution to well-being of an individual. It is possible for output value to rise even if output volume remains constant (or falls). For example, computers are now immensely more valuable to users now than they were twenty years ago, even though the volume of computer output – measured in material terms – has fallen sharply. But, more importantly, as economies become more service-oriented – and as the relative importance of recreational services and environmental amenities rise – we might expect to see q/v falling.
- Emissions will fall if N falls. There is no prospect of this for many decades. Indeed, for some time rising global population will be a contributory factor to growing emissions. But as we saw under Topic 2, global population might fall by the end of the 21st century, and certainly cannot grow without limit indefinitely.

One must be wary of trying to extract too much from accounting identities of this kind. However, they can provide some insight into how policy to reduce GHG emissions might operate. For example, we could consider how an energy or carbon tax as well as introduction of tradeable carbon permits might alter the components we have been discussing.

Figure 7.13 shows estimated costs of reducing emissions by investment in various sectors of the economy. The figures are given based on projections for 2030. Costs are shown on the vertical axis, while the amount of potential reduction is measured on the horizontal axis. Note that up to 12 billion tons of emissions reductions can be achieved at *negative* costs, or net economic savings, primarily by increasing energy systems efficiency. In other words, such projects offer potentials for *double dividends*. Another 20 billion tons of reductions can be achieved at costs of less than 20 euros per ton (about $24/ton).

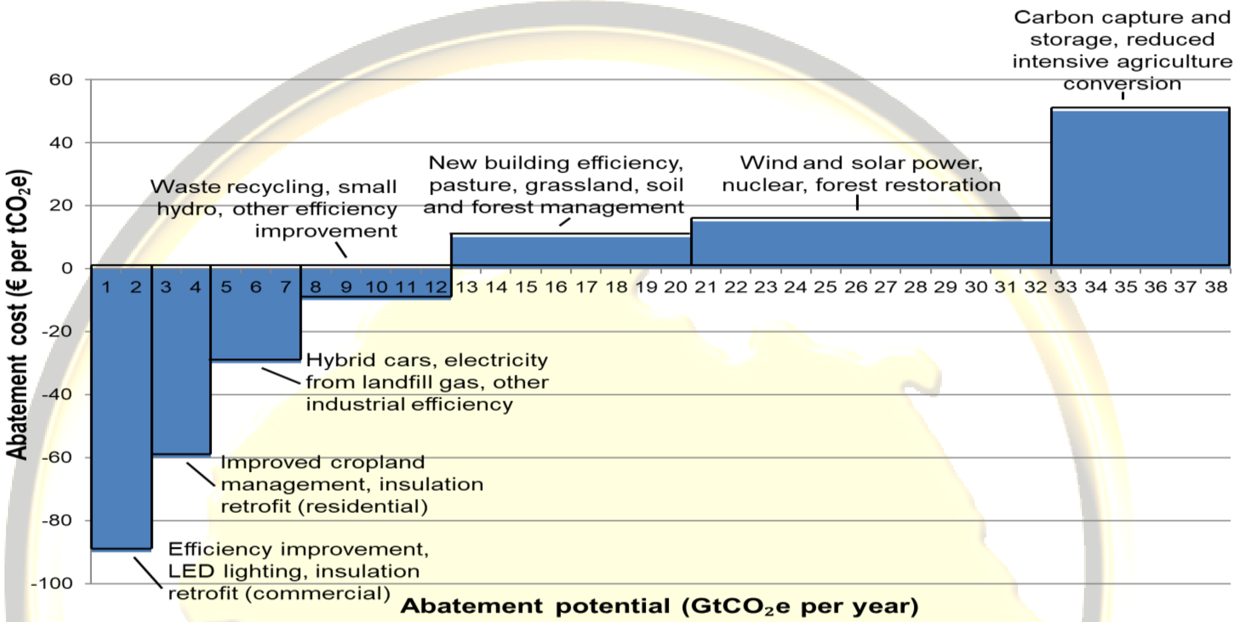

Fig. 7.13 Global Greenhouse Gas Abatement Cost Curve for 2030. **Source:** Adapted from McKinsey & Company, 2009. Also, in Jonathan and Roach., 2017)

Figure 7.14 helps to sum up what we have learnt so far on climate change: drivers, impacts and responses.

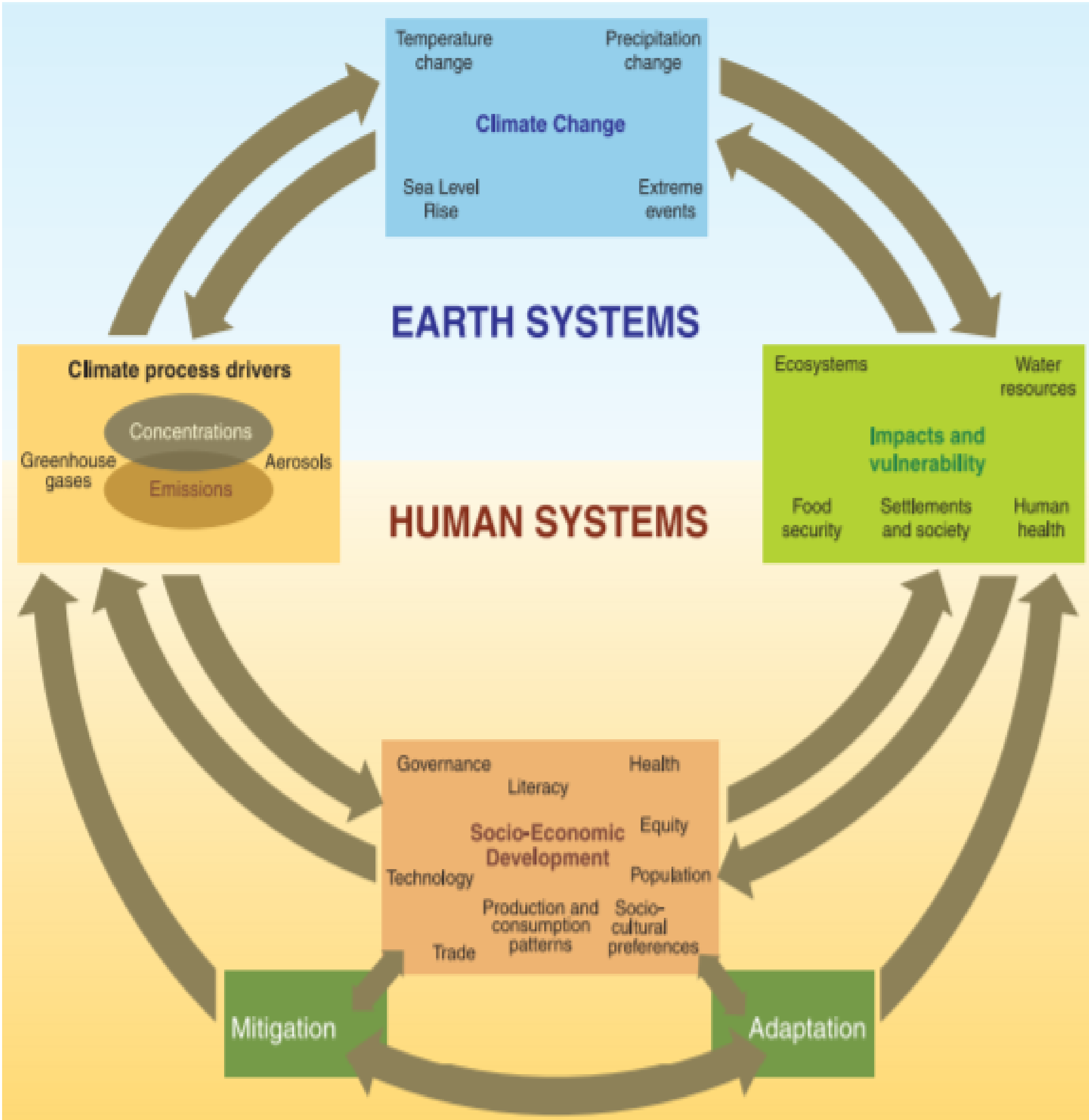

Fig. 7.14. Schematic framework representing anthropogenic drivers, impacts of and responses to climate change, and their linkages. **Source** IPCC, Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104.

7.2.5. Integrated (Climate change) Assessment Models (IAMs)[58]

The final section of this module takes on an introductory consideration of climate economic modeling and their uses. The basic tool here is what is often called an Integrated (Climate Change) Assessment Model (IAM). Such a model combines scientific and socioeconomic aspects of climate change for the purpose of assessing impacts and policies. It is based on the understanding that there exists a continuous interaction between the economy, welfare, and climate system.

- GHG emissions affect climate change
- Climate change affects economic production and welfare
- Economic production and welfare affect GHG emission.

Thus, a policy that affect one of the above chains (by impacting on any of the variables) will affect other aspects (variables) and how they develop and influence each other over time. Economic modeling places monetary values both on measures that would reduce greenhouse gas emissions and avoid climate damages and on the physical damages that are avoided. Comparisons of climate costs and benefits are then offered to policy makers as recommendations of the best actions to take.

The prototype IAM is the Dynamic Integrated Climate-Economy (DICE) model. This is a computer-based integrated assessment model developed by 2018 Nobel Laureate William Nordhaus. The model seeks to find the optimal emission, temperature and carbon tax trajectories by balancing the costs of emissions reductions and the damages of climate change, measured in economic terms. Emissions reductions are justified provided the benefits of avoiding climate damages outweigh the costs; for example, higher costs associated with energy supply.

The elements included in a simplified version of a stylized IAM are

- Analyses of the most important equations determining Production, Investment, and Emissions
- Equations describing how Capital, GHG concentrations, and Temperatures, evolve over time.
- A welfare function to be maximized based on the above equations.

Assessment of climate policies with IAMs, such as DICE, can assume different scenarios, including

(i) No controls (“**baseline**”): no emissions controls for first 250 years.

Baseline, or **business-as-usual**, emission scenarios do not plan for greenhouse gas mitigation. However, the projections under the scenario are sensitive to the assumptions about population and economic growth, innovation and investment in energy technologies, and fuel supply and choice. Thus, baseline emissions for future years vary widely. The most **optimistic business-as-**

[58] This section is based on Traeger C. (2009) Lecture Slides, Economics of Climate Change, UC Berkeley. Chapter 6.

usual scenarios assume significant reductions in carbon per unit energy and in energy per dollar over time, together with slow population growth and slow economic development. These scenarios project atmospheric concentrations of CO_2 as low as 500-600 ppm in 2100. In contrast **pessimistic business-as-usual scenarios** project the growth of global emissions over time, with CO_2 concentrations reaching 900-1,100 ppm by 2100. It should be noted, however, that new research suggests that parameters commonly used to link concentrations to emissions may be mis-specified; the fraction of CO_2 emissions sequestered in land and ocean sinks may be shrinking in response to climate change, suggesting that atmospheric concentrations would be higher at every level of emissions (Le Quéré et al. 2009).

(ii) **Optimal policy**: assumes setting emissions and carbon prices at optimal levels from second period in 2010–2019.

(iii) Climatic constraints with **CO_2-concentration constraints**: similar to optimal case except that CO_2 concentrations are constrained to be less than a given upper limit: There are various versions including

- (a) CO_2 concentrations limited to 1.5 pre-industrial level (420 ppm)
- (b) CO_2 concentrations limited to 2 preindustrial level (560 ppm
- (c) CO_2 concentrations limited to 2.5 preindustrial level (700 ppm)

(iv) Climatic constraints with **temperature constraints**: similar to optimal case except that global temperature change is constrained to be less than a given increase from 1900. Again, there are various variants including

- (a) 1.5°C limit
- (b) 2°C limit
- (c) 2.5°C limit, and
- (d) 3°C limit

(v) **Protocol-based control:** This is based on agreed actions under existing international agreement on climate change, e.g., the Kyoto Protocol, the Paris Climate deal (see Module 9.4). Different variants of the Protocol (for example, with or without a major country, such as the U.S., scenario where more nations join etc.) could be assumed.

(vi) **Ambitious proposals:** proposals based on more stringent conditions. Two popular variants

- (a) **Low discount rate**: The need to find the present values of future benefits and cost of economic activities, emissions, and damages from climate change requires the use of a social discount rate. The choice of the discount rate will affect predictions and policy prescriptions. The **Stern Review** suggest use of very low discount rates.[59]

[59] The Economics of Climate Change: The Stern Review, https://www.brown.edu/Departments/Economics/Faculty/Matthew_Turner/ec1340/readings/Sternreview_full.pdf

(b) Very **high emissions reductions**: for example, achieving global emissions reductions of 90 percent by 2050.

(vii) **Low-cost backstop technology**: assumes development of a technology or energy source that can replace all fossil fuels at current costs (though this currently seems unrealistic).

7.2.5.1. IAMs and Climate Policy Controversy and debates: Targets and Pathways

The target set for reducing global warming influences the pathway to be adopted towards achieving the target and thus, the practical policy steps that will be required. Different targets have different implications for policy reflecting in often sharp differences in the stringency of the recommended temperature goals and the implied emission pathways over the century. For example, the Intergovernmental Panel on Climate Change (IPCC) explores four potential futures depending on what policies governments adopt to cut emissions. Figure 7. 15 illustrates the four Representative Concentration Pathway (RCP) scenarios, each projecting a certain amount of carbon to be emitted by 2100, and as a result lead to a different amount of human-driven climate change. Climate change will continue after 2100 and elevated temperatures will remain for many centuries after human CO_2 emissions cease.

7.2.5.2 The pathway to two degrees

Under the UN Paris Agreement (see Module 7.4), countries committed to limiting global warming to well below 2°C and to actively pursue a 1.5°C limit. According to the IPCC, meeting the internationally-agreed target of 2°C means spending what remains of our **carbon budget** wisely. To have a better than two-thirds chance of limiting warming to less than 2°C from pre-industrial levels, the total cumulative CO_2 emissions since the start of the industrial era would need to be limited to 1,000 gigatonnes of carbon. About half of this amount had already been emitted by 2011. The amount of carbon that can be released would be reduced if concentrations of non-CO_2 GHGs continue to rise. Other factors (for example, the unexpected release of GHGs from permafrost) could also tighten this 'carbon budget' (Figure 7.16).

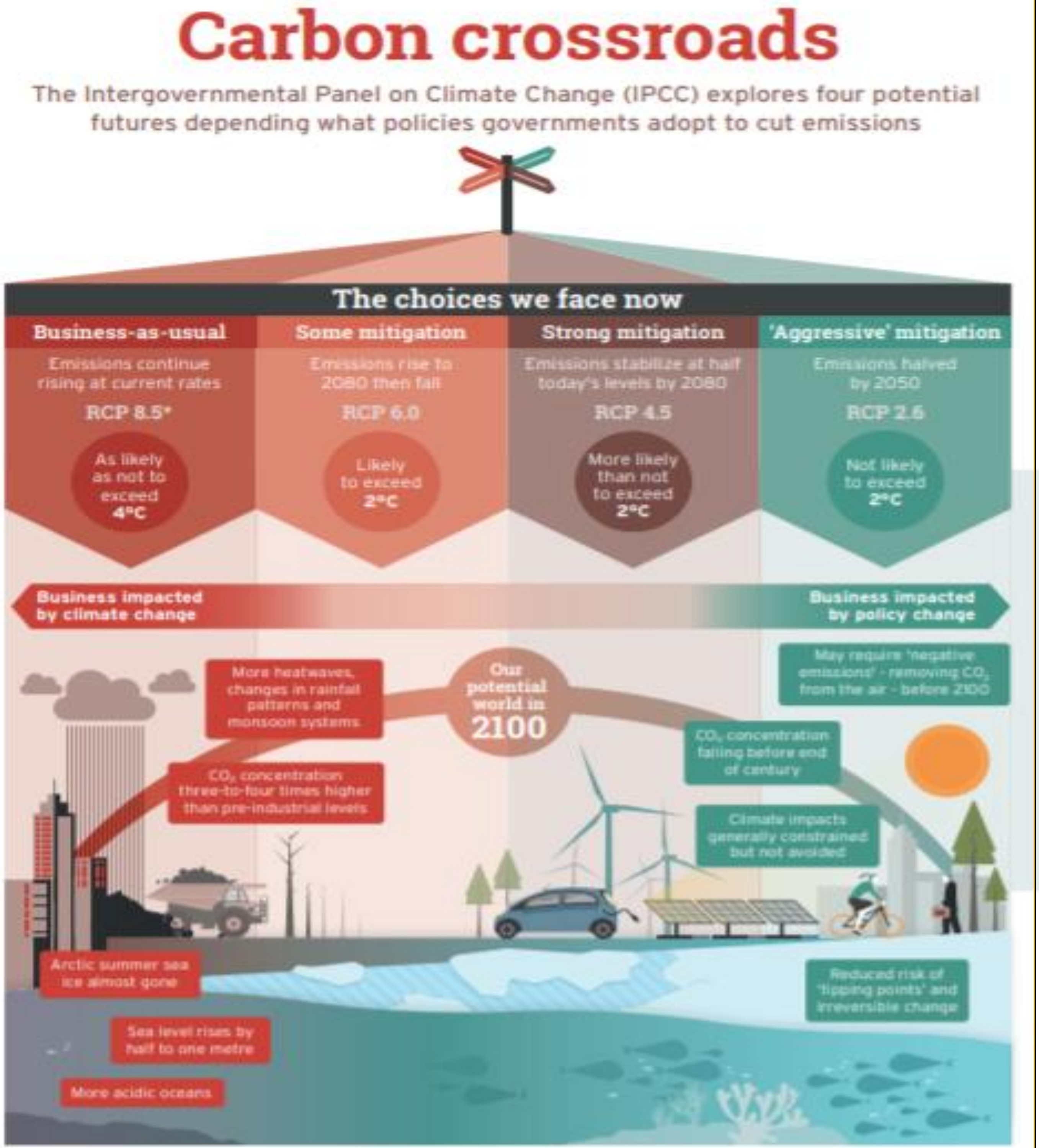

Fig. 7.15. The four RCP (Representative Concentration Pathway) scenarios (IPCC, 2014)

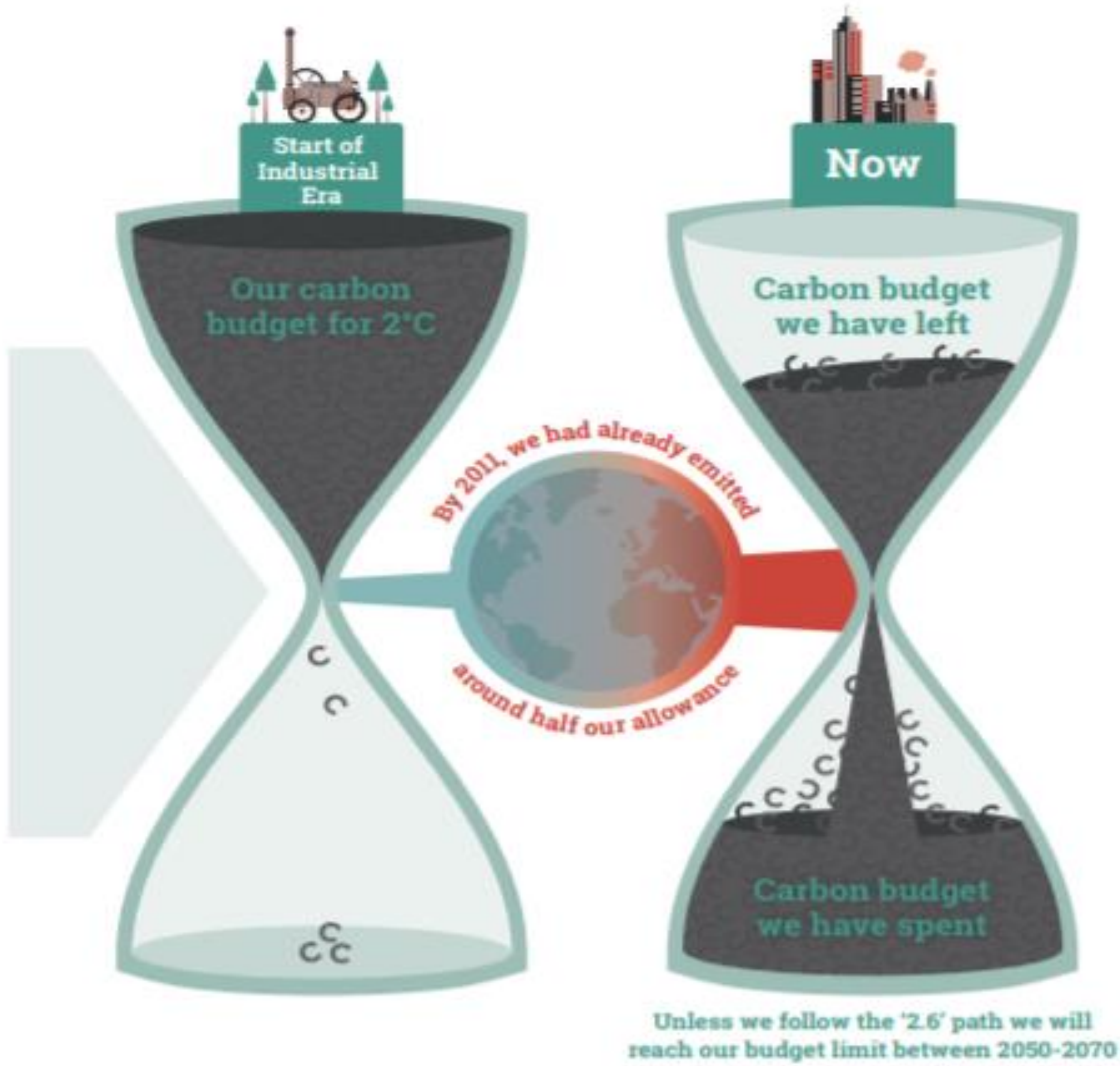

Fig.7.16. The pathway to two degrees

Some, including the 2018 Economics Nobel laureate, William Nordhaus, have argued that the 2.0 °C and 1.5 °C targets set under the Paris Agreement are economically suboptimal or unattainable and the world community should aim for 3.5 °C in 2100 instead. According to Nordhaus, a target of 3.5 °C in 2100 reflects the economically optimal balance between future benefits and current costs. Nordhaus' recommendations are derived from the DICE integrated assessment model (IAM), which he created and developed in several steps.[60]

[60] Nordhaus was early in making his model readily available to the research community and it has become central in climate economic analysis and highly influential in policy discussions. He was rewarded with the 2018 Laureate for

However, Martin and others (2020) provide a counterargument and show that the 2.0 °C target is optimal even in an updated version of the model used by Nordhaus. The DICE model has also been criticized on several grounds. These include the choice of discounting parameters (Nordhaus assumed a discount rate now believed by many to be too high), the model's omission of uncertainty and the risk for climate, the treatment of non-market damages, and details of the assumed climate model (see Martin, et al., 2020). Notably, the DICE model's concept of economic optimality (that is maximizing a discounted utilitarian social welfare function) has been criticized for not reflecting the structure of optimal-control models that incorporate risk and uncertainty and for its reliance on a single conception of intergenerational welfare.

DICE has also been subject to general criticism regarding the use of cost–benefit analysis for climate policy purposes (ibid). Figure 7.17 illustrates the effect of changing the values of some of the parameters in the model (the discount rate used, inclusion of significant non-market impact, and use of relative prices) on the optimal emission path,

In closing, it is important to note that while scientific research has greatly improved the state of knowledge about climate change, substantial uncertainty about critical aspects of climate science remains and will persist in spite of continued progress. That uncertainty contributes to differences of opinion within the scientific community about the potential for significant climate change and about its possible effects.

the methodological contribution of integrated assessment modelling (not necessarily for the specific policy recommendations following from the DICE model's baseline calibration) (Martin and others, 2020).

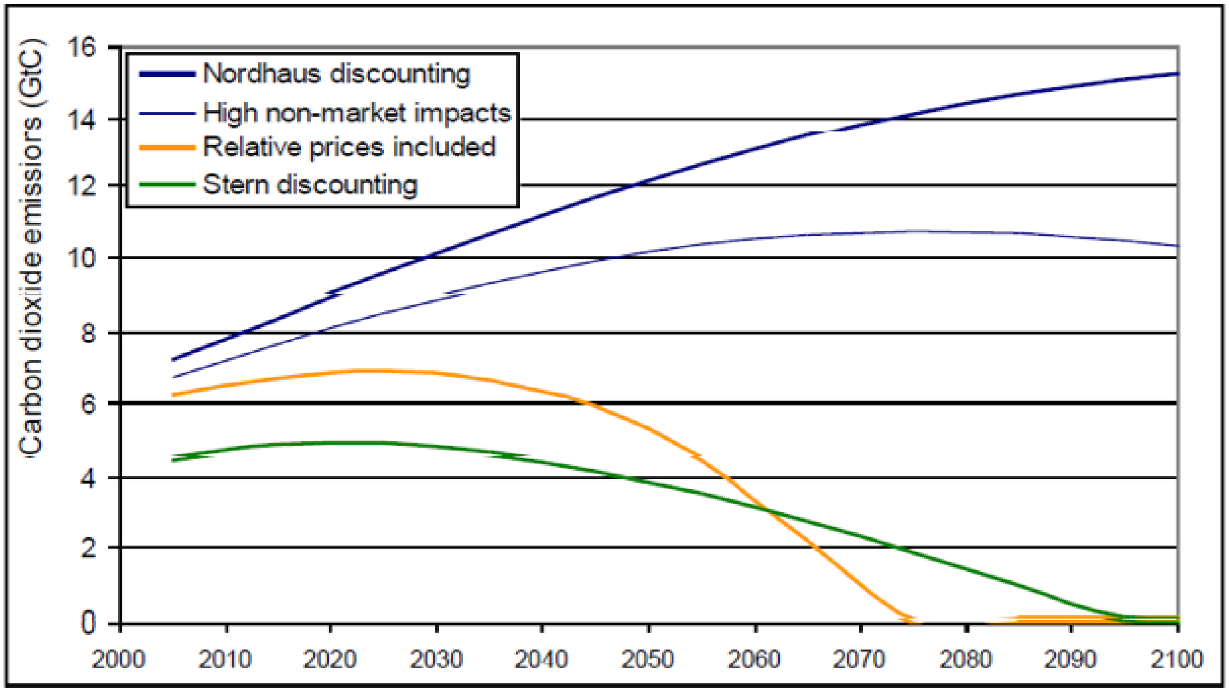

Fig. 7.17 Effect of changes in parameter values on the optimal emission path. **Source:** Sterner & Persson (2008), An even Sterner Review: Introducing Relative Prices into the Discounting Debate. Traeger C. (2009) Lecture Slides, Economics of Climate Change, UC Berkeley.

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Summary

- Climate change can be broadly defined as change in climate over time, whether due to natural variability or as a result of human activity. A major contributor to climate change is greenhouse gases (GHGs).. Although carbon dioxide (CO_2) is the most abundant and the most studied of these GHGs, many others (such as chlorofluorocarbons: CFCs, nitrous oxide, and methane) have similar thermal radiation properties.

- Climate change reflects primarily in changes in global temperature. Global temperatures have risen by more than 1 degree Centigrade since the Industrial Revolution with a sharp upward trend since about 1970. Projections of future temperature trends vary across a wide range, but all show temperatures continuing to rise

- The IPCC reports that most of the warming observed over the last 250 years can, with a very high level of confidence, be attributable to human activities. Evidence is mounting that by burning fossil fuels, leveling tropical forests, and injecting more of the other GHGs into the atmosphere, humans are creating a thermal blanket capable of trapping enough heat to raise the temperature of the earth's surface

- Economic activities give rise to flows of GHG emissions. Since all nations are emitters and each is affected by the emissions of all others, GHG emissions constitute both a reciprocal spillover problem as well as a global public 'bad'.

- At any point in time, GHG concentrations depend on the levels of emissions at all previous points in time, and on the extent to which sinks have sequestered atmospheric GHGs, or the amounts that have decayed into harmless forms, at all previous points in time.

- Temperature changes in the higher range would imply massive impacts especially in hotter, drier, and coastal areas. A 2 to 3°C warming could put about 20 to 30 percent of plant and animal species at high risk of extinction and cause changes in the structure and functioning of terrestrial and aquatic ecosystems. At 4°C of warming, major extinctions are predicted around the world. In October 2018, the IPCC at a meeting in South Korea issued what it called a 'final call to save the world from climate catastrophe' as it believes the world is now heading towards temperature increase of 3°C.

- The impacts of climate change include impacts on natural systems, and impacts on human systems. Impact on natural systems includes impacts on forestry and fisheries. Impacts on human systems include effect on agriculture, coastal settlements, and human health.

- It is generally believed that these impacts may well be very large and will bear down unequally between countries. As far as the regional distribution of damages arising from climate change is concerned, the current consensus view is that there will be few, if any, 'big winners' but there will almost certainly be some very large losers.

- On average, damage is expected to be inversely related to per capita income. Furthermore, those economies with the greatest incentive to cut emissions (or otherwise limit climate change) tend to have the poorest resource base to implement policies that adapt to climate change and minimize the most serious forms of damages. In general, the evidence suggest that the most severe impacts of climate change will occur in developing countries. The number of people suffering loss of water resources, as well as coastal flood victims and population at risk of hunger by 2080 will be relatively larger in Africa, South America, and Asia, where most developing countries are located.

- Strategies to stabilize atmospheric CO_2 includes adaptation and mitigation strategies. Climate change adaptation strategies involve large and diverse set of measures aimed at reducing vulnerability to damages occasioned by climate change and enhancing resilience with regard to changing climatic conditions. They involve efforts to modify natural or human systems in order to minimize harm from climate change impacts resulting from the warming that is already unavoidable due to past emissions.

- Climate mitigation strategies are actions to reduce the rate of growth of atmospheric GHG concentrations in the atmosphere. They include actions to Increase the capacity of 'carbon pools' that sequester carbon dioxide and other greenhouse gases from the atmosphere and/or decrease the rate of emissions of GHGs.

- Given the limited scope for larger terrestrial sinks, a large component of any programme must involve GHG emissions reductions. This has implications for our use of fossil-fuel energy.

- Some studies suggest that up to 12 billion tons of emissions reductions can be achieved at negative costs, or net economic savings, primarily by increasing energy systems efficiency, while another 20 billion tons of reductions can be achieved at costs of less than 20 euros per ton (about $24/ton).

Review/Discussion Questions/Exercises

1. What is the greenhouse effect? What is the difference between the natural greenhouse effect and human-induced climate change? What are some of the expected physical effects of global climate change?

2. Summarize the projected impacts of global climate change over the next century, in terms of both ecological and economic impacts. By how much is the global average temperature expected to increase in the future? What other climate changes are expected? How will these changes impact natural ecosystems and human economies?

3. How can two economists use similar data to assess the economic effects of global climate change but come to different conclusions regarding the actions that should be taken? What different assumptions are likely to lead to different assessments of the urgency of policy action?

4. Does drastic action on climate change imply a reduction in GDP or living standards? Why or why not? What factors are important in determining the effects of climate policy on GDP?

5. How should the global inequality of impacts affect our assessment of climate change?

6. What is the difference between adaptation and mitigation regarding global climate change? List at least three examples of each.

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Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. In Press.

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Module 7.3 World Trade and Environment (2.5 hours)

Learning outcomes

This Module examines whether there is a linkage between free trade and environmental degradation. After going through the Module, the reader should understand

- ✓ the basis for the proposition that free trade raises welfare in trading countries
- ✓ how distortions, in particular environmental externalities, complicates the gains from trade.
- ✓ why it is difficult to determine *apriori* whether trade enhances or harm the environment.
- ✓ the conditions under which free trade lead to greater environmental damages.
- ✓ why free trade *may* be environmentally damaging for a large number of Sub-Saharan African countries

Outline

7.3.1 Introduction

7.3.2 Trade and environment in a simple two-country model

7.3.2.1 Applications: Automobiles

7.3.2.2 Applications: Timber

7.3.3 Issues and Debates

7.3.3.1 Factor endowment hypothesis

7.3.3.2 The pollution haven hypothesis

7.3.3.3 The Porter Hypothesis

7.3.3.4 The Environmental Kuznets Curve (EKC) revisited

7.3.3.4 The Role of Property Rights

Summary

Review/Discussion Questions and Exercises

Materials used for this lecture

7.3.1 Introduction

One of the traditional paths to development involves opening up the economy to trade. Freer international markets provide lower prices for consumer goods (due to the availability of and competition from imported products) and the opportunity for domestic producers to serve foreign markets. The law of comparative advantage suggests that trade can benefit both parties. The proposition that free trade can improve economic welfare in each of the participating countries is one of the oldest, and most widely accepted, principles of economics. It has played a part in shaping much of the international political, economic and institutional framework that has been built up since 1945 (for example, single-market areas such as the European Union, EU, and the World Trade Organization, WTO). However, as we move from theory to practice, the story becomes a bit more complicated. In particular, the existence of environmental pollution has cast doubts on the validity of the benign effect of free trade. A significant number of persons, including some economists, believe that trade liberalization can, in fact, be environmentally damaging.

Does a country's environmental quality improve or deteriorate as a result of free trade? Does free trade lead to aggregate environmental gain or loss for all the countries involved? There may be no clear-cut answer to either question. However, the trade–environment relationships are now among the most actively researched topics in environmental economics. Our task in this Moule is to examine the theoretical arguments and review some of the evidence.

7.3.2 Trade and environment in a simple two-country model

Standard trade theory suggests that there are net gains to both trading nations in a 2-nation model (and by extension to all trading nations in a multinational trading situation). Assume there are only two countries, *X* and *Y*, each of which produces two goods, *A* and *B*. Each country acts as a price-taker, regarding the world price of a good as fixed and beyond its control. The gains from trade can be illustrated by changes in consumers' surplus and producers' surplus that arise from the introduction of trade. Figure 7.18 shows the demand and supply curves for good A in each of the two countries. In the absence of international trade, country X produces and consumes the quantity A_X at price P_X, country Y produces and consumes A_Y at price P_Y. The opening of free trade establishes a common world price, P_W. As the world price is below its pretrade domestic price, *X* becomes an importer of good A; *Y* becomes an exporter of good A.

For country *X* (the importer), the opening of trade causes domestic production to fall to A_{SX} while domestic consumption increases to A_{DX} (Panel (a). Imports make up the shortfall of domestic production relative to domestic consumption. Consumer surplus increases from the area P_Xbd_X to the area P_Wed_X. Producer surplus – the area above the supply function but below the price received by sellers – falls from $0bP_X$ to $0cP_W$. The gain in consumer surplus is greater than the loss of producer surplus by an amount equal to the area *ceb*, and so the importing country has a net gain in welfare from trade in good A.

The exporting country also experiences a net welfare gain from the opening of trade (Panel b). Domestic production of good A is A_{XY} while domestic consumption is A_{DY}. The surplus production is exported to country X. Consumer surplus associated with good A falls from the area $P_Y f$dY to the area $P_W g$dY. Producer surplus increases from 0fP_Y to 0hP_W. The gain in producer surplus is greater than the loss of consumer surplus by an amount equal to the area *fhg*, and so the exporter has a net gain in welfare from trade in good A. Although it is not shown in Figure 7.18, equivalent conclusions must follow from examination of changes in welfare associated with trade in the other good. Note that in this case the direction of trade flows would be reversed).

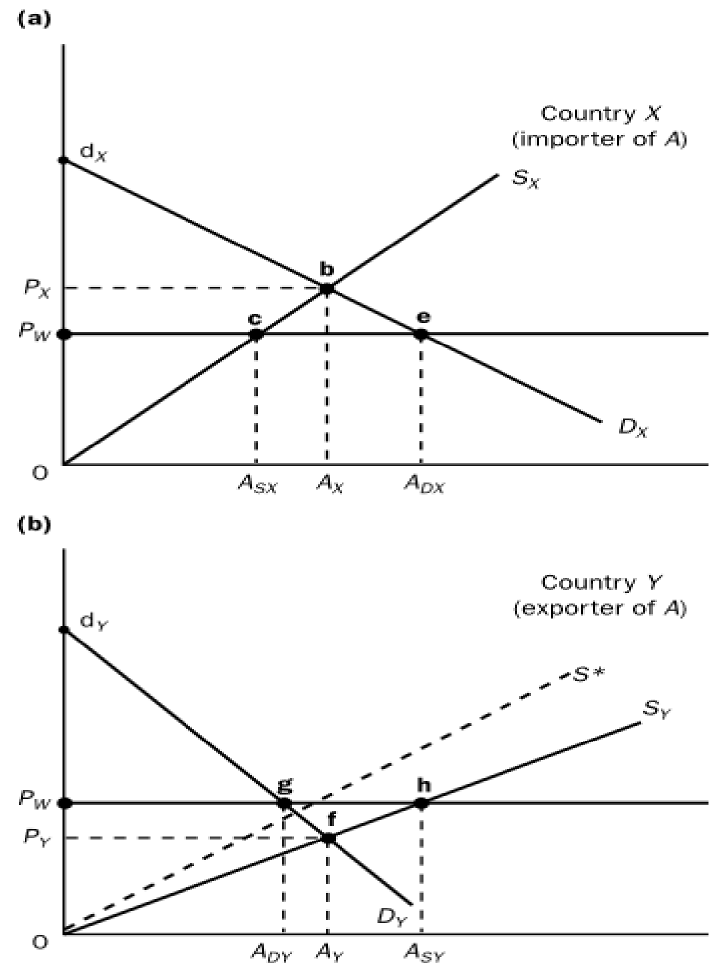


Fig.7.18 Free Trade and Environment. **Source:** Perman et al., 2003. p.340

The analysis above is valid if there are no 'distortions' present anywhere in the economies in question. Complications set in where production generates adverse environmental externalities. The situation will be even more complex if the environmental effects are transboundary or global in nature, such as carbon emissions or water use when rivers cross national boundaries. Suppose, for example, that producing good A generates an adverse externality that affects only the citizens of the producing country (that is, there is no international pollution spillover). For the importing country, we have already seen that the opening of trade reduces its domestic production of the good, and so the magnitude of the environmental externality will also fall there. Bringing external effects into the picture reinforces the argument for trade for this country.

But matters are not clear-cut for the country that becomes an exporter. Its increased volume of production raises external costs, which reduces the net gains from the opening of trade. The rise in pollution externalities may be larger than the previously explained net surplus gain, in which case the country will experience a net welfare loss. Further information will be needed to derive an unambiguous conclusion about whether trade will benefit the exporting country (or indeed the two countries collectively). However, it is clear that the presence of production externalities undermines the case for free trade.

We can now examine the effect of some pollution control policy in the exporting country. Assume that trade is accompanied by the introduction of some pollution control programme, for example, a uniform tax rate was imposed on units of emission in the exporting country. This will cause the supply function to rotate anticlockwise to a position such as that shown by the function 0S* in Figure 7.18 (Panel b). As compared with the *trade-but-no-pollution-control* situation, emissions will fall and so external costs will be reduced. However, producer surplus will also be smaller. Thus, it is not possible to know whether the reduction in pollution externalities will be more or less than the fall in producer surplus. Once again, the overall welfare effect ambiguous. However, if the pollution control programme – whether it uses taxes, permits or other controls – is economically efficient, then, the gain in avoided pollution costs must exceed the fall in producer surplus. In this particular circumstance, therefore, we do have a clear result. This brings us to the conclusion: *opening economies to international trade will result in net welfare gains provided that this is accompanied by the introduction of an economically efficient pollution control programme to internalise any pollution externality* (if that was the only distortion present). The argument could be generalized to many countries and many goods. We will now take some illustrations to drive home the points made so far. We shall use the trade in automobiles and timber as examples.

7.3.2.1 Applications: Automobiles

There are environmental externalities associated with the production and consumption of automobiles. There may be production externalities if production activities involve emission of dangerous chemicals into the air or water for example. Consumption externalities include increased pollution and congestion. As usual, the gains from trade in automobiles in the importing country, without regard to the associated externalities, can be shown by comparing the effects of importing automobiles for domestic consumers and producers (Figure 7.19a). Domestic producers lose area A, since they are forced to compete with lower world prices (P_W) as compared to the domestic price P*, and also because they lose market share Q* - Q_1 to imports. But domestic consumers gain areas A + B because they can afford more cars at lower prices. Thus, there is a net national gain equal to area B.

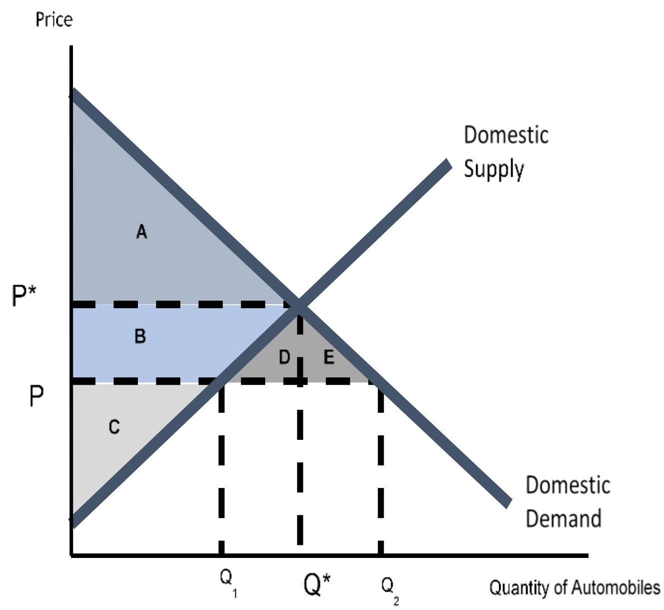


Fig 7.19a. Gains and Losses from Importing Automobiles. **Source:** Jonathan and Roach 2017.

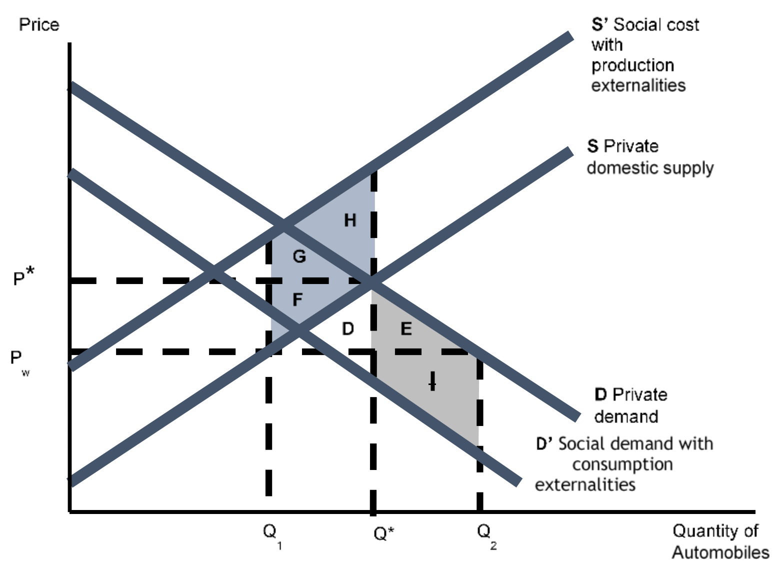


Fig. 7.19b. Welfare Impacts of Importing Automobiles with Externalities. **Source:** Jonathan and Roach 2017.

For the exporting country (not shown), domestic consumers lose because export demand drives up prices, but by a similar graphical logic, domestic producers gain a larger amount than domestic consumers lose.

The figure in panel b takes account of the additional environmental gains and losses associated with trade. In Figure 7.19b, the environmental costs associated with producing automobiles are partly shifted from the importing to the exporting country (areas G + F + H). But the importing country gets increased environmental externalities associated with the consumption of automobiles (areas E + I). These environmental gains and losses need to be weighed against the ordinary gains from trade.

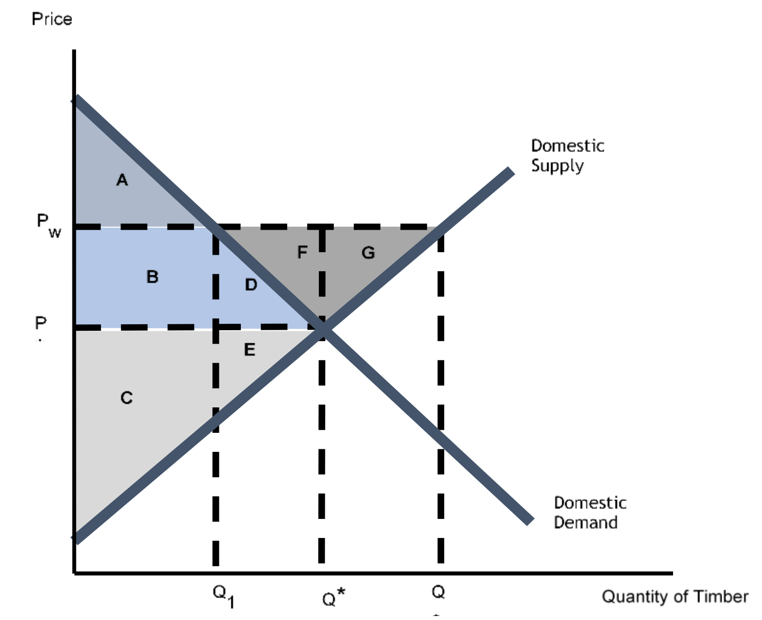


Fig 7.20a. Gains and Losses from Exporting Timber. **Source:** Jonathan and Roach 2017.

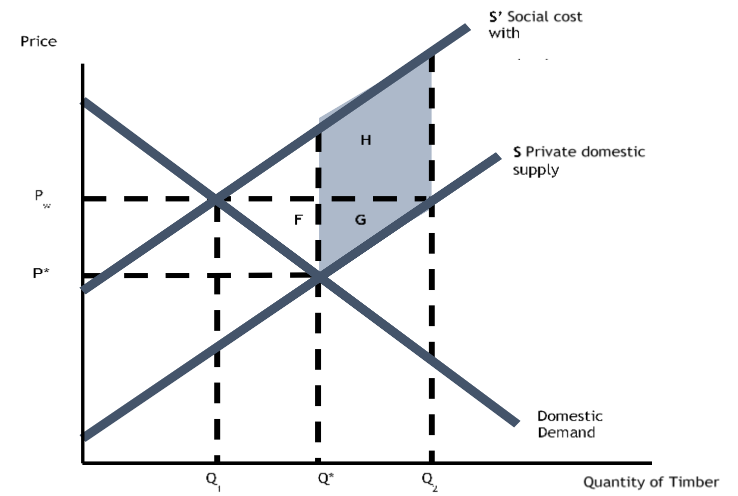


Fig. 7.20b. Welfare Impacts of Exporting Timber with Externalities. Source: **Source:** Jonathan and Roach 2017

7.3.2.2 Applications: Timber

Associated with world trade in timber is deforestation and associated environmental degradation, including damage to watersheds, species loss, and degradation of soils through erosion, as well as global impacts such as net carbon release. Discountenancing these effects, in Figure 7.20a, the export of timber brings the usual national net benefits (F + G) for the exporting country: the gain in producer surplus (B + D + F + G) more than offsets the loss of domestic consumer surplus (B + D).

Figure 7.20b introduces the environmental effects. If the environmental damages (G + H) are large, they might outweigh the gains from trade. The net change in welfare is (F – H). If area F is greater than area H, then there will be a net social gain from trade, but if area H is greater than area F, there will be a net loss.

7.3.3 Issues and Debates

The world is one in which distortions are pervasive, environmental pollution problems are rarely if ever fully internalized, and it is almost impossible to design fully efficient pollution control programmes. Whether free trade is welfare-maximizing – or whether trade liberalization leads to net welfare gains – is, therefore, a moot point. We will now examine two hypotheses that have dominated theoretical discussions about trade–environment linkages: the factor endowment hypothesis and the pollution haven hypothesis.

7.3.3.1 Factor endowment hypothesis

This reflects the classical view of trade (sometimes known as the Heckscher–Ohlin–Samuelson model). Relative factor abundance determines comparative advantage, and so the directions of trade flows. Under this hypothesis, on the assumption that capital-intensive industry is more pollution intensive than labour-intensive industry, trade will cause heavily polluting capital-intensive processes to migrate to capital-abundant affluent economies.

7.3.3.2 The pollution haven hypothesis

According to this hypothesis, producers affected by stricter environmental regulations in one country will either move their dirtiest production facilities to countries with less stringent environmental regulations- pollution havens (presumed to be lower-income countries) or face a loss of market share. Consumers in the country with the strict regulation have an incentive to prefer the cheaper goods produced in the pollution havens.

Pollution levels can change in the pollution havens for three different reasons

I. **The composition effect**- whereby emissions change as the mix of dirty and clean industries changes. As the ratio of dirty to clean industries increases, emissions increase, even if total output remains the same.
II. **The technique effect**- whereby the ratio of emissions per unit output in each industry changes. Emissions could increase in pollution havens via this effect if each firm in the pollution haven became dirtier as a result of openness to trade.
III. **the scale effect**- which shows the role of changes in output level on emissions. Even if the composition and technique effects were zero, emissions could increase in pollution havens simply because output levels increased.

In addition to suggesting a channel for degradation, the 'pollution havens hypothesis', if correct, could provide a justification for developing countries to accept lower environmental standards. In this view, lower environmental standards protect against job loss. In other words, it suggests a "*race to the bottom*" feedback mechanism where competitive incentives among nations force developing countries to keep environmental standards weak in order to attract jobs, and jobs move to those locations in search of the lower costs resulting from lower standards. However, because pollution control costs comprise a relatively small part of the costs of production, it is doubtful if lowering environmental standards could become a major determinant of either firm location decisions or the direction of trade, unless the costs of meeting those standards become a significant component of production cost.

Notice that both the f**actor endowment and pollution haven** hypotheses agree that trade will have environmental consequences but they disagree about how those consequences are distributed. However, neither hypothesis tells us anything about what will happen to the environment in the aggregate sense.

7.3.3.3 The Porter Hypothesis

The Porter hypothesis (popularized by Michael Porter, 1991), that more environmental protection can, under the right circumstances, promote jobs, not destroy them. Now known as the "*Porter induced innovation hypothesis*," this view suggests that firms in nations with the most stringent regulations experience a competitive advantage rather than a competitive disadvantage. Strict environmental regulations force firms to innovate, and innovative firms tend to be more competitive. This advantage is particularly pronounced for firms producing pollution control equipment (which can then be exported to firms in other countries thus raising their environmental standards), but it might also be present for firms that find that meeting environmental regulations actually lowers their production costs.

The Porter hypothesis is valuable because it shows that the conventional wisdom that environmental regulation reduces firm competitiveness is often wrong. It would be a mistake, however, to use it as confirmation of the much stronger proposition that environmental regulation is universally good for competitiveness.

7.3.3.4 The Environmental Kuznets Curve (EKC) revisited

The hypothesis suggests that the potential problems for the environment posed by free trade, will be self-correcting. Specifically, it argues that as freer trade increases incomes, the higher incomes will promote more environmental protection. However, things will be different if the part of the self-correcting mechanism of free trade and rising income level on the environment involve exporting the pollution-intensive industries to other countries. In this case, the EKC will be altered to reflect a transfer of pollution, not a reduction of pollution. This conjecture is especially important in a finite world because it implies that developing countries would never experience the Kuznets turning point. Since they would have nowhere to go, it will be impossible to transfer the pollution-intensive industries out of those countries. It is possible however, that the effect of trade on the EKC relationship may be to delay the 'turning point', if any.

Box 7.6 provides an illustration of these issues based the effect of trade and membership of North America Free Trade Area (NAFTA) on the environment in Mexico.

Box 7.6. NAFTA and the Environment in Mexico

The North American Free Trade Agreement (NAFTA) took effect in 1994. By lowering tariff barriers and promoting the freer flow of goods and capital, NAFTA integrated the United States, Canada, and Mexico into a single, giant market. The agreement has apparently been successful in promoting trade and investment. Has it also been successful in promoting environmental protection in Mexico? According to a study by Kevin Gallagher (2004), it has not, although not necessarily due to the forces identified by the pollution havens hypothesis. Some effects clearly resulted in less pollution and others more, although on balance, air quality has deteriorated. The pollution havens hypothesis might lead us to expect a relocation of heavily polluting firms from the United States to Mexico, but that apparently did not happen. None of the numerous statistical tests performed by the author supported that hypothesis. In terms of positive effects on air quality from trade, Gallagher found significant shifts in Mexican industry away from pollution-intensive sectors; the posttrade Mexican industrial mix was less polluting than the pretrade industrial mix (the opposite of what would be expected from the pollution havens hypothesis). He even found that some Mexican industries (specifically steel and cement) were cleaner than their counterparts in the United States, a fact he attributes to their success in securing new investment for more modern plants with cleaner technologies. The largest trade-related source of air quality degradation was the scale effect. Although the posttrade industrial mix generally shifted away from the most polluting sectors (meaning fewer average emissions per unit output), the promotion of exports increased output levels considerably. Increased output meant more emissions (in this case, almost a doubling). One expectation emanating from the Environmental Kuznets Curve is that the increased incomes from trade would result in more environmental regulation, which, in turn, would curb emissions. That expectation was not met either. Gallagher found that both real government spending on environmental policy and the number of Mexican plant-level environmental compliance inspections fell by 45 percent after NAFTA, despite the fact that income levels reached the turning point expected by the pretrade studies.

Source : Kevin P. Gallagher. Free Trade and the Environment: Mexico, NAFTA and Beyond (Palo Alto, CA:Stanford University Press, 2004). Also in Jonathan and Roach, 2017.

7.3.3.4 The Role of Property Rights

Trade would inflict detrimental (and inefficient) effects on the environment when some nations (presumably those in the less developed South) have poorly defined property rights or have not internalized their externalities (such as pollution). In this kind of situation, the *tragedy of the commons* can become greatly intensified by freer trade (Chichilnisky, 1994). Poorly defined property rights in the exporting nations encourage the importing nations (by artificially lowering prices) to greatly expand their consumption of the underpriced resources. In this scenario, trade intensifies environmental problems by increasing the pressure on open-access resources and hastening their degradation.

When deterioration is caused by inadequate local property right regimes or inadequate internalization of externalities, it may not be necessary or desirable to prevent trade, but rather to correct these sources of market failure. These inefficiencies associated with trade could be solved with adequate property regimes and appropriate pollution control mechanisms. On the other hand, if establishing appropriate property regimes or pollution control mechanisms is not politically feasible, other means of protecting the resources must be found, including possibly restricting detrimental trade. However, caution must be used in imposing these trade restrictions, since they are a second-best policy instrument in this case and can even be counterproductive.

While the foregoing argument suggests that the starkest claims against the environmental effects of free trade do not bear up under close scrutiny, it would be equally wrong to suggest that opening borders to freer trade inevitably results in a gain in efficiency and/or sustainability. The truth, it seems, depends on the circumstances; context matters. There are also emerging issues in the area of trade and environment. Among these are issues are the environmental consequences of protections for companies investing in foreign countries that are adversely affected by environmental regulations, and international trade rules under the General Agreement on Tariffs and Trade (GATT) and the World Trade Organization.

Summary

- One of the traditional paths to development involves opening up the economy to trade. Freer international markets provide lower prices for consumer goods and the opportunity for domestic producers to serve foreign markets.

- The proposition that free trade can improve economic welfare in each of the participating countries is one of the oldest, and most widely accepted, principles of economics. However, the existence of environmental pollution has cast doubts on the validity of the benign effect of free trade.

- Where production generates adverse environmental externalities, this must be taken into account in weighing the benefits of trade. The situation will be even more complex if the environmental effects are transboundary or global in nature, such as carbon emissions or water use when rivers cross national boundaries.

- In this case, opening economies to international trade will result in net welfare gains provided that this is accompanied by the introduction of an economically efficient pollution control programme to internalize any pollution externality, if this was the only distortion present.

- But the world is one in which distortions are pervasive, environmental pollution problems are rarely if ever fully internalized, and it is almost impossible to design fully efficient pollution control programmes. Whether free trade is welfare-maximizing – or whether trade liberalization leads to net welfare gains – is, therefore, a moot point.

- Two hypotheses have dominated theoretical discussions about trade–environment linkages: the factor endowment hypothesis and the pollution haven hypothesis.

- Under the factor endowment hypothesis, on the assumption that capital-intensive industry is more pollution intensive than labour-intensive industry, trade will cause heavily polluting capital-intensive processes to migrate to capital-abundant affluent economies.

- According to the pollution haven hypothesis, producers affected by stricter environmental regulations in one country will either move their dirtiest production facilities to countries with less stringent environmental regulations- pollution havens (presumed to be lower-income countries) or face a loss of market share. Consumers in the country with the strict regulation have an incentive to prefer the cheaper goods produced in the pollution havens.

- In addition to suggesting a channel for degradation, the 'pollution havens hypothesis', if correct, could provide a justification for developing countries to accept lower environmental standards. In this view, lower environmental standards protect against job loss. Thus, it suggests a "*race to the bottom*" feedback mechanism where competitive incentives among nations force developing countries to keep environmental standards weak, in order to attract jobs, and jobs move to those locations in search of the lower costs resulting from lower standards.

- The Porter hypothesis posits that more environmental protection can, under the right circumstances, promote jobs, not destroy them; firms in nations with the most stringent regulations experience a competitive advantage rather than a competitive disadvantage. It shows that the conventional wisdom that environmental regulation reduces firm competitiveness is often wrong. It would be a mistake, however, to use it as confirmation of the much stronger proposition that environmental regulation is universally good for competitiveness

- Trade would inflict detrimental (and inefficient) effects on the environment when some nations (presumably those in the less developed South) have poorly defined property rights or have not internalized their externalities (such as pollution). In this kind of situation, the *tragedy of the commons* can become greatly intensified by freer trade.

- When deterioration is caused by inadequate local property right regimes or inadequate internalization of externalities, it may not be necessary or desirable to prevent trade, but rather to correct these sources of market failure. These inefficiencies associated with trade could be solved with adequate property regimes and appropriate pollution control mechanisms. On the other hand, if establishing appropriate property regimes or pollution control mechanisms is not politically feasible, other means of protecting the resources must be found, including possibly restricting detrimental trade.

Review/Discussion Questions and Exercises

1. Assuming two countries and two goods, provide, a diagrammatic analysis to show that free trade is mutually beneficial to both countries and the conditions under which this assertion holds.

2. As a follow-up on (1) above, how will the presence of a negative externality, such as pollution in the production of the good, affect the gains from trade in both countries (a) in the absence of a pollution control programme, (b) with a pollution control programme?

3. Examine and evaluate the factor endowment hypothesis and the pollution haven hypothesis in the light of the experiences of Sub-Saharan African countries.

4. What are the likely effects of the pollution haven hypothesis on the Environmental Kuznet Curve?

5. Evaluate the potential benefit to Sub-Saharan African countries from free trade in (a) used cars and (b) timber.

Materials used for this section

1. Jonathan M. Harris and Brian Roach (2017), **Environmental and Natural Resource Economics** *4th Edition*, Routledge.

2. Perman, R., Ma Y., McGilvray J. and Common M. (2012). Natural Resource and Environmental Economics, 4th Edition, Edinburgh, Longman.

3. Titenberg, T. & Lewis, L. (2012). **Environmental & Natural Resource Economics** 9th Edition, The Pearson Series in Economics

Module 7.4 International Agreements (3 hours)

Learning outcomes

This Module examines International Agreements on international environmental problems, with a focus on global pollution. After going through the module, you should

- ✓ understand the concept on an international environmental agreement and the framework for implementation, such as international treaties or protocols,
- ✓ understand the concept of a self-enforcing international environmental agreement and its characteristics,
- ✓ have some understanding of why some international agreements, such as the global effort to reduce ozone depletion, have been largely successful, while others have not,
- ✓ appreciate why it has been difficult to achieve an effective global cooperation to address climate change,
- ✓ have insights into some of the options that could enhance global cooperation to address climate change.

Outline

7.4.1. Introduction
7.4.2. Characteristics of a self-enforcing International Environmental Agreement (IEA)
    7.4.2.1 Role of commitment
    7.4.2.2 Transfers and side-payments
    7.4.2.3 Linkage benefits and costs and reciprocity
7.4.3 Some Environmental International Agreements
    7.4.3.1 International agreements for reducing ozone-depleting gases
    7.4.3.2 International agreements on Climate Change
7.4.4 On Climate Change Agreement and Policy Timing

Summary

Discussion/Review Questions/Exercises

Materials used for the Lecture

7.4.1. Introduction

International environment problems pose a significant challenge to our economic and political institutions. This is because significant barriers confront any attempt to move toward a solution. Consider the problem of climate change, one of the most urgent environmental problem today. Any action taken to moderate climate change provides a global public good, implying the strong possibility of free-rider actions. Free-rider effects not only cause emissions to be abnormally high, but they also inhibit investment in research and development, a key ingredient in promoting innovative, low-carbon technologies. Free-rider effects also inhibit the participation of nations in the climate change agreements that are designed to correct these market failures. And unlike a normal marketed good, the scarcity of a stable, hospitable climate is not signaled by rising prices for that good.

To further complicate matters, the damage caused by greenhouse pollutants is an externality in both space and time. Spatially, the largest emitters (the industrialized nations) have the greatest capacity to reduce emissions, but they are not expected to experience as much damage from insufficient actions as the developing countries. Temporally, the costs of controlling GHGs fall on current generations, while the benefits from controlling them occur well into the future, making it more difficult to convince members of the current generation to join the mitigation effort.

The implication of these insights is that decentralized actions by markets and individual governments are likely to violate both the efficiency and sustainability criteria. International collective action is both necessary and terribly difficult. In the absence of a formal supranational political apparatus with decision-making sovereignty, the coordination of behaviour across countries seeking environmental improvements must take place through other forms of international cooperation. Formal international treaties or protocols represent the most visible outcome of that cooperation.

More than 170 international environmental treaties have been adopted to date, covering a wide range of actual or potential environmental problems. Many of the early treaties concerned regulation of behaviour at sea: marine fishing, transportation in international waters, dumping and disposal of wastes, and exploitation of the sea beds. Another set related to regional pollution spillover problems. In recent years, great attention has been paid to attempts to develop agreements about the use of two global public goods: composition of the atmosphere and the stock of biological diversity. This Module will focus on the first of these two areas.

The main vehicle that has been used in attempts to reach cooperative solutions to regional and global environmental problems is that of the intergovernmental conference (on a platform provided by the United Nations (UN) system of international institutions). The adoption of a treaty through such a framework does not of itself imply that objectives and targets will be met. However, the moral, financial and political pressures that such treaties can bring to bear may be large. Also noteworthy is the way in which the UN environmental strategy has attempted to link issues of environmental protection, environmental sustainability and economic development (the latter particularly in the poorer nations). However, initiatives through the United Nations are not the only, or even the most important, framework within which international environmental cooperation has taken place. Much of what is important has been dealt with at regional or bilateral levels, and takes place in relatively loose, informal ways.

How effective has international cooperation been? Does it merely reflect what countries would have done anyway, and so offers little real improvement over the status quo? Or have there been significant environmental (and efficiency) gains arising from cooperation? Box 7.7 presents some hypotheses (some may consider them to be 'stylized facts') about international environmental cooperation. They help guide our considerations of the above questions and to summarize the basic issues we will be looking at in this Module.

Box 7.7. Conditions that are conducive to effective cooperation between nations in dealing with international environmental problems

Game theory suggests that some conditions are conducive to effective international cooperation. These conditions include the following

- The existence of an international political institution with the authority and power to construct, administer and enforce a collective agreement.
- The output of the international agreement would yield private rather than public goods.
- A large proportion of nation-specific or localized benefits relative to transnational benefits coming from the actions of participating countries.
- A small number of cooperating countries.
- Relatively high cultural similarity among the affected or negotiating parties.
- A substantial concentration of interests among the adversely affected parties.
- The adoption of a leadership role by one 'important' nation.
- A small degree of uncertainty about the costs and benefits associated with resolving the problem.
- The agreement is self-enforcing.
- There is a continuous relationship between the parties.
- The existence of linked benefits.
- The short-run cost of implementation is low, and so current sacrifice is small.
- The time profile of benefits is such that a high proportion of the available benefits are obtained currently and in the near future.
- The costs of bargaining are small relative to the gains expected from cooperate

Source: Perman, et al., p.300)

7.4.2. Characteristics of a self-enforcing International Environmental Agreement (IEA)

A self-enforcing IEA is an equilibrium outcome to a negotiated environmental problem that has the following properties:

- There are N countries in total, of which K choose to cooperate
- Each cooperating country selects abatement level that maximizes aggregate pay-off for cooperating countries.
- Each defecting country maximizes individual pay-off.
- No signatory country can gain by unilaterally withdrawing from agreement (*internal stability*). In other words,

  $$\Pi_s(k^*) \geq \Pi_n(k^* - 1) \qquad (7.2)$$

  where $\Pi_s(k^*)$ is the pay-off accruing to a signatory country given that the number of countries cooperating remains at the equilibrium level, k^*, and $\Pi_n(k^* - 1)$ is the pay-off accruing to non-signatory country given that the number of countries cooperating is reduced by one.
- No non-signatory country can gain by unilaterally acceding to the agreement (*external stability*). In other words,

  $$\Pi_n(k^*) \geq \Pi_s(k^* + 1) \qquad (7.8)$$

  where $\Pi_n(k^*)$ is the pay-off accruing to a non-signatory country, given that the number of countries cooperating remains at the equilibrium level, k^*, and $\Pi_s(k^* + 1)$ is the pay-off accruing to a signatory country, given that the number of countries cooperating increases by one.

To arrive at such an agreement, each country that participates in negotiation of the treaty must decide whether or not to participate and also on the terms of the agreement. The terms concern how much abatement a signatory will undertake. More precisely, this requires a schedule of abatement levels, one for each possible number of other countries acceding to the agreement. Therefore, implicitly or explicitly, the terms include penalties and rewards that reflect what signatories will do if a country were to accede to, or to leave, the group of cooperating countries. This will involve developing some mechanism whereby if a country accedes the signatories increase their abatement (thus rewarding accession), or reduce their abatement if a country leaves (thus punishing defection).

Several writers have examined what kind of self-enforcing IEA we would expect to see, if any, under a variety of different circumstances (see Barrett, 1994a, 1995 for example). The main conclusions are as follows.

- Non-signatories and signatories would both do better if all cooperate. (In this respect, self-enforcing IEAs resemble a Prisoner's Dilemma game.)
- Non-signatories do better than signatories. (In this respect, the game is like a Chicken game.)
- Full cooperation is not usually stable (it is not self-enforcing and so renegotiation-proof).

- An IEA may enjoy a high degree of cooperation but only if the difference between global net benefits under the full cooperative and noncooperative solutions is small; when this difference is large, a self-enforcing IEA cannot support a large number of countries.
- When N is very large, treaties can achieve very little, no matter how many signatories there are.

As explained in Barrett (1994a, 1995), the larger are the potential gains to cooperation, the greater are the benefits of free-riding and so the larger are the incentives to defect. But the larger are the incentives to defect, the smaller will be the number of signatories. The reason here is that when N is large, defection or accession by any country has only a negligible effect on the abatement of the other cooperators. A classic example is attempt to control GHGs emissions. There the gains from cooperation are very large, and so defection is very likely. Given this, it will be difficult to secure agreement among a large number of countries.

The notion of self-enforcing IEAs is a very useful way of thinking about international environmental cooperation. However, as we have seen, it does tend to generate rather pessimistic conclusions about the effectiveness of agreements. Are there other mechanisms by which cooperation could deliver large benefits; are there factors that enhance the probability of international agreements, or of achieving a higher degree of cooperation among countries? A basic point learnt in Module 7.1 is that incentives matter. Put differently incentives that face countries could be altered to encourage cooperation. Some of the factors that have been identified include commitment, use of transfers and side-payments, linkage benefits and costs and reciprocity. Prospects of cooperation is also higher when interactions are infinitely-repeated though there still difficulties when the number of countries involved is large. We examine the role of commitments, transfers and linkage briefly below.

7.4.2.1 Role of commitment

Cooperating countries may voluntarily make commitments to do things irrespective of what others do. By giving up the right to change abatement levels in response to changes in K, any agreement that is obtained will not in general be self-enforcing. However, if the commitments are regarded as credible, then – depending on what kinds of commitments are made – it can be possible to achieve and sustain a full (complete) IEA. The difficulty here, of course, is that as commitments typically lead to self-sacrifice in some circumstances, it may be hard to make them credible.

7.4.2.2 Transfers and side-payments

Countries often differ in their costs of and/or benefits from international environmental control, thus making it harder to establish a coalition. If the gainers from an effective agreement were willing to share some of those gains with reluctant nations who have more to lose, the reluctant nations could be encouraged to join If these side payments are larger than the inducements in the original IEA. In some circumstances, such side-payments can bring about a complete IEA, and so maximize collective benefits. However, as the resulting agreement will, by construction, not be self-enforcing, we have the same difficulty as in the case of commitment; that is, such IEAs may not be credible. Indeed, transfers between countries are rarely observed in reality, at least for environmental agreements. It seems that side-payment systems will require that signatories find a way to make a credible commitment to the system (and in effect suspend the self-enforcing constraints).

7.4.2.3 Linkage benefits and costs and reciprocity

Linking benefits (and maybe cost) of participating in a particular IEA to other agreements, some other actions, or reputation, may also enhance the possibility of greater cooperation. Doing this in effect alters the pay-off matrix to the game. Countries typically cooperate (or at least try to do so) over many things: international trade restrictions, antiterrorism measures, health and safety standards, and so on. It is believed that there may be economies of scope available by linking these various goals. Moreover, reputations for willingness to act in the common interest in any one of these dimensions may secure benefits in negotiations about another. What policy makers might try and obtain is linkages over two or more policy objectives so that the set of agreements about these objectives creates overall positive net benefits for the entire set of participants, and net gains which are distributed so that every participant perceives a net linkage gain. In these cases, there can be very substantial gains from international cooperation. For example, some have suggested linking IEAs to some desirable club (like joining WTO, NAFTA, EU). Of course, this may raise 'additional' costs of cooperation, including transaction and enforcement costs, and perceived costs of interdependency itself (such as feelings about loss of sovereignty). The larger are these costs, the smaller are the possible net gains from cooperation.

Other typical candidates for linkage are agreements on trade liberalization, cooperation on research and development (R&D), or international debt. The intuition behind this approach is that some countries gain from resolving the first issue, while others gain from the second. Linking the two issues increases the chances that cooperation may result in mutual gain and, hence, increases the incentives to join the coalition.

7.4.3 Some Environmental International Agreements

7.4.3.1 International agreements for reducing ozone-depleting gases

The first global pollutant problem confronted by the international community arose when ozone-depleting gases were implicated in the destruction of the stratospheric ozone shield that protects the earth's surface from harmful ultraviolet radiation. Because these are accumulating pollutants, an efficient response to this problem involves reducing their emissions over time. In principle, this could be accomplished by either an emissions charge that rises over time or an allowance system that allows a fixed amount of emissions.

The first steps towards international control measures were taken at the **Vienna Convention** in 1985, at which agreements were made for international cooperation in research, monitoring and the exchange of information. By 1989, 27 countries had ratified the Vienna Convention. The **Montreal Protocol** was agreed in 1987, and came into effect in 1989. In September 1988, signatories to the Montreal Protocol (at that time 24 mainly industrialized countries) agreed to phased reductions in domestic consumption and production of ozone-depleting substances, and in particular to cease the production of chlorofluorocarbons (CFCs) by 1996. Developing countries could increase CFC production until 1999, after which it must be progressively reduced until it ends in 2010.

The **London Protocol**, signed in July 1990 by 59 nations, agreed to a complete phasing out of halons and CFCs by the year 2000. In addition, controls were agreed on two other substances implicated in the depletion of ozone, carbon tetrachloride (to be eliminated by 2000) and methyl chloroform (by 2005). Financial support was made available to assist in the funding of projects to substitute from ozone-depleting substances in poorer counties.

To restrict their accumulation in the atmosphere, the international agreements on ozone-depleting substances created a system of limits on production and consumption. As part of its obligation under the agreements, the United States adopted a transferable allowance system, coupled with a tax on the additional profits generated when the supply of allowances was restricted (see Box 7.8).

In 1990. the parties to the Protocol agreed to establish the **Multilateral Fund**, which was designed to cover the incremental costs that developing countries incur as a result of taking action to eliminate the production and use of ozone-depleting chemicals. Contributions to the Multilateral Fund come from the industrialized countries. The fund has been replenished seven times. As of July 2008, the contributions made to the Multilateral Fund by some 49 industrialized countries, including Countries with Economies in Transition (CEIT), totaled more than $2.4 billion. The Fund promotes technical change and facilitates the transfer of more environmentally safe products, materials, and equipment to developing countries. It offers developing countries that have ratified the agreement access to technical expertise, information on new replacement technologies, training and demonstration projects, and financial assistance for projects to eliminate the use of ozone-depleting substances. Currently, some 96 chemicals are controlled by these agreements to some degree.

Box 7.8 Tradable allowance for ozone-depleting chemicals

On August 12, 1988, the U.S. Environmental Protection Agency issued its first regulations implementing a tradable allowance system to achieve the targeted reductions in ozone-depleting substances. According to these regulations, all major U.S. producers and consumers of the controlled substances were allocated baseline production or consumption allowances, using 1986 levels as the basis for the proration. Each producer and consumer was allowed 100 percent of this baseline allowance initially, with smaller allowances granted after predefined deadlines. Following the London conference, these percent-of-baseline allocations were reduced in order to reflect the new, earlier deadlines and lower limits. These allowances are transferable within producer and consumer categories, and allowances can be transferred across international borders to producers in other signatory nations if the transaction is approved by the EPA and results in the appropriate adjustments in the buyer or seller allowances in their respective countries. Production allowances can be augmented by demonstrating the safe destruction of an equivalent amount of controlled substances by an approved means. Some interpollutant trading is even possible within categories of pollutants. (The categories are defined so as to group pollutants with similar environmental effects.) All information on trades is confidential (known only to the traders and the regulators), which makes it difficult to know how effective this program has been. Since the demand for these allowances is quite inelastic, supply restrictions increase revenue.

Because of the allocation of allowances to the seven major domestic producers of CFCs and halons, the EPA was concerned that its regulation would result in sizable windfall profits (estimated to be in the billions of dollars) for those producers. The EPA handled this problem by imposing a tax on production in order to "soak up" the rents created by the regulation-induced scarcity. This application was unique in two ways. It not only allowed international trading of allowances, but also it involved the simultaneous application of tradable allowance and tax systems. Taxes on production, when coupled with allowances, have the effect of lowering allowance prices. The combined policy, however, is no less cost-effective than allowances would be by themselves, and it does allow the government to acquire some of the rent that would otherwise go to allowance holders.

Source: Tom Tietenberg, "Design Lessons from Existing Air Pollution Control Systems: The United States." **Property rights in a social and ecological context: case studies and design application**s by S. Hanna and M. Munasinghe, eds. (Washington, DC: World Bank, 1995), pp. 15–32. Also, in Titenberg and Lewis, 2012, p

Attempts have been made internationally to use this agreement as the basis for phasing out hydrofluorocarbons (HFCs), one class of chemicals used to replace the CFCs, because they also turn out to be powerful greenhouse gases. Along with Mexico and Canada, the United States proposed a series of steps to reduce HFC production, with wealthier countries not only facing a quicker deadline than developing nations, but also providing financing for poorer countries to adopt substitutes. The Environmental Protection Agency estimates that adopting the HFC proposal could slow global warming by a decade.

7.4.3.2 International agreements on Climate Change

Climate change is appropriately considered a more difficult problem to solve than ozone depletion. In addition to the features it shares with ozone depletion, such as the free-rider problem, and the fact that the current generation bears the costs while the benefits accrue in the future, climate change presents some unique challenges. Some countries, for example, may be benefited, not harmed, by climate change, diminishing even further their incentive to control. And in contrast to ozone-depleting substances, which had readily available substitutes, controlling greenhouse gases (GHGs) means controlling energy use from fossil fuels, the lynchpin of modern society.

Attempts to secure internationally coordinated reductions in greenhouse gas emissions have taken place largely through a series of international conventions organized under the auspices of the United Nations. First steps were taken at the 1988 **Toronto Conference**, at which the principle of carbon dioxide targets was first set. The conference recommended that CO_2 emissions should be reduced by 20% from 1988 levels by 2005. This essentially specified GHG control in terms of quantitative emissions targets, rather than in terms of price incentives such as carbon tax rates. The year 1988 also saw the establishment of the IPCC. IPCC Assessment Reports have been produced each fifth year from 1990. Table 7.6 presents the evolution of agreements on climate change since after 1990.

Up to 150 countries were signatories to the Framework Convention on Climate Change (FCCC) (Rio de Janeiro, Brazil, 1992) but the large number prepared to sign reflects the situation that FCCC required no country to commit itself to a particular emissions reduction nor a timetable for any such reduction. The parties to the **Rio agreement** were still unable to agree strict emissions limits at the Berlin summit in 1995, agreeing only on a procedure for negotiating such limits (to be concluded by 1997) and accepting in principle the need for industrialized countries to reduce emissions below 1990 levels.

Table 7.6 Important Events in International Climate Change Negotiations

Year, Location	**Outcome**
1992, Rio de Janeiro	UN Framework Convention on Climate Change (UNFCCC). Countries agree to reduce emissions with "common but differentiated responsibilities."
1995, Berlin	The first annual Conference of the Parties to the framework, known as a COP. U.S. agrees to exempt developing countries from binding obligations.
1997, Kyoto	At the third Conference of the Parties (COP-3) the Kyoto Protocol is approved, mandating developed countries to cut greenhouse gas emissions relative to baseline emissions by 2008-2012 period.
2001, Bonn	(COP-6) reaches agreement on terms for compliance and financing. Bush administration rejects the Kyoto Protocol; U.S.is only an observer at the talks.
2009, Copenhagen	COP-15 fails to produce a binding post-Kyoto agreement, but declares the importance of limiting warming to under 2°C. Developed countries pledge $100 billion in climate aid to developing countries.
2011, Durban	(COP-17) participating countries agreed to adopt a universal legal agreement on climate change as soon as possible, and no later than 2015, to take effect by 2020.
2015, Paris	COP-21 195 nations sign the Paris Agreement, providing for worldwide voluntary actions (INDC's) by individual countries.

Source: Jonathan and Roach 2017

Progress in securing agreement at Berlin was primarily hampered by the existence of marked differences of interest between various sub-groups within the nations present.

Kyoto Protocol, adopted by the Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC) and which became effective in 2005, was the first step toward setting binding obligations on countries to reduce pollutants. It has several "Annexes" making separate provisions for developed, and developing countries, and countries in transition in addressing global environmental problems. The Protocol establishes binding commitments for countries specified in Annex I of the protocol (mostly developed countries) to reduce GHG emissions and allows trade of emission permits among them.

The Kyoto Protocol conference focused on five principal GHGs, and set the objective of cutting combined emissions of GHGs from developed countries by 5% from 1990 levels by the years 2008–2012. Moreover, it specifies the amount each industrialized nation must contribute towards the overall target. The Protocol did not set any binding commitments on developing countries. The Protocol is notable for its advocacy of several so-called ‘flexible mechanisms’, which are particularly interesting to economists. By generating incentives for control to take place in those countries that have the lowest abatement costs, they create the potential for greatly reducing the total cost of attaining overall policy targets. These mechanisms include emissions trading[61], emission banking, Joint Implementation and the Clean Development Mechanism (CDM).

Emission banking imply that emissions targets do not have to be met every year, only on average over the period 2008–2012. Moreover, emissions reductions above Kyoto targets attained in the years 2008–2012 can be banked for credit in the following control period. This provision will allow economies flexibility in the timing of their abatement programmes (thereby reducing overall abatement costs), while giving countries incentives to act early.

joint Implementation is a provision of the Kyoto Protocol that allows Annex I countries to implement projects that reduce emissions, or remove carbon from the atmosphere, in other Annex I countries, in return for emission reduction units. The investing Annex I country can then count the carbon benefits towards meeting its emissions targets under the Kyoto Protocol.

Clean Development Mechanism (CDM) is an instrument authorized by the Kyoto Protocol that enables both the private and the public sectors of Annex I countries (mostly developed countries) to invest in projects, which result in emission reduction undertaken in non-Annex I countries (mostly developing countries and countries in transition). The investing (Annex I) country receives credits against its Kyoto Protocol emission reduction commitments for some of the resulting reductions in the non-Annex I country.

While the emissions trading mechanism is the driving force behind the suite of cooperative mechanisms, the CDM provides a means for motivating industrialized countries (or individual companies) to invest in projects in developing countries that result in reductions of greenhouse gases. The incentive to invest is provided by the fact that investors can receive credit for the reductions that are “additional” to reductions that would have been achieved otherwise. Once

[61] Many environmentalists have criticized this provision as allowing some countries – particularly the more affluent ones such as the USA with the means to purchase credits – to buy their way out of abatement, without there being any corresponding increase in abatement elsewhere.

verified and certified, these credits can then be used as one means of meeting the investor's "assigned amount" obligation. The incentive for the host developing countries to participate comes from the fact that many of these projects increase productivity while reducing emissions. Projects that replace old coal-burning power plants with newer facilities based on photovoltaics or natural gas illustrate the point.

Emission trading with respect to climate change is also laden with controversies, ranging from issues, such as the morality of global emissions trading (see Box 7.10 for example) and concerns about weaknesses in the implementation details. On implementation, it is believed that GHG emissions trading will only achieve the goals of the Protocol if monitoring and enforcement is adequate. Monitoring and enforcing international agreements is much more difficult than enforcing domestic laws and regulations. In addition, due to the way the goals of the Protocol were specified, some countries (specifically Russia and the Ukraine) found themselves with a considerable number of "unearned" surplus allowances to sell.[62] The presence of these surplus allowances naturally lowers prices and allows countries to undertake less domestic abatement than would otherwise have been necessary.

In the Greenhouse Development Rights (GDR) framework, "capacity" is balanced with "responsibility" in terms of cumulative greenhouse gas emissions since 1990. The "responsibility/capacity index" (RCI) represents each country's obligation to contribute to financing policy responses (see Table7.7). Only those with income above a "development threshold" of $7,500 per year are obliged to contribute to the costs of greenhouse gas mitigation and adaptation. The "capacity" of a country such as China to contribute is calculated based on the proportion of the population above this threshold – about 25% in China. This system has been proposed, but never adopted, and it seems unlikely that such an agreement on sharing costs could be politically feasible. It may, however, provide some guidance for the structure of more limited agreements

[62] Since Protocol requirements are defined in terms of 1990 emissions levels and emissions in these countries have fallen below those levels due to the depressed state of their economies, the difference, known popularly as "hot air," can be traded to other countries.

Box 7.10. Is Global Greenhouse Gas Trading Immoral?

In a December 1997 editorial in The New York Times, Michael Sandel, a Harvard government professor, suggested that greenhouse gas trading is immoral. He argues that treating pollution as a commodity to be bought and sold not only removes the moral stigma that is appropriately associated with polluting, but also trading reductions undermines an important sense of shared responsibilities that global cooperation requires. He illustrated the point by suggesting that legitimizing further emission by offsetting it with a credit acquired from a project in a poorer nation would be very different from penalizing the firm for emitting, even if the cost of the credit were equal to the penalty. Not only would the now-authorized emission become inappropriately "socially acceptable," but also the wealthier nation would have met its moral obligation by paying a poorer nation to fulfill a responsibility that should have been fulfilled by a domestic emissions reduction. Published responses to this editorial countered with several points. First, it was pointed out that since it is voluntary, international emissions trading typically benefits both nations; one nation is not imposing its will on another. Second, the historical use of these programs has resulted in much cleaner air at a much lower cost than would otherwise have been possible, so the ends would seem to justify the means. Third, with few exceptions, virtually all pollution-control regulations allow some emission that is not penalized; this is simply a recognition that zero pollution is rarely either efficient or politically feasible. **Source:** Michael J. Sandel, "It's Immoral to Buy the Right to Pollute" with replies by Steven Shavell, Robert Stavins, Sanford Gaines, and Eric Maskin. THE NEW YORK TIMES, December 17, 199; excerpts reprinted in Robert N. Stavins, ed. Economics of the Environment: Selected Readings, 4th ed. (New York: W.W. Norton & Company, 2000) pp. 449–452. Also in Tietinberg and Lewis, 2012.p.

After failed efforts to produce a binding post-Kyoto agreement, the Paris conference of 2015 established a voluntary, but inclusive, program including commitments to reduce or slow greenhouse gas emissions by 195 nations (now 194 after withdrawal of the United States under the Trump administration). Commitments by the world's major emitters include a 40% pledge by the European Union, and 25-30% reductions by Russia and Japan (see Table 7.8). The U.S. has formally abandoned its 26-28% commitment, but may still move towards it as a result of state, local, and business initiatives. Prior to the U.S. withdrawal from the Paris agreement, the country had agreed to emissions reduction targets of 26-28% below 2005 levels by 2025. At the time of the withdrawal, U.S. emissions had been on a declining path for a decade, and this may continue due to state, local and business initiatives despite the change in Federal policy (see Figure 7.21). The commitments of major developing nations, like China and India, are not to immediate reductions, but rather to a reduction in carbon intensity (carbon emissions per unit GDP) and in China's case to a peaking and then decline in emissions by 2030.

Table 7.7. Responsibility Capacity Indices, Greenhouse Development Rights Framework, (percent of global total)

Country or group	Population	Capacity	Responsibility	RCI
United States	4.5	29.7	36.4	33.1
EU-27	7.3	28.8	22.6	25.7
Japan	1.9	8.3	7.3	7.8
China	19.7	5.8	5.2	5.5
Russia	2.0	2.7	4.9	3.8
Brazil	2.9	2.3	1.1	1.7
Mexico	1.6	1.8	1.4	1.6
South Africa	0.7	0.6	1.3	1.0
India	17.2	0.7	0.3	0.5
Least-developed countries	11.7	0.1	0.04	0.1

Source: Baer et al., 2007**.** Also, in Jonathan and Roach 2017

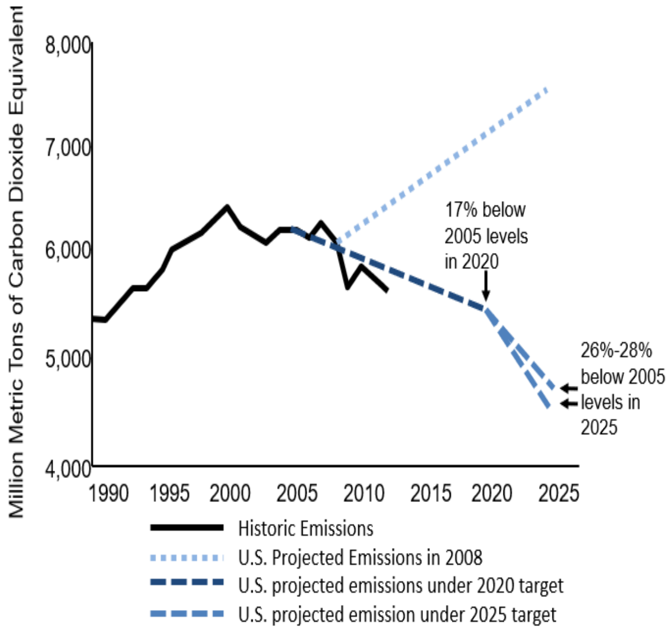
Table 7.8. INDC commitment by major emitters

	Base Level	Reduction Target	Target Year	Land-use inclusion/accounting method:
China	2005	Emissions peaking 60-65% (carbon intensity)	2030 (or before)	Target to increase forest stock volume by around 4.5 billion cubic meters
United States	2005	26-28%	2025	"Net-net" approach
EU	1990	40%	2030	Policy on land-use accounting to be decided prior to 2020
India	2005	33-35% (carbon intensity)	2030	Not specified
Russia	1990	25-30%	2030	Target depends on the "maximum absorption capacity of forests"
Japan	2013	26%	2030	Forest and agricultural sectors are accounted for using approaches similar to those under the Kyoto Protocol

Source: http:/www.c2es.org/indc-comparison. Also in Jonathan and Raoch, 2017

The Paris Agreement on climate change shifted global greenhouse-gas mitigation strategies from a mandatory to a voluntary framework, using "nationally determined contributions". Although it might appear that a voluntary framework would be less effective, the negotiating deadlock over mandatory limits made this approach unavoidable, and at least initially the results were surprisingly positive, with almost all of the world's countries pledging specific actions. Even with the reversal of the United States' position under the Trump administration, the Paris Agreement stands as an essential benchmark for progress on emissions reduction, with periodic review planned to indicate whether targets are being met or can be strengthened.

However, it is generally believed that the Paris targets are currently inadequate to meet the goal of a 2°C limit on temperature increase. Assuming the pledges were not followed beyond 2030, emissions would start to rise again, leading to an estimated temperature increase of 3.5 degrees Centigrade (see Figure 7.22). The Paris agreement, however, includes a 5-year review mechanism with the goal of extending and strengthening pledges. Even assuming that this process is successful, the 2-degree-target remains challenging. In Figure 7.23, the bar for each climate change impact reflects scientific uncertainty about how much temperatures must increase to make that impact inevitable. The darker the shading, the higher the probability the impact will occur. So, for example, if global average temperatures increase only 1°C there is a small probability that alpine glaciers will be lost. But if temperatures increase more than 2.5°C it is nearly certain that alpine glaciers will be lost based on the current research, and there is a strong possibility of Greenland ice sheet loss. The vertical bar represents the range of the Paris climate targets, from 1.5°C to 2°C.



Fig, 7.21. US Emissions Targets. **Source:** U.N Framework Convention on Climate Change. Also, in Jonathan and Roach, 2017.

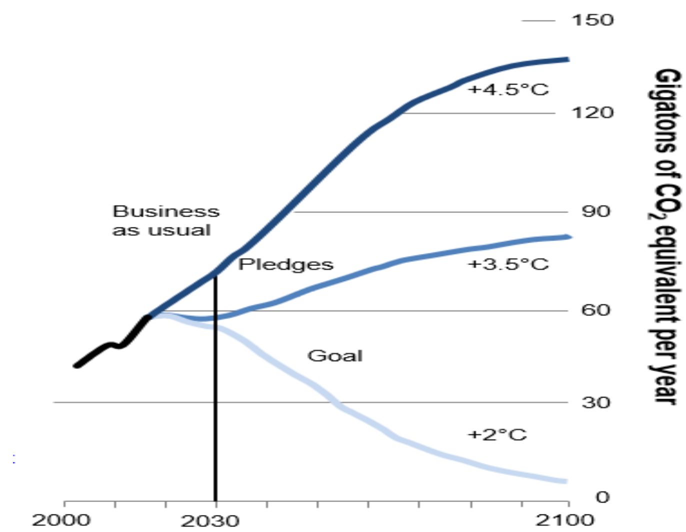


Fig 7.22. Business as Usual, Paris Pledges, and 2°C Path. **Note:** 2°C = 3.6°F; 3.5°C = 6.3°F; 2 4.5°C = 8.1°F **Source**:http://www.nytimes.com/interactive/2015/11/23/world/carbon-pledges.html?_r=1. Also, in Jonathan and Roach, 2017.

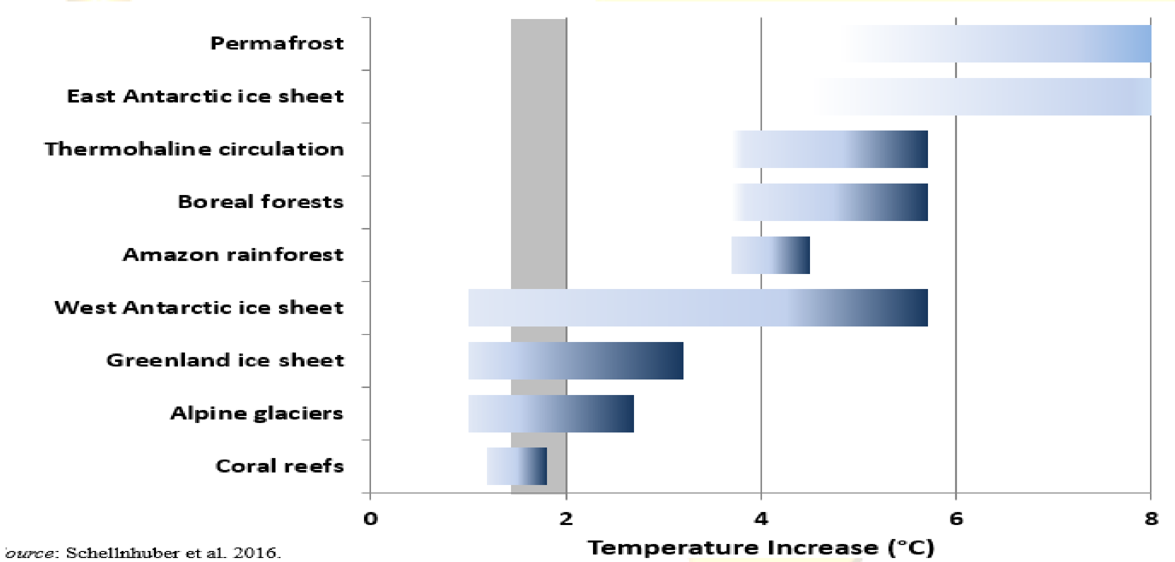


Fig. 7.23. Paris Climate Targets and Catastrophic Impacts. Note: The vertical bar represents the range of the Paris climate targets, from 1.5°C to 2.0°C. **Source:** Schellnhuber et al, 2016. Also, in Jonathan and Roach, 2017

It is worth considering whether the situation following Paris merits optimism or pessimism. One major factor is the increasingly favorable economic case for renewable energy, which suggests significant economic and environmental co-benefits for countries that choose to follow a lower-carbon development path.

7.4.4 On Climate Change Agreement and Policy Timing

What is the optimal level of current investments in greenhouse gas reduction? In order to answer this question, we must first discover just how serious the problem is and then ascertain the costs of being wrong, either by acting too hastily or by procrastinating. Because uncertainties are associated with virtually every link in the logical chain from human activities to subsequent consequences, we cannot at this juncture state unequivocally how serious the damage will be. We can, however, begin to elaborate the range of possibilities and see how sensitive the outcomes are to the choices before us. Benefit–cost studies of options for controlling climate change that ignore uncertainties in the state of our knowledge typically suggest a "go slow" or "wait-and-see" policy. The reasons for these results are instructive. First, the benefits from current control are experienced well into the future, while the costs occur now. The present-value criterion in benefit–cost analysis discounts future values more than current values. Second, both energy-using and energy-producing capital are long-lived. Replacing them all at an accelerated pace now would be more expensive than replacing them over time closer to the end of their useful lives. Third, the models anticipate that the number of new emissions-reducing technologies would be larger in the future and, due to this larger menu of options, the costs of reduction would be lower with delay.

The use of benefit–cost analysis based upon the present-value criterion in climate change discussion is controversial. Although this approach is not inherently biased against future generations, their interests will only be adequately protected if they are adequately compensated for the damage inflicted on them either by higher incomes or actual compensation. Because it is not obvious that growth in per capita well-being would be adequate, the long lead times associated with this particular problem place the interests of future generations in maintaining a stable climate in jeopardy, raising an important ethical concern (Portney and Weyant, 1999). The other reasons have economic merit, but they do not necessarily imply a "wait-and-see" policy. Spreading the capital investment decisions over time implies that some investments take place now as current capital is replaced. Furthermore, the expectation that future technical change can reduce costs will only be fulfilled if the incentives for producing the technical change are in place now. In both cases, waiting simply postpones the process of change.

Another powerful consideration in the debate over the timing of control investments involves uncertainty about both the costs and the benefits of climate change. Governments must act without complete knowledge. How can they respond reasonably to this uncertainty? The risks of being wrong are clearly asymmetric. If it turns out that we controlled more than we must, current generations would bear a larger-than-necessary cost. On the other hand, if the problem turns out to be as serious as the worst predictions indicate, catastrophic and largely irreversible damage to the planet could be inflicted on future generations.

Yohe, Andronova, and Schlesinger (2004) investigate both consequences of being wrong using a standard, well-respected global climate model. Their model assumes that decision makers choose global mitigation policies in 2005 that will be in effect for 30 years, but that in 2035 policy-makers would be able to modify the policies to take into account the better understanding of climate change consequences that would have afforded by the intervening 30 years. The specific source of uncertainty in their model results from our imperfect knowledge about the relationship between the atmospheric greenhouse gas concentrations and the resulting change in climate impacts. The specific question they examine is, “What is the best strategy now?” They find that a hedging strategy that involves modest reductions now dominates a “wait-and-see” strategy. Not only does current action initiate the capital turnover process and provide incentives for technical change, but also it allows the avoidance of very costly and potentially irreversible mistakes later. Since emissions from the “wait-and-see” strategy would be much higher by 2035, the reductions necessary to meet a given concentration target would have to be not only larger, but also concentrated within a smaller period of time. If in 2035, for example, scientists discover the need to stabilize greenhouse gas concentrations at a more stringent level to avoid exceeding important thresholds, that may not only be much more difficult and much more expensive to do later, but it may be impossible (because it would be too late).

Summary

- International environment problems pose a significant challenge to our economic and political institutions. This is because significant barriers confront any attempt to move toward a solution.

- Formal international treaties or protocols represent the most visible outcome of cooperation to address an international environmental problem. The main vehicle that has been used in attempts to reach cooperative solutions to regional and global environmental problems is that of the intergovernmental conference (on a platform provided by the United Nations (UN) system of international institutions). The adoption of a treaty through such a framework does not of itself imply that objectives and targets will be met. However, the moral, financial and political pressures that such treaties can bring to bear may be large.

- However, initiatives through the United Nations are not the only, or even the most important, framework within which international environmental cooperation has taken place. Much of what is important has been dealt with at regional or bilateral levels, and takes place in relatively loose, informal ways.

- There are conditions that favour international cooperation to solve environmental problems. When these conditions are lacking, cooperative solution may be difficult to realize.

- The notion of self-enforcing IEAs is a very useful way of thinking about international environmental cooperation. A self-enforcing IEA has some basic characteristic features. Other factors that enhance the probability of international agreements, or of achieving a higher degree of cooperation among countries the use of incentives, such commitments, transfers and side-payments, linkage benefits and costs, and reciprocity.

- In recent years, great attention has been paid to attempts to develop agreements about the use of two global public goods: composition of the atmosphere and the stock of biological diversity.

- International cooperation to reduce ozone layer depletion has been generally more effective than global effort to address climate change.

Review Questions

1. Mention and explain the characteristics of a self-enforcing international environmental agreement.

2. Distinguish between ozone depletion and climate change. Why is it that international cooperation to reduce ozone depletion has been more successful than cooperation to reduce climate change?

3. Explain and comment on the assertion that Paris targets are currently inadequate to meet the goal of a 2°C limit on temperature increase.

4. What are the prospects for an effective climate change mitigation?

5. Explain the principles involved in the Greenhouse Development Rights proposal. How do the principles of equity, capacity, and responsibility affect global climate change policy at the international level?

Materials used for this module

1. Jonathan M. Harris and Brian Roach (2017), **Environmental and Natural Resource Economics** *4th Edition*, Routledge.
2. Perman, R., Ma Y., McGilvray J. and Common M. (203). **Natural Resource and Environmental Economics**, *3rd* Edition, Edinburgh, Longman.
3. Titenberg, T. & Lewis, L. (2012). **Environmental & Natural Resource Economics** 9th Edition, The Pearson Series in Economics

Module 7.5. Application to Sub-Saharan Africa (1 hour)

The Modules in this section (7.1 through 7.4) have addressed international environmental problems. We focused particularly on global greenhouse gas (GHG) emission and climate change, and free trade and environmental degradation. Both issues are of paramount concern to Sub-Sharan Africa.

As indicated in Module 7.2 Sub-Sharan is one of the continents that is likely to be more heavily affected by climate change. The high dependence on natural resources, the significant role of agriculture in the economy and in livelihoods, and the high level of poverty, make the Continent more at risk. Yet, it is least equipped to undertake largescale effective mitigation and adaptation strategies. Low income level and poor governance, including ineffective service delivery and corruption, throw up significant challenges for many countries in the Continent. The Continent's weak bargaining position, relative to others, also means that there is not much countries can do to coerce heavy polluters, such as China, India and many countries in the global North, into an agreement to scale down emission or even implement decisions reached under any Protocol.

In the area of trade, many Sub-Saharan African countries are exporters of mainly primary products. The Continent is also home to many wildlife species. A large proportion of countries depend on minerals for foreign earnings and even government revenue. For many countries, environmental regulation in the extractive sector is abysmally weak. In addition, the Continent heavily depends on import of manufactured goods. Given the weak regulatory quality in many countries, there are significant risk on the environment that are associated with free trade.

There is scope for cooperation to manage regional commons, regulate trade. or address international environmental problems among countries in Sub-Saharan Africa. The series of lectures under this topic assist us to know that such agreements are possible and could be effective under certain conditions. They also show that cooperative outcomes can be difficult to achieve.

There are many issues arising from the lectures in these Modules that particularly relate to Sub-Saharan Africa and can be taken up in class/group discussions or undertaken as assignments or term papers. They include the following

Climate change

Climate change and agriculture: There is a growing interest in the impact of climate change on agricultural productivity in Sub-Saharan Africa, particularly at country levels. Interesting areas that may be considered include

- **L**inking climate change, agricultural productivity and poverty and the effectiveness of climate change adaptation strategies.

- The feedback mechanisms between climate change and agriculture arising from efforts by local farmers to raise productivity through intensive use of pesticides etc. Of interest here are such issues as effect of climate change on agricultural exports, climate change adaptation practices in the agricultural export sector.

Climate Change agreement: What can be done to increase the benefits to Sub-Saharan Africa from participation in climate change agreements?

Trade and Environmental degradation

Relevance of the pollution haven hypothesis and the race to the bottom. Investigations can be carried out at national and cross-sectional levels. Interesting questions that can be asked include

- whether there are differences in outcomes among countries arising from difference in the structure of their economies.

- Whether there are differences in outcomes among countries with similar characteristics. What accounts for differences, if any? What is the significance of environmental policies and regulatory quality on outcomes?

Trade agreements in environmentally-damaging substances/resources.

- How successful has been the ban on global trade in Sub-Saharan Africa's endangered species? What are the limiting factors if any?

- The Kimberly process was introduced to regulate global trade in diamonds and prevent trade in 'blood diamond'. There have been suggestions to introduce similar control processes to trade in 'blood oil' (or 'dirty oil'). Why has this been difficult and what are the prospects?

Regional trade agreements

- How successful has been regional trade agreements within the continent. What effects have regional trade agreements had on environmental quality in participating countries?

Free trade and the WTO

- Are there factors that particularly put the Continent or countries in the continent in a weak position in relation to free trade and the environment?

International cooperation to manage regional commons

- How successful has been international cooperation to manage regional commons in the continent? Examples include the Nile river in North Africa, Lake Victoria in East Africa, and the Chad basin in West and Central Africa

The supplementary materials listed in the course outline on this topic provide materials which deals with some aspects of these issues/problems.

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2. Prof. Aderoju Oyefusi, University of Benin, Nigeria. (Email: aderoju.oyefusi@uniben.edu; aderojuoyefusi@yahoo.com);
3. Dr. John Mutenyo, Makerere University, Uganda. (Email: jkmutenyo@bams.mak.ac.ug; jkmutenyo@yahoo.com);
4. Prof. Samuel A. Igbatayo, Afe Babalola University, Nigeria. (Email: remisamuel2002@yahoo.com).

Thank you.

Facebook Twitter Website Email Website

Our mailing address is:
African Economic Research Consortium (AERC)
3rd Floor, Middle East Bank Towers, Jakaya Kikwete Road
P. O. Box 62882
00200 Nairobi
Kenya