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Economics in the Air: An Introduction to Economic Issues of the Atmosphere and Climate

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PREFACE

Many of the problems societies face today are not limited in accordance with the boundaries of the traditional scientific disciplines. This situation holds especially true for environmental problems. While on the one hand economic activity is the principal cause of environmental problems, economic analysis is increasingly called upon to be an arbiter of problems which have in turn been studied by, for example, atmospheric scientists, ecologists, geographers, and agronomists. Just as economists often have difficulty understanding the results of research in the natural sciences, the framework and possibilities for economic analysis are often poorly understood by natural scientists, engineers, and others when they undertake joint studies of problems which require an integrated multidisciplinary approach. Such mutual lack of comprehension has been evident, for example, in recent efforts toward analysis of the effects of long-term climatic change. This paper is intended as an introductory, but broadly inclusive essay for investigators setting out on the study of various aspects of atmospheric issues for which economic analysis may be relevant.

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ECONOMICS IN THE AIR -- An Introduction to Economic Issues of the Atmosphere and Climate

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> *Is it conceivable...that a scientific calculus exists for deciding what increases of environmental disruptions and frequencies of disease are acceptable in exchange for such-and-such advantages of industrialization, and what are not?*
>
> *We will never be able to judge what is good or bad with respect to nature if we do not from the outset start with a normative concept of nature, including the recognition of nature as our own nature.* *(Meyer-Abich, 1979)*

INTRODUCTION

The atmosphere is obviously recognized as an asset to society. Yet, long after this asset has begun in certain respects to become scarce and valuable, societies continue to treat the atmosphere as if it were limitless and endlessly assimilative. Because for most purposes the atmosphere carries no price, and because many of the consequences of use of the atmosphere are felt far away in space and time, individuals and industries use it with freedom, rarely economizing on it as one normally would with a conventional factor of production. Of course, the atmosphere is one of a class of environmental goods which has been treated this way. As Kneese and Schultz (1975:1) have commented:

> To an important extent the nation's economic and social structure has been conditioned by the fact that, historically, we have paid little attention to the problems of the environment. Goods and services have not commanded a price to cover the real environmental costs that their production and use imposed on society. As a consequence, we have enjoyed cheap automobiles, paper, chemicals, food, energy, and a host of other products while suffering a deteriorated environment.

And now, for example, climatic change may take place because the institutional arrangements of societies encourage heavy use of environmental assets.

But, just as the costs of a deteriorated environment are real, so are the costs of the alternative. In most circumstances, the value of resources that might be directed toward controlling emissions into the atmosphere will not be available for meeting the other wants of societies. It is not merely a question of capturing profits from oil and coal companies, but of altered and probably higher prices and taxes which everyone will be paying for a modified or different set of commodities, some of which are environmental. Thus, making policy with respect to climate or other aspects of the atmospheric environment confronts us, especially as higher levels of control are proposed, with choices between environmental quality and other aspects of the standard of living. There is obviously no such thing as a "forever wild" position with respect to the atmosphere. The societal choice with respect to the atmosphere is almost never whether or not to have an activity, but to determine up to what level a particular activity should be undertaken, and how one activity should be balanced against another.

While struggles over well-identified wealth are all too evident, it is also true, as Wilkinson (1979:254) has commented, that from an economic point of view conflicts tend to proliferate in a setting where no competing party or interest group is accurately informed about the value of resources in question. In trying to decide how much, if any, of an atmospheric activity should be undertaken, this problem of a lack of information is severe. At a basic level there is a need to improve analytical criteria for use of atmospheric resources. There is a need, with respect to certain crucial uses, to develop these one by one, on a partial basis. There may also be a need for a broader analytical approach, which permits the simultaneous determination of the value of many activities related to the atmosphere, if economic criteria are to be applied to the entire set of uses of the atmosphere in order to allow us to consider the welfare implications of tradeoffs between alternative uses or groups of uses.

This paper is an introduction to issues and concepts in economics which are relevant to explaining the current condition of the atmosphere and to some perspectives which may be useful in advancing management of atmospheric resources. It is an attempt at breadth and inclusiveness, and as such may be informative primarily for researchers from disciplines other than economics, or as preliminary material to the more sophisticated and detailed analysis related to atmospheric problems which is currently being conducted by Kneese, Lave, Ayres, and others. The paper begins with a discussion of the concept of common property, and a survey in the framework of national income accounting of what the uses of the atmosphere are. Then, it examines some of the problems economic analysis has with evaluating the atmosphere, largely because of problems of externalities and technical difficulties in arriving at consistent and reliable cost and benefit estimates. Implications for allocative efficiency and equity are discussed. Finally, the paper looks briefly at the potential application of decision analysis for the major conflicting uses of the atmosphere and concludes by examining various obstacles to the improvement of atmospheric management.

THE ATMOSPHERIC COMMON

In recent years discussions in international law and economics have frequently referred to problems of "common property resources" and "the global commons." What are these concepts? Do they shed light on the condition and problems of the atmosphere?

First, let us look briefly at the history of the term "commons." Commons originally referred to a form of land tenure widespread during the Middle Ages in England and in continental Europe. This form of land tenure probably reflected elements of ancient practices or customs which had survived the Roman conquest of northern Europe and were maintained, in partial form, on feudal estates. As Schauer (1977:69) describes it:

> Areas of the feudal estate (were) more or less permanently set aside for continuing common use. These included forests, pastures, ponds, streams, and wastelands. Although these areas remained under the political and legal authority of the feudal lord and/or other civil authority, custom reserved them for specified uses by all the inhabitants of the estate. Customary uses included the gathering of wild vegetables and fruits, lumber, fuel, water, dirt, stones as well as pasturage, fishing, and fowling. Commons also provided housing sites for the landless poor, and offered locations for social and recreational activity of the community.

As these lands and their associated resources became more valuable, or in economic terms, scarcities arose relative to the demands being made, the customary forms of jurisdiction and land use began to break down. In the case of land, the usual response was to carve up the area in question and transfer ownership to individuals. This was the main characteristic of the so-called "enclosure movement" in England. The feudal commons basically succumbed to pressures of population and income encouraged by technologies which made profitable cultivation possible in previously undesirable areas.

While the historical land commons have all but disappeared, the concept of commons has been used increasingly to refer to various other shared resources, for example, river systems and lakes. A number of such common property resources—major river systems, some inland lakes and seas, Antarctica—are shared by several nations. Some are, or are potentially, shared by all nations. These are the great "global" commons—the oceans, the atmosphere, the electromagnetic spectrum, and outer space. But these global commons are not quite the same as the traditional commons, as well as being diverse among themselves. The dominating sense of them is not that they are the property of some identifiable individual entity and subject to use by a traditional community, but that they are part of the "common heritage" of all nations and people, either in terms of established or anticipated access. The global commons may be used by all nations but are the property of none.

Clearly, each common area has distinctive characteristics. For example, the fluid realms, the oceans and atmosphere, have been regarded in a way somewhat different from common agricultural lands.

> Ubiquity has created feelings which are deeply ingrained in the human experience against exclusive ownership of large parts of these realms. International law has reflected this sentiment in the durable doctrine that these realms are *res nullius*, the property of no-one (Brown, *et al.* 1977:5).

Thus the regime which prevailed on the high seas was one in which property *per se* did not exist. But, while the seas themselves were the property of no-one, the capacities of the seas, which were assumed to be unlimited, were a thing held in common, a *res communis*, available for anyone's exploitation. Freedom of access for transportation, fisheries, waste disposal, and so forth, could be maintained almost without any group restricting access to others for these or for other purposes. While the resources were little managed, and said to be the property of no-one (or anyone), it is not correct to say that the oceans were ungoverned. As Wilkinson (1979:251) has noted, one of the conditions for the maintenance of this system was the military and economic domination of the world by those powers best served by open access. In the case of the oceans, this role was played largely by the British. There has been no parallel in the atmosphere to the British role on the oceans.

Where the atmosphere has been less politically salient and organized than the oceans, until the 20th century atmospheric politics and law reserved the atmosphere as an open space similar in important respects to the ocean. One may say that the atmospheric regime met the conditions proposed by Wilkinson in that the heavy users of the atmosphere, for example, those involved in the coal economy, were nations or firms well served by open access, and they were militarily and economically dominant. A second condition offered by Wilkinson for the maintenance of a system of open access to the seas was the slow evolution of technology for industrial, transportation, and military purposes, and, indeed, many of the techniques which underlie present use and exploitation of the atmosphere were similarly little used or unknown until this century.

As use has intensified and the need has grown to enforce, for example, pollution control and traffic separation, there has been a movement of "enclosure" with respect to the oceans and atmosphere comparable to what took place with common agricultural lands. Coastal states have increasingly asserted legal, political, and economic control of nearby marine areas in the case of the oceans, and in the case of the atmosphere, nations have increased their claims to overlying airspace in various respects. If parts, or characteristics, of the atmosphere are being "enclosed," can the atmosphere still meaningfully be considered a common either at a global or national level?

In his effort to define a common for outer space, Schauer (1977:69) postulates four requirements:

(1) a common must exist within and as a part of a wider rule or custom;

(2) a common must be identified by practical laws or rules which distinguish it from what is not a common;

(3) a common must be open to community or public use and closed to exclusive appropriation;

(4) a common must be, by nature or as a result of laws or rules applied thereto, in such a condition that use by some does not preclude or significantly interfere with use by others.

While reservations may be expressed with respect to the atmosphere for all four of these postulates, one may argue that the atmosphere still maintains much of the character of a common. Of course, both the jurisdictional scale and the degree to which the atmosphere is a commons vary with respect to the uses of the atmosphere under consideration. That is, with respect to carbon dioxide emissions and climate change, we may need to think of the atmosphere as a global common, but with respect to another case of waste disposal, or a different use, the atmosphere may be considered as the property, or shared resource, of a smaller community.

In considering the first of Schauer's requirements, one may point to the growing body, both nationally and internationally, of what may be called "air law." At the national level this is often in the form of ambient air quality standards and emissions standards. The implication of much of this body of material is clearly that the atmosphere is to be treated as a commons. In a similar fashion (and perhaps equally problematic) we find a growing body of case law, treaties, and declarations among nations about the atmosphere. The earliest important event in the international context was the "Trail Smelter Case," a case of transboundary air pollution involving the US and Canada. A number of relevant doctrines emerged from the United Nations Conference on Human Environment, held in Stockholm in 1972:

Principle 21—calls on states to ensure that activities within their jurisdiction or control do not cause damage to the environment of other states or areas beyond the limits of their national jurisdiction.

Principle 22—calls on states to cooperate to develop international law regarding liability and compensation for victims of pollution and other environmental damage.

Recommendation 70 calls for states to:

> evaluate carefully the likelihood and magnitude of climatic effects from a contemplated action, and to disseminate these findings to the maximum extent feasible before embarking on such activities;
>
> consult fully with other interested states when activities carrying a risk of such effects are being contemplated or implemented. (Quoted in Kellogg and Mead, eds., 1977:82).

More recently one may cite the Nordic Air Pollution Convention, various agreements on weather modification, and efforts to prepare "Draft Principles of Conduct in the Field of the Environment for the Guidance of States in the Conservation and Harmonious Utilization of Natural Resources Shared by Two or More States." (Adede 1979 and UNEP 1978.)

The second requirement of a practical delimitation of space is not neatly fulfilled by the atmosphere. There are difficulties in specifying where the atmospheric common begins and ends. One might roughly suggest that the atmospheric commons begins beyond highly defined local environments, is questionable above an altitude of 50 miles, and may, in some sense, be "stronger" where associated with other common resources, for example, over a national park or over the high seas. For the lower portion of the atmosphere (the troposphere) and the local atmospheric environment, to such an extent as the distinction may be drawn, legal control and rights of use have been established on a municipal, provincial, or national scale. In the upper atmosphere (stratosphere) control and rights have not been clearly established. Again, the nature of the use of the atmosphere is crucial. For example, with regard to certain spatial uses of the atmosphere, like air transport, access to the atmospheric environment is under the control of the sovereignty directly underneath it by provisions of common law and international treaty. Indeed, for certain purposes, according to Schachter (1977:75) "...we are accustomed to the legal principle that the airspace over a country is part of its national territory and entirely under its control." But this still leaves definition of ownership far from complete. Specifically, how does one allot the atmosphere over the oceans or the upper atmosphere? In conclusion, one can only say that for certain purposes and problems, the atmosphere is a global common, for other probably a national common, for others perhaps a local common, and for others it still remains undefined. And with the introduction of novel regulatory devices, like marketable emission permits, new categories may yet need to be created.

Schauer's third postulate, that a common is necessarily open to community use and closed to exclusive appropriation, well suits the essential physical character of the atmosphere. The atmosphere is mobile, nondivisible, and has little natural basis for being apportioned. It is impossible to separate the atmosphere into physically or biologically unique contents over each sovereignty. From the point of view of waste disposal, it is clear that mixing takes place on geographical scales which have little or nothing to do with political or legal boundaries. Similarly, local supplies of climate are indissociable functions of the global climate system. Even local weather conditions, which may appear to "belong" to a particular area, especially where natural barriers are important features, are self-contained only in a very limited sense, as no local patterns are decoupled from larger circulations.

While the physical character of the atmosphere undermines any attempt at appropriation, firms might be said to be evolving in effect a certain sort of proprietary right by obtaining leases and permits, or even by conforming to certain standards. However, ownership in the more powerful sense of "exclusive authority to dispose of, confer rights to, or otherwise affect the conditions of some thing or place" (Brown *et al.* 1977:10) is remaining either in the hands of the community or in the hands of no-one. Another way of expressing Schauer's third requirement is that the atmosphere may be said to conform, to a considerable extent, to the economist's criteria for a collective or public good: joint availability, non-exclusion, and non-divisibility. There is open access and free use for most purposes: no individual or firm owns the atmosphere, very few can be denied entry, and there is little collection of economic rent for its use.

Schauer's final requirement is not only a part of the definition of a common, but also a condition for its maintenance. In effect, it says that a common must either be so rich as to accommodate all its users without conflict or that it must be successfully regulated. Why is this final qualification needed? The answer is that the dynamic of the previous postulate of open access is what Hardin (1968) aptly called "The Tradegy of the Commons." What is this tragedy and does it have any applicability to the atmosphere?

In general, one sees that, historically, norms of open access and free use which traditionally characterize the use of commons are incompatible with resource scarcities, and that these norms give way to various forms of allocative regimes. Problems have arisen primarily because already accessible regions and resources of commons are being exploited more intensively. Conditions of abundance change to conditions of scarcity, and resources are severely despoiled or depleted. Problems have also arisen sometimes because scientific and technical developments have made it possible to exploit previously inaccessible portions of the earth's common resources. As Brown *et al.* (1977:22) have commented, if the supply were inexhaustible or infinitely elastic, increase in demand would simply cause greater extraction or utilization of a particular resource, often through the development of technologies to reach previously inaccessible supplies. However, in some categories, like fishing, demand for the resource has been rising at a rate which is substantially greater than the supply, and, thus, the applications of new technology may have served only to accelerate the depletion of the supply.

The recognition of scarcity of common resources and the increasing possibilities for the abuse of land and non-land environments have "increased the impetus for extended national ownership to assure supplies and control of at least adjacent areas, and, on the other hand, have stimulated discussions of forms of international ownership as a means of assuring responsible national and private use." (Brown *et al.* 1977:10.)

In general, as Morse (1977) argues, technological change, crowding, environmental degradation, and the growth of complex interdependencies have created new problems of managing common property in society, both nationally and internationally.

In the case of atmospheric resources, the supply is becoming increasingly scarce not only because of the characteristics of each resource use, but also because the uses are not independent—nor are their supply conditions. For example, consider the use of the atmosphere as a medium of transport. Use of the spatial characteristics of the atmosphere for transportation is not one that consumes, or destroys, the spatial characteristics with use. However, congestion problems do arise, and users have to be coordinated. Moreover, use of the atmosphere for transportation may interfere with other uses. For example, at one time it was believed that the residuals associated with stratospheric transport would diminish the capacity of the atmosphere to shield the biosphere from damaging ultraviolet radiation. Another conflict and potential scarcity arises from the use of the atmosphere as a receptacle for waste and as a modulator of the supply of climate. Climate is depletable from an economic point of view: the supply available and suitable for productive activity may augment or diminish. One does not ordinarily think of weather and climate as scarce commodities, but it can be argued that in many parts of the globe the demand for certain kinds of weather and climate regularly exceeds the supply. While there are natural variations of the supply of climate on all time scales, in the last decade a series of human activities involving the atmosphere as a receptacle for waste (for NO_x, CFMs, CO_2, dust, and so forth) has raised the specter of a long-term climatic change. Here then is a fascinating tradeoff between functions of the atmosphere as a receptacle for waste and as a "supplier" of climate. There are other important tradeoffs involving use of the atmosphere for waste disposal, for example, with clean (healthy) air and with clear (aesthetically pleasing) air.

So again, we find that according to which use is under consideration, the atmosphere is to varying degrees a common. For certain purposes, like the supply of oxygen, it remains "by nature" in a condition that use by some does not preclude or significantly interfere with use by others. For some purposes, like air transport, this is true as a result of rules and laws applied to it. For other purposes, principally those relating to waste disposal, the atmosphere may manifest growing characteristics of the tragedy of the commons, where there is a deterioration of quality or decrease in supply. The commons characteristics of the atmosphere may then explain a good deal about its current state and have important implications for attempts at management.

Meanwhile, policies for the most part continue to treat the atmospheric common as if its supply were infinitely elastic, that is, as if there were no expectations of future prices changes. "Allocations" take place most often on the basis of unilateral appropriation, or, in some cases, by more widely agreed methods of determining rights and use. Priority tends to go to first and current users, and important attributes, including "nonexcludability, absence of congestion, and something that might be called renewability (i.e., the asset recovers so that use by one individual does not impair the asset for use by others)," (Krutilla and Fisher 1977:23) are diminishing. What economists usually suggest in such cases is a mechanism for rationing the resource, ending free and unrestricted access for all. What is happening, particularly at the international level? While the "Law of the Seas" has been the subject of much debate, the atmosphere has received much softer and vaguer treatment to date.

Clearly, the principles and recommendations for utilization of the atmospheric common offered internationally so far are very noncommittal. But then, as Daly (1975) points out, to say that anyone whose use of a common property resource damages others should actually be liable for that damage is, implicitly, a statement of who should own that resource. And that the issue, as we have seen here, is often unresolved.

Is the appropriate social response to the need to manage or allocate the resource to convert common property into private property or into more definitive public property? And, if public, at what scale? The more people who are included in Schauer's phase "use by others," the more the tensions that arise between postulates about open access and nondestructive use. "Who is included in *res communis*—all those now living, or all those now living plus all those still to come? Does the present generation own the resources outright or only in trust for future generations?" (Brown *et al.* 1979:8.)

AN ATMOSPHERIC SECTOR?

Is it possible to conceive of an "atmospheric sector" in the economy? Pontecorvo and Wilkinson (1977) have been developing a sectoral approach to the oceans within a national income accounting framework with interesting results (see also Nathan *et al.* 1974). Could a similar analysis succeed for the atmosphere? It is not difficult to see that in some senses the atmosphere may be regarded as a commodity or a bundle of economic goods, but it remains to be seen whether some sort of "atmospheric sector" may be useful in examining either the relationship between an atmospheric sector and the rest of the economy, or the relationship between subsectors within an atmospheric sector. In order to build a useful analytical tool, it would be necessary first to identify the economic uses or resources of the atmosphere. In other words, what stocks or flows of wealth are associated with the atmosphere? One must have some classification scheme. Let us explore the possibility of an atmospheric sector using two general categories of economic activity: those which extract or capture resources (living, energy, mineral, water, etc.) from the atmosphere or relate primarily to its chemical constituents, and those which require the physical use of atmospheric space (transportation, waste disposal, etc.).

How does the notion of extracting or capturing resources apply to the atmosphere? Certain mineral resources, for example, nitrogen and oxygen, might be regarded as part of an extractable atmospheric stock of wealth. In addition, it might be argued that climatic variables ought to be included. Climatic variables are ordinarily not viewed as direct factors of production, subject to manipulation by the user. "Instead, these variables operate through changes in the production function, and thus, affect the level of output by changing the productivities of the direct factors of production or by affecting the choice of the production process employed." (Crocker (d'Arge) 1975, section 3: 84.) Nonetheless, it may be possible to conceive of climate as resources of matter and energy captured from the atmosphere.

Meteorologists usually talk as if climate is simply a set of statistics, rather than anything tangible which can be regarded as a resource. Yet, if an economist were to describe weather modification to a meteorologist as an attempt to bring about an enhancement or redistribution of climatic resources, I think it would be an acceptable statement. From an economic point of view, climate is matter and energy organized in a certain way. If a climatologist were to say to a farmer that the climate is going to change, the farmer could interpret this to mean that deliveries of matter and energy may be going to change in quantity, time, and place, in ways similar to how supplies of fertilizer or gasoline might change.

Of course, the climatic variables are not exclusive to the atmosphere. Various constituents come into and out of the atmosphere; for example, in the hydrologic cycle, water goes into and out of the ocean, land surface, and so forth. Indeed, climate variability and change are functions of the overall "climatic system," of which the atmosphere is only one component. However, on time scales of interest from an economic point of view, say, months to several generations, climatic variables may be treated primarily as attributes of an atmosphere-centered system. From a scientific point of view, this is not entirely correct, as short-term climatic variability and longer-term change may on these time scales be a function of, for example, behavior of the oceans or the sun, but for purposes of economic analysis the variations in the supply of climate and potential changes can still conveniently be regarded as functions of natural atmospheric turbulence and as consequences of other human uses of the atmosphere. Exceptions to this, as they are more definitively explained, could be treated separately. Clearly, a satisfactory definition of climate for purposes of economic analysis has not yet been arrived at, and it is a question which warrants further examination. One interesting approach may be to explore the economic meaning of climate through von Weizsaecker's (1971) resource triad of matter, energy, and information, through which climate cuts in an unusual way. However, for the time being let us use the idea sketched above.

In identifying uses of the atmosphere for potential evaluation, one must also inevitably caution that if one were to evaluate completely the uses, their value would be incalculable or infinite, because the atmosphere is a necessary component for life. The entire supply of 6×10^{15} tons of air may not be indispensable, but every adult human must breath about 30 to 35 lbs of it each day to extract the oxygen necessary for life. So, we must look for uses for which in some sense economics is relevant.

Is there a non-trivial sense in which the atmosphere can be regarded either as a source of minerals or from the point of view of its chemical constituents? While "clean" air may be a complex and difficult term to define, if the atmosphere does not provide a certain level or amount of this, there can be serious health effects, and, thus, supplies may be discussed in economic terms. Another mineral the atmosphere provides, although perhaps in a trivial sense, is nitrogen. Fixed nitrogen, mostly in the form of synthetic ammonia, is compacted by industrial processes from the atmosphere's gaseous supply in enormous quantities for agricultural fertilizers. However, this nitrogen, which composes about 78% of the atmosphere, is in such plentiful supply (price essentially zero), that analysis may be superfluous. Another set of functions of the atmosphere relates to its role as a protective shield. The ozone layer, for example, acts as an important shield against incoming ultraviolet rays. This is not an extractive role, narrowly defined, but as a function of the chemical composition of the atmosphere, it may be left in our first category. The weather and climate variables, principally rain, insolation, and wind, may be regarded as either mineral or energy resources. Finally, one could attribute birds to a category of the living resources of the atmosphere.

Uses of the atmosphere emphasizing physical space include the various functions of the atmosphere as a medium, as, for example, for transporting people and goods, or signals. The uses for transport would also include military uses, for example, for reconnaisance, and for testing and delivery of weapons. A similar use is as the medium of departure to and entry from outer space.

Certainly the most important and difficult spatial use of the atmosphere, from an economic point of view, is as a receptacle for waste. The role of the atmosphere as a receptacle for waste was taken for granted for many years. The quantities involved were relatively modest and geographically distributed, and the substances themselves were usually not inherently very dangerous. Under such conditions, taking advantage of the atmosphere's capacity to transport, dilute, and absorb wastes was generally a health way of disposing of them, for both humans and the environment. However, in a modern economy, waste disposal becomes a serious and pervasive phenomena, rather than a trivial and exceptional one. The contributors are various: transportation, stationary fuel combustion, industrial processes, and agricultural burning. Some products are intentionally disposed, and some are residuals, from both intermediate production processes and final consumption. There are primary pollutants: dust, soot, ash, and smoke. There are secondary pollutants: hydrocarbons, and oxides of nitrogen, sulfur, and carbon.

With respect to the atmosphere, the immensity of the problem of waste disposal can be impressively illustrated with carbon. The earth harbors enormous reservoirs of carbon in the form of gas, oil, coal, and biomass. These undergo combustion, primarily to produce energy for human uses, and as the carbon from these reservoirs is "consumed" by the economy, it must be "disposed" of in the atmosphere, oceans, and biosphere. The apparent inevitability of the exploitation of the earth's carbon wealth and concomitant transfer of huge volumes of carbon dioxide to the atmosphere pose one of the most interesting questions as to what the present state of our atmosphere and its climate are worth. If one were to apply some sort of "residuals generator" to our current economic and technical processes and extrapolate decades into the future as has been done for carbon dioxide, many other ominous quantities would undoubtedly appear destined to find a home in the atmosphere.

Use for disposal of wastes also raises an issue which one familiarly confronts in identifying the value of natural environments: there is a tendency to regard these environments as having value only when they are assumed to offer a future store of extraction, or, in this case, of assimilation. Problems are often considered in terms of the optimal rate of depletion. However, resources may also have another value, realized only if they are left alone. There is a value from an undistrubed environment. An important set of spatial uses relates to such "environmental" or amenity functions. The atmosphere is an important source of aesthetic and recreational values. Even when left alone, one may assume the atmosphere is generating a service, which is degraded by the accumulation of wastes. Amenity and asethetic values may be perceived in terms of wage differentials and land values. Indeed, one recent study (Kneese and Williams 1980) suggests that maintaining atmospheric visibility may be the key constraint to development of energy resources in the southwestern part of the United States. Some features of weather and climate, including nuisance costs of snow removal and so forth, might also be analyzed in some sort of framework of amenity (and disamenity) uses.

While one can tentatively identify a range of uses of the atmosphere (see Table 1), would it be possible and useful to arrange these into some sort of "atmospheric sector" in the style of national income accounts? National income accounts have traditionally sought spatial unity by country or political entity, and for purposes of policy analysis they are divided into production sectors, usually defined by purposes of intermediate production and final consumption. An atmospheric sector could be seen as a further step in developing the two-dimensional spatial and product matrix of economic accounts which describe the economy (cf. Pontecorvo and Wilkinson 1977). To include an atmospheric sector consistently in the larger set of national accounts, it would be necessary to identify which product sectors have activities originating in both the atmospheric and non-atmospheric spatial sectors and identify what portion of each product sector's output is due to the atmospheric sector. The atmospheric sector might be defined as the element of the overall production vector containing those goods and services whose value added can be directly identified with either an extractive or spatial use of the atmosphere, or more broadly, which directly utilize some characteristic of the atmosphere as an input in their production function.

Table 1. An Atmospheric Sector—Outline.

Major Divisions	Activities
I Resource Extraction or Capture	
A Energy Resources	Insolation Wind
B Mineral Resources	Rain (Net Evaporation) Nitrogen Oxygen and ozone CO_2
C Living Resources	Birds
II Spatial Activities	
A Commerce and transport	Air transport, service and handling; departure to and entry from outer space
B Commercial and other	Recreation and sports (amenity, aesthetic) Scientific research Waste disposal Communication
C Construction	Airport facilities Aircraft
D Government (federal, state, local)	National security Administration of air control Weather forecasting Transportation enforcement

Clearly, some value added from production which is identified with the atmosphere takes place on land. The aircraft industry might be a case of this. Indeed, because of the interdependence of economic and physical systems, all sorts of activities might be said to owe their existence to the atmosphere. So, it is necessary to limit the definition of the sector in some meaningful way. The overall measurement system would need to adhere to consistency and independence conditions. Imposing a consistent spatial definition across productive subsectors might be difficult.

To accomplish the actual measurement of income associated with some satisfactorily defined atmospheric sector, it would be necessary to specify the method selected for evaluation of each sector, and adjust for possible non-equivalence of methods. The need for adjustment raises problems from several points of view. Later, some problems relating to evaluation techniques for climate will be discussed. These are largely problems of different cost measures. But, there are also questions about what and where in the production process to measure. These can be illustrated by considering the difficulties involved in evaluating the atmosphere as a receptacle for waste.

First, there is the question of what is waste, or at what point residuals need to be accounted for economically. Wastes may be defined in contrast to "products." From an economic point of view, products can be sold at positive prices, while wastes cannot, or the cost of recovery is more than the value of the recovered material (Page 1977). Pollution goes beyond mere waste. Rothenberg (1970:35) characterizes it as "a competing and dissimilar use of the environment which alters the characteristics of the environmental resources in a way that is in some sense destructive, and in which there is a uni-directional flow of the costs associated with resource exploitation." Thus, by these definitions, CO_2, until its consequences are better understood, should not be labeled a pollutant. Unfortunately, the distinction between constructive and destructive uses is often not clear cut. Moreover, with slowly accumulating long-lasting residuals it may be difficult to use an accounting framework oriented toward assessing annual flows of wealth.

Obviously, some direct costs of waste collection, treatment, and disposition can be identified and estimated. Putting aside for the moment concern about alteration of the weather and climate or pollution of the atmosphere, one could measure the economic activity deriving from the use of the atmosphere as a receptacle for waste by the sum of the capital and labor employed in dumping. This might be relatively small, consisting mainly of the costs of piping wastes (via chimneys) into the atmosphere. The value derived from this use of the atmosphere would be a proportion of the opportunity cost of alternative sites and modes of disposal, which could be very large.

However, there are arguments to be made about whether these dumping activities should then be part of the atmospheric sector. One could argue for the inclusion of industries which dispose of gaseous or thermal wastes because they utilize a spatial characteristic of the atmosphere as an input in their production processes. On the other hand, one could argue for exclusion because the use of the zone may not be necessary for the survival of the industries in question. If access to the atmosphere were restricted, the industries would remain in production by using alternative non-atmospheric disposal technologies. The economic activity generated by employment of resources in defending any specific quality standard for the atmosphere could, at least in theory, be measured in the national accounts framework either by (a) the increase in the gross product originating in the disposal activities, if the waste costs were internalized into the cost structure, or (b) in the externalized costs of cleaning up (or otherwise compensating) the air. An economic rent for the atmosphere would only be realized if the externalized cost is less.

An interesting conceptual variant of this has been proposed by Ayres (1979:120). He suggests the creation of an "abatement sector," which accepts gross residual outputs from other sectors as inputs, even if no processing is actually carried out. The residuals would correspond, in some cases, to production sectors (industrial wastes), and in others to final private consumption (household wastes). Precautions against double counting could be taken by attributing a negative price to the residuals as inputs. But, if we look at a general equilibrium model including environmental links (Maeler 1974), we immediately see the difficulty of a consistent, unified atmospheric sector. The atmosphere is not simply located in the macroeconomic model (see Figure 1).

For several reasons, then, arriving at good, consistent, overall measures of the level of economic activity generated by using the atmosphere as a dump is complex. In addition to the absence of a framework of analysis, not enough is known about the volume and characteristics of waste disposal in the atmosphere. Partly this is due to monitoring expense and difficulties, partly it is due to the fact that one is dealing with diverse sources coming from both production and consumption processes. Also the "need" or desire to know about the amount of disposal varies. Consequences, to the extent they are known, depend heavily on the nature of the particular waste materials, and their quantity and spatial concentration and distribution. One more difficulty may be added to the difficulties so far mentioned. Suppose we wanted to know the costs of holding waste disposal to some specified level that may be "tolerable," what would tolerable limits of contamination be? If Antarctic or primeval standards of purity are applied, the value of the atmosphere will again be virtually limitless. If standards associated with the various uses are applied, the costs will vary from place to place and from time to time according to the uses to which the atmosphere is put, but this does suggest encouragingly that some more modest measurements can be usefully achieved.

One must conclude, then, that it appears at this first exploration of a full national income approach to an "atmospheric sector," that such an idea remains far away, and perhaps impossible to realize fully. However, such a notion, and its further definition, especially with respect to waste disposal, may still be fruitful to pursue.

EXTERNALITIES AND ALLOCATIVE EFFICIENCY

As we have mentioned, there is a tendency toward overexploitation and degradation of common property resources. As long as the resources, including assimilative capacity, of the atmosphere were for all practical purposes unlimited, there was no confrontation with the problem of how to assign them. As soon as scarcity becomes a problem, a principle is

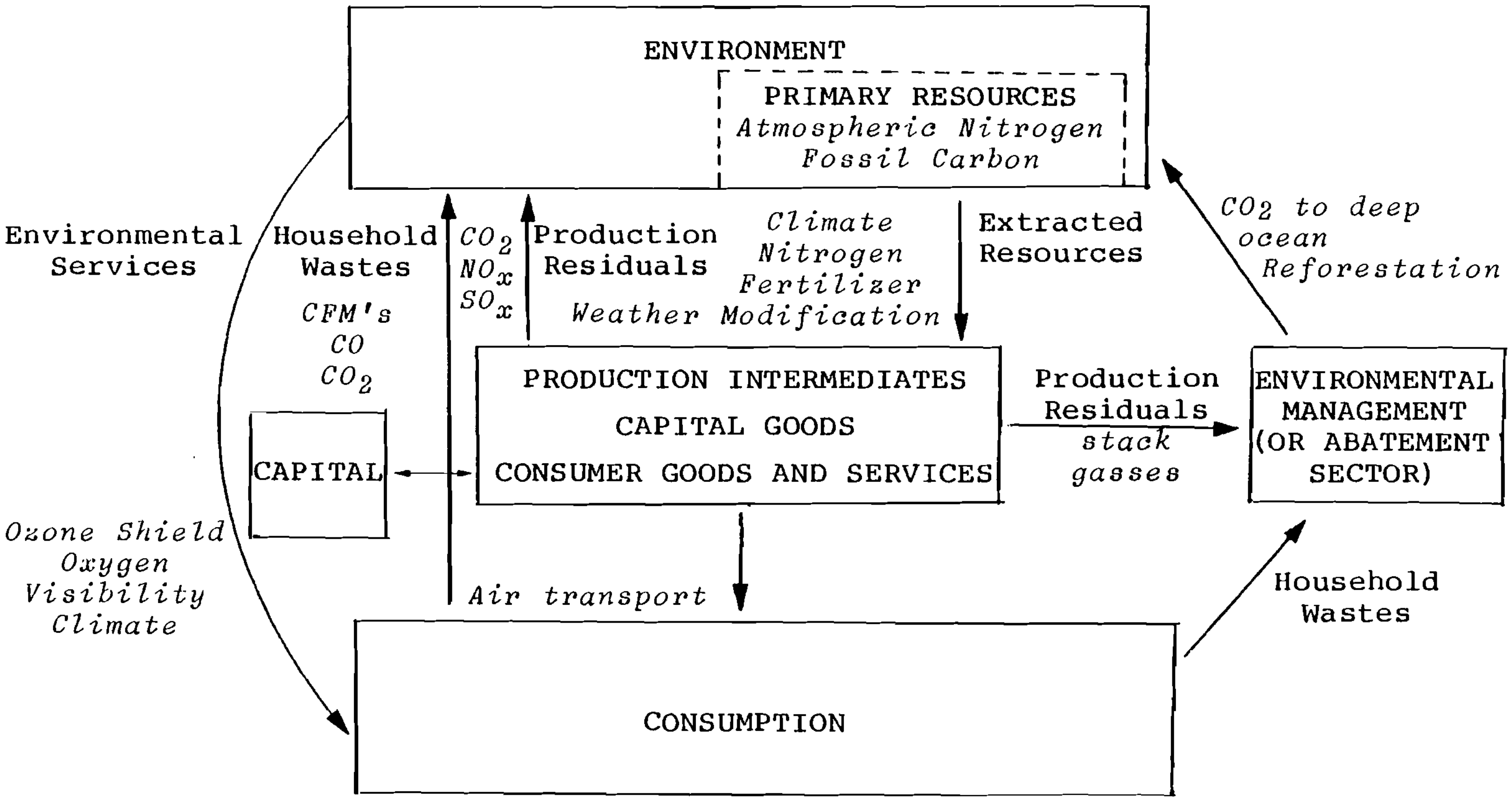

Figure 1. Simple economic model with environment examples related to the atmosphere.

needed to determine how scarce goods will be used. Thus, the basic allocation problem is the determination of the socially optimal level of atmospheric goods in all relevant dimensions. One strategy, which we will explore here, is for economic efficiency to govern all allocations. This discussion is phrased in terms of a market economy, but the underlying issue of externalities is endemic to all economic activity, although in centrally planned economies it may not manifest itself primarily as a shortcoming of the price system.

The general efficiency rule is that more atmospheric goods should be provided up to the point at which additional social benefits no longer exceed additional costs. If producers, users of the atmosphere, maximize profits while taking into account "externalities," optimal production allocation can be achieved. Problems arise, however, because the atmosphere is characterized by elusive externalities, and the absence of information provided automatically in market transfers sometimes makes it difficult even to determine the magnitude of the relevant benefits and costs. What are these externalities which tend to be omitted from the decision calculus and confuse the optimal management of atmospheric resources?

"Externalities" is a term used to describe effects on persons or firms who are not directly party to a decision leading to an activity. While the definition has been much argued, and remains in debate, we may offer a variety of descriptions which give a good feeling for the notion. Externalities are the side effects, or spillovers, associated with human behavior, ranging from minor impingements on amenities to major irreversible effects on life. An externality is said to exist whenever an output of one economic agent appears as an input in the consumption or production vector of another, without accompanying payment (Holtermann 1972).

> Externalities arise whenever the value of an objective function, for example, the profits of a firm or the happiness of an individual, depends upon the unintended or incidental by-products of some activity of others (Lin 1976:1).

Heller and Starrett (1976:10) have emphasized the aspect of markets.

> One can think of externalities as nearly synonymous with the existence of markets. We define an externality to be a situation in which the private economy lacks sufficient incentives to create a potential market in some good and the nonexistence of this market results in losses of Pareto efficiency.

For Heller and Starret, the relevant market failures consist of:

(1) difficulties in defining private property or nonexclusiveness of commodities;

(2) noncompetitive behavior;

(3) nonconvexities in transactions sets;

(4) imperfect or incomplete information.

What do these market failures mean? They mean that commodities characterized by externalities will either not have prices or the prices will in some sense be incorrect. The result is that, as Pigou (1932) pointed out, externalities appear as one of the chief causes of divergence between "private net product" and "social net product." As Kneese and Schultz (1975) have argued,

> The problem is not that the price system does not work—it works with marvelous efficiency but in the wrong direction. When the signal it sends out indicates that air and water are free goods, thousands of firms and millions of consumers bend their efforts to use those cheap resources. And so electric utilities dispose of their sulfur residuals from coal and oil not by scrubbing them from their stacks or by other expensive means but by pouring them freely into the atmosphere...And consumers avoid the cost of eliminating hydrocarbon emissions by depositing them in the air.

and:

> In most circumstances the price system provides incentives for economizing on scarce resources. Those who use such resources must pay for them, at a price that reflects scarcity. Goods whose production requires scarce resources in large amounts are expensive compared with those that do not, so consumption of the former is discouraged and use of the latter is encouraged. Business firms, motivated by the search for profits—indeed, by the need to survive—seek ways to minimize the use of costly resources in their production processes. But since the waste-assimilating capacities of air and water as common property resources do not command a price, the private market system encourages their overuse rather than their conservation.

and:

> The free use of the air and water as dumps for residuals, therefore, creates a situation in which the costs and the prices of goods and services diverge in varying degrees from the true costs that their production and consumption

> impose upon society. The greater the environmental damage caused by residuals from any particular production or consumption activity, the greater the divergence.

It is easy to see the extreme external diseconomy of several uses of the atmosphere. "Pollution" in a modern industrial economy is the all too pervasive consequence of production and consumption activities of virtually all firms and households. The degree of externality of pollution may vary. Imagine the different responses to a firm dumping its wastes onto its own property, directly onto someone's garden, or into the atmosphere. While the diseconomy is obvious in all cases—consumption of pollution obviously reduces the utility of consumers or the profits of producers—the degree of externality allows varying persistence of divergence of private and social cost and varying amounts of interference with efforts at optimal allocation. But, the question of externalities is not just one of remembering to include some of the often omitted negative element in the decision calculus. In certain cases the external costs may be quite ambiguous. For example, the social costs of a potential climate-altering activity, such as the use of CFM-powered spray cans, may be made up of distinct components, private costs, such as those for labor and capital goods which are directly used in the creation of the product, and external costs, which are probably not only unmeasured, but also could include, in theory, either the reduced *or* increased (and redistributed) output of the economy as a result of climate change.

Just as there are negative and ambiguous externalities associated with the atmosphere, there are also many respects in which the atmosphere, or the use of it, is a public good. Consider an array of all possible goods and services running from pure private goods, where property is private and access is limited by rights which are bought and sold, to common property with open access. One of the principal distinguishing characteristics is the degree of externality involved in their production and consumption. A public good is the service provided by a common-property resource under conditions of no exclusion (or where the difficulty or costliness of exclusion is prohibitive) and demand insufficient to generate congestion or marginal resource costs. It is the positive limiting case or extreme of an externality. Environmental quality is very close to a pure public good. Once provided for one, it can be enjoyed by others in society at almost no cost. But, like pollution and other negative externalities, the positive externalities associated with the atmosphere, including its health, amenity, and possibly climatic values, have tended not to pass through markets or be included in evaluation activities. Of course, the development of air quality standards represents a change in this situation.

One way or another then, one wishes to "internalize" external costs (or benefits). Staying for the moment with the example of negative externalities of production processes, one wants to induce the incentive of the firm to increase (or reduce) production to the point where price equals internal marginal costs and environmental costs. "Transferring social costs to the responsible firms could serve two purposes: It could lead the firm to reduce the pollution aspects of its activities or, as the internalized costs are passed on in higher prices, it could signal consumers, to shift away from pollution-intensive products, or both" (Page 1973:6). There are several strategies to try to bring about the internalization of costs and optimal allocation under conditions of externalities. One school (Coase 1960) has emphasized private bargaining. Another group has preferred governmentally imposed tax or subsidy schemes for achieving efficient resource allocation, especially where decentralized bargaining is expensive or impossible.

Basically, the bargaining solution calls for the formation of a new market. Are markets for the uses of the atmosphere feasible? The fact that such markets generally do not exist suggests that they are not feasible. However, there are indications this situation may be changing. In Long Beach, California, there has been activity which resembles the creation of a pollution rights market (New York Times, 1 August 1977). Firms are being given the incentive of seeking the lowest cost alternative in buying and treating a certain amount of pollution from existing waste sources, which they can balance against new discharges. But, generally, the situation is difficult. Those who wish to buy reduced air pollution are usually not able to call forth a supply response. This kind of market solution requires the existence of enforceable property rights to the environmental resource, and the possibility of contractual agreements between parties affected by the externality and those responsible for its creation.

Moreover, the establishment of property rights may not succeed in resolving the externality problem. A reason often cited is that the transaction costs may exceed the per unit potential profit, for example, in cases of waste disposal. The likelihood of market failure is greater the larger the number of parties involved in the externality relationship, and the more complex the relationships are. In any case, whenever exclusion is costly or impossible, property rights are difficult to define meaningfully, and this is the case with respect to most uses of the atmosphere. In fact, by definition of the atmosphere as a public good for selected purposes, exclusion is an unacceptable policy for certain activities. Heller and Starrett (1976) point out that when exclusion is undesirable, we should clearly not establish a market by assigning property rights to any physical commodity. Thus, with many of the attributes of the atmosphere, we have tended to find various other forms of regulation rather than developing private markets.

Still, it is intriguing to consider whether, for example, a CO_2 market could function.

It is clear that the widespread and persistent presence of externalities is a major obstacle to achieving an efficient allocation of atmospheric resources. But let us put aside this problem for a moment, and see what cost and benefit estimates might still be undertaken and whether they might still lead us closer to an optimal treatment of the atmosphere.

MEASURING ATMOSPHERIC COSTS AND VALUES

We have been suggesting in this paper that, from an economic point of view, the ideal treatment of the atmosphere would identify its highest value in alternative uses. Resources would be allocated to those uses in which social benefits exceed social costs. Efficiency would be achieved by pursuing these activities to the point at which social benefits cease to exceed the social costs at the margin. Presumably, the atmosphere can accommodate several uses, although, as we have seen, there may be conflicts among certain uses or attributes of the atmosphere. Because of the potential of certain uses of the atmosphere to change the supply of atmospheric resources for other purposes, for better or for worse, as with waste disposal affecting the supply of climate, it is desirable not only to analyze current uses of the atmosphere and include or discourage them according to the efficiency criterion, but also to compare the current ensemble of uses with different potential patterns of utilization.

In order to arrive at a highest or optimal value of use of the atmosphere, one thus needs to know the benefits and costs of the various uses, both the current ones, which includes the "production" of our present configuration of macro- and micro-climates, and other feasible ones. What is the present state of measurement of uses of the atmosphere? Can it approach the certainty or knowledge needed for an optimal allocation?

As we have seen, there is little direct measurement of the flow of wealth associated with uses of the atmosphere, and this is true of environmental intangibles in general (Coomber and Biswas 1973). However, while there may be no direct market for air quality or climate, there are indirect ones, for example, for the sites which experience the relevant conditions. To illustrate, an individual contemplating migration to an area with atmosphere N_1, faces a level of *per capita* air pollution costs of C_1, or the average air pollution cost level associated with density N. If he moves to the city, he will have to pay the amount C_1 (plus some small amount added for his own marginal contribution) either in the form of pollution prevention costs, journey to work or, for example, in the form of outright welfare damage to his health and property. He will rationally migrate to the city at this density level only if a sufficiently high wage differential or other net advantage of living in the city compensates him by at least an amount of C_1. Clearly, people will pay to avoid air and climates that are not attractive by travelling long distances, purchasing filtration systems, venturing outside as little as possible, etc. Among others, Hoch (1975) has explored this situation with respect to climate, while Seneca and Taussig (1979) explain the argument in greater detail with respect to air pollution.

With respect to atmospheric goods, it can thus be said that in purchasing a site, an individual is assured the provision of the nonmarketed service as an attribute of the site. There is a kind of weak complementarity between the public good and a private good, with an observable linkage. The problem is to know the relation between objective measures of the level of the services of the environmental common property resource at a site and the individual's perception and evaluation of them. In concept, one can arrive at this relation because it should be possible to measure the marginal costs of meeting certain levels of residuals abatement and thereby increase (or decrease) the availability of the services of the environmental resource. In practice, this kind of analysis turns out to be somewhat more difficult and complex than expected. We shall illustrate the problem with a discussion of cost measures and property rights.

While one line of argument (Coase 1960) has it that resource allocation, explicitly, and resource valuation, implicitly, are invariant with respect to property rights, variation in value corresponding in general to different assignments of property rights can be demonstrated. In fact, with respect to uses of the atmosphere, there are at least three theoretically correct measures of cost. If it is accepted that there are several potentially significantly different measures of the values of these uses, the question of which is appropriate naturally arises, as well as the question of how to combine and compare. First, let us look at the different measures of costs.

One way of assessing the value of things like climate and air quality is by a "willingness-to-pay" (WTP) criterion. For example, the demand curve for clean air may be estimated as the measure of the willingness of the population to give up income for cleaner air. Such an estimate depends on the assumption that the public must pay for the property rights to environmental resources. If the waste disposer has the initial property right, then the consumer, with a given budget line, would be willing to pay an amount which would leave him just as well off as before the transaction for the right to use (part of) the site for its amenity service. Clearly, this measure is not only a function of willingness to pay, but ability to pay. It is bounded by income. While there may be some information on this kind of transaction, in general WTP involves not only the current costs of resources, but also intrinsic preferences or preferences not currently expressed in markets by individuals (d'Arge 1975).

Now, alternatively, begin from the plausible assumption that property rights to the atmosphere (air quality, climate, etc.) reside in the general public and cannot be appropriated by any private parties without adequate compensation. Then, one asks, what is the minimum amount all individuals would collectively be willing to accept as compensation to give up their rights to all higher (better) levels of supply. While the WTP seeks to determine the maximum amount the consumer would be willing to pay to remain in the original regime, this measure of "opportunity cost," here in particular a "willingness-to-sell," (WTS), seeks to determine the minimum compensatory income necessary to render a consumer indifferent. The amount the consumer would accept is largely independent of his income and typically would exceed the amount he is willing to pay. The difference between opportunity cost and willingness to pay is in the presumption regarding property rights, that is, on whom the burden for compensation is to fall. Opportunity cost measures presume the consumer is to be compensated. Willingness-to-pay measures, conversely, presume that the consumer is to pay compensation to prevent a change.

A third theoretically valid measure of value is alternative cost. Alternative cost tries to estimate how much it would cost to provide an equivalent bundle of goods and services by some other means. For example, in the area of water resources, how much would it cost to implement programs and construct required facilities to meet a region's postulated needs during some future period if the climate changed? The difference between net willingness to pay and alternative cost is shown in Figure 2.

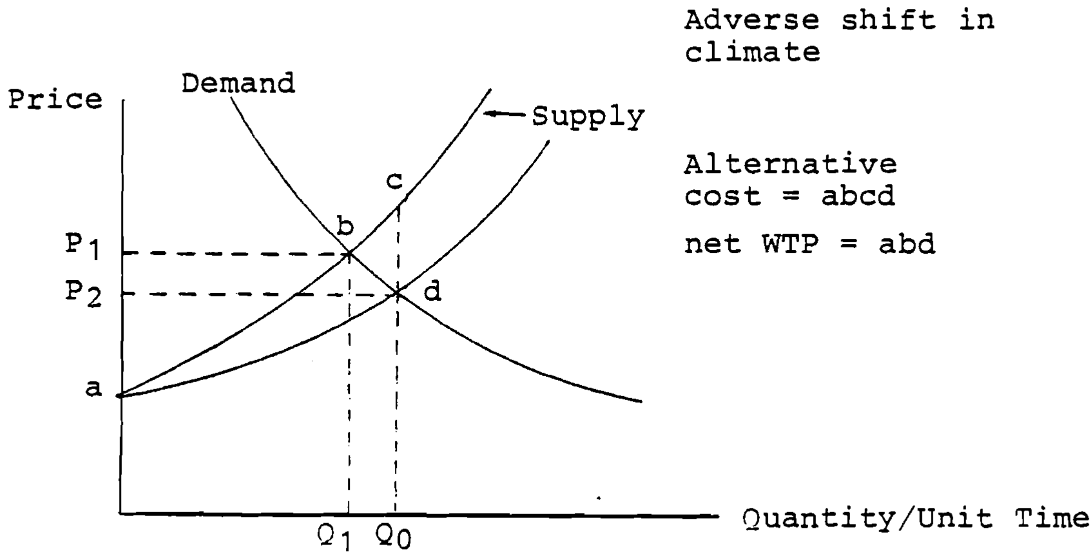

Figure 2.

> The essential difference between the opportunity cost and alternative cost measures is in the applicable constraint. In calculating opportunity cost measures, the individual is constrained to be indifferent; in calculating alternative-cost measures, he is constrained to the same consumption pattern (at least to a subset of the same consumption pattern)(Anderson *et al.* 1975, section 4:5).

One is inclined to think that the possibilities for empirical estimation of alternative cost measures is much greater than that of opportunity cost measures (both WTP and WTS). While estimation of alternative cost measures requires determination of the ways in which consumers can combine goods and services to produce utility-yielding characteristics, this kind of determination is probably less difficult than learning about the basic consumer valuation of the characteristics themselves.

In addition to conflicts arising because there may be several conceptually satisfactory, but quantitatively varying, ways of measuring the uses of the atmosphere, the measurement itself will be drastically inhibited by data difficulties. As Anderson *et al.* (d'Arge 1975, section 4:6) have written,

> Without knowledge of individuals' utility functions or direct experimentation, it is strictly impossible to evaluate either opportunity cost or willingness to pay measures. Use of measures of consumer surplus obtained from empirically estimated demand functions to estimate willingness to pay, as is well known, is only an approximation—and not always a very good one.

Numerical solutions will tend to come from disturbingly simplified cases, and they may be very sensitive to error in functional specification and assumed parameter values.

Moreover, as one estimates the value of the various uses, or performs "impact studies" of climate change, the various different valuation methods will be used, out of necessity. This will be on account of inadequacy or limited availability of data in certain cases, but in others because a good measure for one type of use, for example, the amenity services of clean air, may be a poor measure for another type of use, for example, climatic resources needed in rice production. Because different sets of measures will be used to derive approximations of losses and benefits, consistency among the measures will be difficult to achieve. In some cases, it may be that the difference between using different measures would be trivially small; but in others, it might be significant. Moreoever, realistically, no examination will be comprehensive. In an examination of the value of present climate for agriculture, important crops are likely to be left out or only poorly considered. As one looks at changing ensembles of uses, important effects will not be anticipated. Thus, it will be very difficult to sum the uses of the atmosphere and climate at any given time, much less compare one summation against another.

Moreover, all the measures we have talked about are essentially ones which hold at the margin, that is, for small changes in price and quantity. As changes become larger, or as they interact, the validity of the whole measurement project comes more and more into question. Nevertheless, it may be that for certain policy decisions, the information at the margin is all that is necessary. While for optimal control it is desirable to have information about all the stocks and flows of wealth associated with the atmosphere, for certain decisions much more restricted information may be useful. But there is no getting around the fact that for the larger issues, like those relating to human activities and climate change, one would like a grand piece of analysis: a figure for damages, which would be a summary number over many crops, sectors, and geographic areas, which would be a function primarily of a vector of climate variables, which in turn would be a function of a vector of accumulated emission components, and secondarily of direct effects of the emissions; and also a summary figure for benefits, which would be a function of (a) the vector of climate variables, which would be a function of the emission component vector, (b) direct benefits associated with the emissions, like fertilization of the atmosphere from CO_2, and perhaps (c) some sort of consumer surplus measure associated with emission producing activities, such as the use of fossil fuels, or other means of including costs of prevention or abatement in the calculation.

Finally, there are the uses of the atmosphere which are difficult to monetize at all. Some aspects of nature and human activity are simply not well-denominated by money, while for important changes, which may take place in the environment, people may not be able to have well-articulated preferences, even if the changes are foreseen, which often they are not.

If not dissuaded from certain ambitions by the difficulty of the measurement task, one can still add that even with accurate and detailed information for economic management of the atmosphere there would be perplexing questions from the point of view of "atmospheric optimization." Some recent general equilibrium models have taken the step of seeking optimal policies for economic growth in the presence of resource constraints and a degradable environment, where the degradation is a function of the rate of extraction and consumption. A degradable environment is roughly equivalent to calling the environment an exhaustible resource. For certain purposes one can think of the atmosphere in these terms. For example, the atmosphere might be thought of as having an elasticity with respect to climate as a result of human modification. In the extreme, if human activity were to change the climate of earth to that of, say, Venus, clearly it would be equivalent to exhaustion of climate resources. If one thinks that there is some sort of ceiling then to the use of the atmosphere as a receptacle of waste, whether it is for climatic, health, or other reasons, such a model might apply.

In general, one would expect that extraction and consumption will be discouraged by environmental disamenity (or negative climate change) costs. But, this is not necessarily the case. In one exploration by d'Arge and Kogiku (1973) a rather discouraging result is obtained. Consumption should be sufficient to equate the marginal utility (or shadow price) of consumption to the marginal disutility of the associated waste output, which is assumed to increase as the density of accumulated wastes increases. Consequently, optimal consumption is initially lower when the pollution level is lower. Later it rises as people consume faster to compensate for the disamenity of a high cumulative pollution level. A potential analogy with CO_2 is easy for us to imagine. Carbon is extracted and changes the climate as it is transferred to the atmospheric reservoir. The more the climate changes, the more carbon is extracted to compensate for the changing climate, and the faster the climate changes in turn. This result, symptomatic of some short run optimization, shows that even good information on the uses of the atmosphere might lead to socially unsatisfactory management of the atmosphere. Even if one could treat CO_2 as a big programming problem, distributional questions would have to be faced. What appears optimal here, today, may very well not be desirable in another place, tomorrow.

DISTRIBUTIVE ISSUES

Up to this point we have examined the problems of exploitation of atmospheric resources from the point of view of allocative efficiency. However, there is another major criterion for the formulation of social policy, namely, equity. Are the income distributional impacts of use of the atmosphere an issue, or are they insignificant enough to be safely ignored? The problem here is the traditional one in welfare economics. Any project or policy is likely to result in gains for some individuals, or groups, and losses for others. Schemes of efficient allocation basically try to add, algebraically, all the gains and losses over all the affected individuals to determine the net gain from each of the alternative uses of an area's resources. Thus

> ...underlying any policy prescription from a benefit-cost analysis of a resource use is the potential Pareto, or Kaldor-Hicks criterion, according to which a project is efficient, and presumably therefore desirable, if the gains exceed the losses, so that the gainers could

> compensate the losers and retain a residual gain. Of course, this is not satisfactory to one who is concerned about the actual distribution of gains and losses from alternative use of an environment or any other resource (Krutilla and Fisher 1977: 28-29).

Under such circumstances, the policy maker must select a degree of efficiency, as, for example, measured by output foregone, which he is willing to trade off to achieve a given distributional objective.

While atmospheric resources may be widespread and open for most purposes, they still tend to be subject to more concentrated use by certain specific groups. As with most resources, benefits from using those of the atmosphere tend to be allocated in proportion to the quantity consumed, and consumption has been essentially on a first-come, first-served basis. Thus, questions of equity of atmospheric exploitation depend both on the equity of the present distribution and of proposed alternative patterns. What can be said about the distributional effects, both in time and space, of the present and alternative situations?

To illustrate this, let us look at distributive effects of the present climate and a policy to prevent a CO_2-induced climatic change. Present climates have obviously favored human settlement and economic activity in some regions more than others. Those who currently live in pleasant and favorable climates will plausibly gain more from restricting CO_2 than those who do not. At the same time, preventing climatic change will raise the costs of those goods and services whose production, or consumption, may have contributed to a change of climate. The price of electricity may rise, as utilities switch fuel sources. Machinery with CO_2 control equipment may be more expensive to own and operate, and property taxes may rise as municipalities construct and operate CO_2 scrubbers. Overall, costs of climate conservation will probably resemble excise taxes, with the heaviest taxes falling on goods whose production "pollutes" most. The costs of climate conservation will be widely borne by individuals, as producers, consumers, and taxpayers.

A period of adjustment to a climate conservationist position could bring other kinds of costs. Some firms, finding that they simply cannot afford the costs, may have to cease operation and go out of business. Indeed, some industries including ones like coal mining around which whole communities may be based, might have to close down important facilities. In contrast, some areas may have prepared for modifications of their climate. Their investments may prove worthless, while they still have to pay higher prices required to cover the costs of producing goods elsewhere under conditions which do not lead to climate change.

Obviously, the benefits of climate conservation will not be distributed equally. For those who make windmills or nuclear power plants, it may prove a bonanza, while for some portions of the labor force and some localities there will be painful transition costs. However, at present we have almost no information in several respects about what the distribution of benefits and losses will be. One can make guesses based on geographical analysis about where people stand to gain or lose. But will the poor suffer more than the rich? Will the urbanite care less than the suburbanite who spends so much effort on a green lawn? Or will he prefer an easy-to-care-for cactus or a tropical fern to today's temperate vegetation? In the long run, industrialized economies should be able to absorb the labor and capital displaced by these adjustments, and various forms of assistance can be devised to ease the adjustment process, but climate conservation could alter the distribution of income, even if both benefits and losses are widely distributed. Would it alter the distribution more or less than climate change?

What is the distributive situation at the international level? We have said that the net benefits of atmospheric use presumably accrue principally to the nations that produce and consume such services. This suggests that the principal national beneficiaries of the CO_2 increase, at least in the short term, are those countries engaged in carbon extraction, trade, and combustion. If we reason that there is a benefit associated with the production of CO_2 emissions, it becomes interesting to ask what is the present origin by region of such emissions. Following Pearson (1979:271), my estimation of the distribution of emissions from burning of fossil fuels and cement production can be seen in Table 2. Similarly, one may look at the world distribution of coal resources as a proxy measure of potential contribution to an extremely serious CO_2 scenario (see Table 3). Clearly, the beneficiaries of the production of CO_2 from an enormously enlarged coal economy are very unevenly distributed.

Table 2. CO_2 emission by region: 1973

	Developed countries	Developing countries	Centrally planned economies	World
Total carbon converted to CO_2 in Gt	2.67	0.48	1.37	4.5
Percentage world totals	59	11	30	100

Table 3. World Distribution of Coal Resources (in 10^9 tce).

Greater than 10^{12} tce (1,000 x 10^9 tce)		Between 10^{11} and 10^{12} tce (100 and 1,000 x 10^9 tce)		Between 10^{10} and 10^{11} tce (10 and 100 x 10^9 tce)		Between 10^9 and 10^{10} tce (1 and 10 x 10^9 tce)	
USSR	4,860	Australia	262	India	57.0	GDR[a]	9.4
USA	2,570	FRG	247	South Africa	57.0	Japan	8.5
China	1,438	UK	163	Czechoslovakia	17.5	Columbia	8.3
		Poland	126	Yugoslavia[a]	10.9	Zimbabwe	7.1
		Canada	115	Brazil	10.0	Mexico	5.5
		Botswana	100			Swaziland	5.0
						Chile	4.6
						Indonesia[a]	3.7
						Hungary[a]	3.5
						Turkey	3.3
						Netherlands	2.9
						France	2.3
						Spain	2.3
						North Korea	2.0
						Romania	1.8
						Bangladesh	1.6
						Venezuela	1.6
						Peru	1.0

[a]Mostly lignite.

Source: Based on data after World Energy Conference (1978).

The principal losers, if any, will be those societies in which economic activity will be adversely affected by climatic change, and those, in the case of a preventive strategy of climate conservation, who are left holding untransformed stocks of carbon. Thus, the question of equity appears again: is it just for those favored by geographic endowment or technological capability to act unilaterally (by stimulating the carbon economy) without being held accountable for consequences to other users of the atmosphere? Such action, may, for example, raise the price to others of access to preferred supplies (through a need to shift agriculture to areas without equally good infrastructure), use up those supplies (by increasing scarcity of temperate climates for agriculture), or degrade the quality of future supplies (for example, by increasing variability of climate). Those who cannot themselves exploit atmospheric resources, particularly as a receptacle for waste, may seek to obtain rent from those who can, or at least share the benefits with them. Or, they may try to forestall the use of the resource, until they can develop their own exploitation capability.

Issues of distributive justice have assumed growing importance in arguments about international order during recent years. As d'Arge and Kneese (1973) have pointed out:

> No nation will easily accept international agreements on entitlement of universal common property resources without compensating payments to retain its perception of national wealth. In consequence, the classical answer to externality problems of internalizing the decision-making process for the resource is not easily transferable to these transnational problems. A new overriding element of distributional gains and losses must be simultaneously included in efficiency considerations.

The efficient allocation of the uses of the atmosphere at the national level will probably not resolve the distributional implications of climate change satisfactorily from an international point of view, and perhaps not from a national point of view either.

Lurking in this discussion is the second major feature of the distribution question, intertemporal fairness. This is a serious question with respect to use of the atmosphere. The atmosphere is not only jointly valued by many communities and nations but also by many generations, and in the context of the brief history of industrial civilization the life of some atmospheric problems may be very long. When the present generation evaluates alternative uses of the atmosphere, it is making judgments about the welfare of future generations relative to the welfare of the current generation. On the one hand, measures taken today may reduce the consumption level of those presently alive and raise the consumption level of those not yet born. On the other hand, current decisions may indicate society's willingness to transfer potentially catastrophic or risky prospects to future generations.

As Krutilla and Fisher (1977:39) point out:

> Some of the distinctive and challenging problems for valuation and allocation of the resources of natural environments are dynamic. Clearly, if decisions with respect to the use of these resources are impossible to reverse in a way that ordinary economic decisions are not, effects over long periods of time must be considered.

The problem here is similar to the one of choosing the correct social rate of discount, an indicator of society's willingness to transfer income or wealth over time. This is an extensively argued question in economics, often revolving around the determination of the discount rate for public projects. As Pigou (1932) first suggested, the conservation of exhaustible natural resources might be achieved through lowering of the discount rate in evaluation of projects involving their exploitation. Why should this question of discount rates be at issue?

It is conventionally argued that the market-determined rate of discount (interest) is partially determined by the private time preferences of the present generation of individuals. There are, of course, important ethical implications to the fact that only the present generation of humans participates in the decisions as to what proportion of the natural endowment will be preserved for the future. There is a rampant assymetry in this intergenerational distribution decision which makes its bias dangerous to forget. In addition, one may cite the lively debate in philosophy, involving Singer and others (Singer 1977; Singer and Regan 1976), about the rights of animals. In fact, the questions of environmental preservation and species habitat and distribution may turn out to be major ones, as problems such as climatic change and acid rain could have drastic implications for national parks, wildlife preserves, and so forth. Such issues aside, it may be expected that

> ...individuals with finite life expectancies, among other things, are likely to be guided in their private consumption decisions in a manner that is not necessrarily optimal for a society that has a collective commitment to life in perpetuity. Accordingly, the supply of funds available for investment is at least influenced by private time preferences that depart from what might be a collectively determined social time preference. The rate of discount will be too high and the level of investment too low to make adequate provision for future generations (Krutilla and Fisher 1977:61).

(Of course, we do find counters to this tendency, for example, in the setting aside of parks and in the behavior of some firms, such as timber companies, which may be planting trees that grow on an 80 year cycle.)

Two factors further complicate the question of economic evaluation of the future. The first is uncertainty. In many cases, of which the atmosphere is exemplary, information about benefits and costs of alternative uses is extremely poor, due both to the long period of time over which projections are needed and to technical evaluation problems, such as are connected with common property resources and externalities, as well as to uncertainties transferred from the physical sciences. The second factor is irreversibility. In some sense, of course, all human actions are irreversible, but the term does capture a particular quality of a subset of decision situations. If, for example, a natural environment, once developed or used, cannot for some combination of geophysical, ecological, and financial reasons be restored, then the appropriate social attitude toward decisions regarding it should in some way be different.

What makes irreversibilities important? As Wilen (d'Arge 1975, section 2:113) has written:

> In a world of perfect certainty, whether the consequences of a particular action were irreversible would not really matter. In such a perfectly certain world, decision makers would know the preferences of present and future generations, the physical processes that take place outside of the social systems sphere, and the linkages between physical and social systems. Decisions could then be made that maximize net social benefits over the entire planning horizon; and hence, no decision would ever require reversal of its consequences.

With the atmosphere (indeed, with society), the rule is that information is uncertain, both with regard to physical consequences and economic evaluation. The uncertainties would be of little consequence if the effects of a "wrong" or inefficient decision can be quickly or cheaply reversed. Losses might even be recovered; the overall net from the sequence of wrong decisions plus corrective policies could be positive. However, if the results of an action are irreversible, the possibility of a loss in perpetuity clearly increases. But still, the loss might be of trivial dimensions. Thus, it is important that the costs of the incorrect irreversible decision be potentially large.

In the case of the atmosphere, physical scientists have presented the public with a series of "threats" over the last decade. Possibilities of very large scale costs to health were at one time connected to stratospheric flight. More recently the principal potential threat has been a rise of sea level as a consequence of changes in polar ice caused by extreme climatic change from increases in atmospheric carbon dioxide. Indeed, the consensus of a distinguished group of scientists at a recent workshop (AAAS, Annapolis, 1979) was that a scientifically defensible case can be made that the possibility of disintegration of parts of the Antarctic ice sheet should be taken seriously, through there is no immediate cause for alarm. While the particular causes of disastrous perturbations of the atmosphere may come and go, it is, unfortunately, all too convincing that something very dangerous may be going into the air. Thus, with respect to the atmosphere, the two conditions which are important for irreversibilities, namely the lack of good information and potentially large costs, hold. The significance of irreversibility is further heightened, in this case, by the fact that the atmosphere has common property characteristics: people are not in a position to reject any consequences they do not like. They will be shared.

Arrow and Fisher (1974) have argued that this feature of irreversibility evokes an option value. The passage of time may result in new information about the costs or benefits of alternative uses of an environment, and this knowledge may inform the eventual decision if the decision to develop or use has been deferred. In contrast, since development is not reversible, once a decision to develop has been made, it cannot be affected by the presence of new information which suggests that it would be a mistake in the future. The analysis of Arrow and Fischer (1974) shows that in cases of irreversibility there is a positive option value to refraining from development. Other formulations suggest that this option value can be regarded as a risk premium. (See also Schneider and Mesirow 1976, on an idea of "global insurance.") Intuitively, it is easy to understand such ideas as being indicative of the need for policies which can compensate for the asymmetric implications of intertemporal decision situations.

An example which captures the problems of discounting, uncertainty, and irreversibility, may easily be presented for CO_2. At present, it is very possible that calculations using a positive discount rate (the US Department of Transportation's Climatic Impact Assessment Program used 3, 5, and 8%) would yield the result that the "project" of burning up available fossil fuel reserves for the next 40 years and using the atmosphere as a receptacle for waste would be attractive: net gains would exceed costs. According to Kaldor-Hicks or Pareto criteria the project should be undertaken, because the gainers would compensate the losers and still have something left over. With the project there is a reallocation of goods that would make everyone better off. However, as the present value criterion slides forward through time, future generations may be increasingly less desirous of the project, either because of its costs or because they prefer the services provided by the unused environment.

At some time (t_1) in the future, benefits from the project are less than benefits from foregoing it. The gainers from not having the project could compensate the losers, all those who would benefit from having the project. It may even be possible that the gainers could compensate all those benefiting in the period between the present and this future decision. Were bargaining possible, conceivably the future generation could compensate the present for not pursuing a project which would otherwise provide net benefits, especially in the period between now and t_1. As in the first case, there exists a reallocation of goods that would make everyone better off, only now it is without the project. Thus, under such conditions, intertemporal welfare tests can yield ambiguous results.

The foregoing discussion is not meant to diminish the validity of discounting. Discounting is merely an implication of, as Koopmans (1979:7) has put it, the

> ...simple fact (that)—short of capital saturation—society can temporarily curtail the production of current consumption goods by transferring some factors of production to the formation of additional suitable capital goods, in such a way as to return a multiple (>1) of the same unit bundle of consumption goods in the future.

The confusion and difficulty arises because, in practice, as Koopmans goes on to point out, present values tend to reflect a curious mixture of the present preference between consumption and production, an assumption about savings behavior of coming generations, and an intertemporal ethical rule. It is the intertemporal ethical rule, perhaps unquantifiable in some respects, that in balancing risks to human life in the present and in the future one is inclined to feel that equal numbers of lives should receive equal weight, making the "present value" of future human life independent of the time at which it is lived, in contrast to the present value of a bundle of consumption goods, that specially complicates the evaluation process.

Clearly then, one can argue that resource depletion and the future long-term quality of the environment, in this case relating primarily to the use of the atmosphere as a receptacle for waste, are not merely problems of market failure, but distributional problems. They may be even more difficult than internalizing cost, because people and nations will not agree on the distributional criteria for societies. Should the criteria emphasize maximization of returns to the international community? Conservation of natural resources? Passing on a stock of environmental wealth *per capita* at least equal in value to the one which was inherited? Or, in contrast, passing on a legacy of infrastructure from development which will minimize the "loss" from environmental change? The decision rules and the population to which they apply remain open questions.

DECISION ANALYSIS

When faced with major atmospheric policy questions such as the threats to the ozone layer or climatic change, is it possible that decision analysis would be applicable to choosing among the uses of the atmosphere? The traditional method of decision analysis essentially consists of determining the monetary value of each potential state of the atmosphere (or ensemble of uses), or some other kind of social indicator or set of them (lives lost, or life span, for example) and weighting it by the probability that the state will occur. What would one need to do this? To begin with, one would want detailed current and projected information on the use of the atmosphere, as, for example, a receptacle for the specific waste. Then one would want valid relationships about rates of residuals emission (and accumulation) and atmospheric effects. Then, one would need information on the cost of residuals control and regulation, and of course, one would need a complete and concise estimate of costs and benefits evolving through time from atmospheric changes according to the different levels of use of the atmosphere as a sink for the waste.

All this is to say, that one would like to foresee every possible event and know all the relevant characteristics of all possible evolving alternative states. Or, as Fischhoff *et al.* (1979:18) have written, decision analysis assumes

> ...all possible events and all significant consequences can be enumerated in advance, that meaningful probability, cost, and benefit values can be obtained and assigned to them; and that the often disparate costs and benefits can somehow be made comparable to one another.

What is the situation with the atmosphere? Clearly we must make decisions "without knowing every potential event or, at best, knowing only a few characteristics of potential states" (Wilen (d'Arge) section 2:114). In fact, the underlying assumptions, with respect to allocations of the atmosphere, must be at the opposite end of the spectrum for what is desirable for decision analysis. Our present knowledge of our use of the atmosphere and the value of these uses, including climate, is very poor. It would be difficult simply to come to a consistent estimate of the value of our current practices. As we try to estimate and evaluate cumulative uses or changing uses, the transfer functions between cause and effect are subject to extreme uncertainty at the times the decisions are being or will be made. Indeed, the assumptions we must make are all of continuing uncertainty. For example, with respect to climate:

— there are large uncertainties in the effects on climate of various emissions. It is sometimes assumed that resolution of these uncertainties would make the question of deciding on how to use the atmosphere easy; but alas,

- there are large uncertainties about translating the effects of changed climate and atmospheric composition into effects on the managed and unmanaged biosphere and other aspects of the environment; and
- there are large uncertainties about how societies and economies would react to these changes, especially in a dynamic context of other major world developments and technological change; and
- it is quite possible that none of these substantial uncertainties will be reduced in the next decade.

In other words, the often assumed process of learning over time may be irrelevant. It is possible we will face virtually the same decision in 10 years that we face now, with only slightly more reliable information.

While all of these problems undermine decision making based on the estimation of the value of uses of the atmosphere, there is a companion problem that is often ignored. Suppose we have, in some sense, a good estimate of the value of continuing to put CO_2 in the atmosphere, a forecast of the climate 50 years from today, a good deal of information about redistribution of biota, and so forth. There would still be an enormously difficult issue of evaluating use for climate-changing waste disposal. People can hardly be said to have well articulated preferences about the uses of the atmosphere. As Fischhoff *et al.* (1979:33) have pointed out, on new and complex issues people's values may in some fundamental sense be incoherent. They may be unfamiliar with the terms (social discount rates, miniscule probabilities, megadeaths) in which the issues are formulated, and they may not even know how to begin thinking about some issues (gradual rise in sea level). They may have contradictory values (desire for environmental preservation and desire for energy-intensive existence), and vacillate between incompatible, but strongly held positions (need for regulation and importance of minimal government). Finally, "their views may change over time (say, as the hour of decision or the consequence itself draws near), and they may not know which view should form the basis of a decision." In fact, people occupy different roles in life which will continue to produce clear-cut but inconsistent or conflicting values.

Is there still some method society can apply to the kinds of atmospheric policy issues we have mentioned? Some way to try to value the consequences of decisions involving potentially severe or even catastrophic outcomes, when the outcomes can only be barely sketched, if at all, and probabilities of such outcomes are unknown or anticipated to be low? It may be possible to utilize a hypothetical set of outcomes and probabilities to get a feeling for the problem. After all, doing nothing about analyzing and comparing the uses of the atmosphere is effectively the same as deriving an expected value measure for the question by weighing the "unknown" outcomes with a zero probability, and present concern over issues is evidence of unwillingness to do that. Normally, "decision analysis attempts to accommodate the uncertainties inherent in the assessment of problems and of the variables involved through the judicious use of sensitivity analysis." The calculations of expected costs and benefits are repeated using alternative values of some troublesome probability, cost, or benefit. If each reanalysis produces the same relative preponderance of expected costs and benefits, then it is argued that these particular differences do not matter. (Fischhoff *et al.* 1979:19.) But with respect to the atmosphere and climate change, there may be a danger than even if one does not make unrealistic assumptions about the availability of data needed to complete the analysis, the decision analysis may begin to attain some kind of autonomous reality on its own. Thus, in this area decision analysis may be illustrative and helpful in some way, for example, in eliciting or helping to form preferences, but it will be far from a basis on which a decision could actually be made.

POLICY AND MANAGEMENT

A policy discussion must concern itself both with appropriate techniques for incentive and control and with institutions for formation and implementation of these techniques. While almost all atmospheric policy issues may eventually involve the design of a regulatory mechanism to promote more rational management of atmospheric resources, the economist's conventional wisdom about external effects, equity, and social policy may be followed in many ways, according to the specific characteristics of the problem and the atmosphere in general. Moreover, because the history of regulation of the atmosphere, to the extent that there is one, has not been one of clear management goals, proper regulations, and adequate information, it is worthwhile to look broadly at possibilities. Given the nature of the users, receptors, sources, and characteristics of the externalities in question, what are the available strategies? And what level and kind of government should determine and enforce controls? In fact, should it at all? As Mead (1979: 356) has pointed out,

> ...the presence of a net externality is not a sufficient justification for government intervention. The costs of correction, including the costs added in the legislative compromise process and actual administration..., must be less than the cost of the net externality to be corrected. Failure to meet this test will lead to even greater misallocation.

There are a variety of approaches for achieving particular goals with respect to the atmosphere. Focusing on issues with respect to waste disposal, one can suggest following Kneese and Schultz (1975):

— Change the way economic activity is carried out so that it generates less residual to begin with, for example, shift away from fossil fuels.
— Treat the residual as it emerges so as to render it less harmful, for example, use catalytic converters on automobiles.
— Increase the capacity of the environment to absorb residuals, or change discharge points in a way that does less damage to society, for example, do not allow emissions in the stratosphere or plant trees to absorb CO_2.
— Divert the residual to a different environmental medium. For example, dump CO_2 into the deep ocean.
— Make society less dependent on (products which are damaged by wastes accumulating in) the atmosphere, for example, shift resources from climate-sensitive activities to climate-insensitive activities.

The number of specific policies to implement these approaches is quite large, but the types of policies traditionally considered and discussed by economists are comparatively few in number. Daly((d'Arge) section 2:127), following Kneese and Bower (1968), offers this list of general alternatives:

— to do nothing, allowing voluntary negotiations to materialize aided by specification of property rights (i.e., assigning liability for damages)
— system of charges, for example, in the form of an effluent tax
— payment of subsidies to discourage the creation of the external effects, for example, subsidizing the installation of abatement equipment
— enforcement of quality standards for the environment and/or quantity standards regarding, for example, the amounts of particular effluents
— auctioning of a predetermined quantity of rights with respect to the particular activity being considered
— merger or other form of coalition between inflictor and receptor
— various hybrid schemes involving some combination or combinations of the above techniques

While a wide array of control techniques and policies may be available, few are likely to satisfactorily fulfill the various performance criteria which may be proposed. First, we have emphasized allocative efficiency. To produce economic efficiency, the tax or effluent charge (or other selected method of regulation) has to be set to equal the marginal external damage caused by effluents. This presupposes knowledge on the part of the regulatory body, of the precise nature of the damage function, and of the costs of regulation. It is, thus, difficult in many cases, for example, CO_2, to imagine adoption of such a scheme. This also raises a second issue, that of flexibility. What control techniques are capable of responding to changing situations, so that we are not locked into a choice which itself may be characterized by lack of good information on costs or consequences? For example, dumping CO_2 into the deep ocean may appear desirable at the moment, but it may only be because the risks have not been explored. A third criterion revolves around effectiveness and enforceability. Seneca and Taussig (1979:74) explain the difficulties here:

> Consider the problem of sanctions against lawbreakers in any hypothetical market for air pollution rights. That is, suppose that contracts to provide cleaner air were somehow negotiated in spite of the large information and transaction costs discussed above. Successful delivery of clean air to buyers would depend critically on the ability of the police and the courts to enforce the terms of such contracts. Effective enforcement would depend among other things, on detection of innumerable potential violators on the sellers' side of the contracts. Enforcement probably would be prohibitively expensive, especially if the general public feels that everyone has an inalienable right to burn his garbage or drive his car and refuses to cooperate with law enforcement officials.

Moreover, the question of enforcement raises again the basic issue that part of the process of regulation is specification of the ownership and rules for exchange of property. The selection of rules and institutions to guide the use of atmospheric resources, no matter how efficiently and fairly it may be done, cannot be accomplished without new encroachments on common property resources which some may be reluctant to see further defined or enclosed. The intrinsically multinational character of many of the externalities associated with the use of the atmosphere further suggests the limited applicability of much of the literature on regulation in economics. This literature usually assumes the existence of a governmental entity with both the information and authority to regulate efficiently the activity in question. Taxation powers, for example, are often assumed, for purposes of discussion, of potential national policies. Internationally, there is almost no power to tax firms or individuals within nations. Moreoever, suggestions of such authority are almost always received as an unwelcome attack on the sovereignty of nations.

The existence of an effective international organization to concern itself with the management of the atmosphere might, in some respects, be desirable. Unfortunately, the history of international organizations and a look at analogous areas, such as the oceans, suggest that progress in this respect is uncertain and likely to be slow, and, indeed, developments are potentially regressive, both from a technical and a managerial standpoint. This is not to suggest that interested organizations, such as the UN Environment Program, the International Council of Scientific Unions (ICSU), and the World Meteorological Organization (WMO) are lacking in talent or incapable of influencing events. It is to suggest, however, that the powers presently available to these bodies will not assure efficient or equitable use of the atmosphere in the senses we have been discussing. Because the fundamental legal and political entities of the world are sovereign nations, regulation must almost certainly begin with national mechanisms and cooperation among the nations who are the most concerned and concentrated users of the atmosphere. But, this just returns us to the discouraging situation of confronting global issues with fragmentary national resources.

While there are specific problems of policy design as discussed so far, there is also the broad question whether we are considering issues from the correct point of view. The tendency in resource management has been to organize functionally defined units across spatial or physical regimes. But, is it best to organize management primarily around geopolitical "space" (the oceans, atmosphere, Antarctica, outer space) rather than around the functional areas (waste disposal, etc.)? It should be noted that this is an issue both at the global and national level, where concepts like "ocean management" have not always served well. Some have argued that as issues and relationships become more complexly linked, the tradeoffs and choices must be made in a way that is impeded by defining institutions in spatial terms. Morse (1977:18) proposes,

> ...it would be better to link issues via regimes according to the purposes the issues are to be put or the uses made of them (e.g., "industrial policy," or "protein") rather than according to a "natural system" into which they seem to fall (e.g., grains, oceans, population, trade, etc.).

Certainly, CO_2 is an issue of competing uses of the atmosphere, but it is also an issue of energy paths, and of waste disposal, and it may be more important to redesign policies from these points of view than from the spatial point of view.

This critique does not mean there is no place for something like "atmospheric management" or attempts at optimization of the uses of the atmosphere. It suggests, rather, that different types and degrees of interdependence of issues call for different kinds of regimes. Some regimes will simply aim at problem definition, some at standardization and harmonization of policies, while others may, in fact, need to play a dominant role in managing activities. While the spatial organization may be a particularly convenient way of confronting governments with issues, the issues will probably most of the time need to be considered in terms of broader policy bundles. And implementation of relevant decisions (on energy, land-use policy, and so forth) may take place through quite different mechanisms.

Morse suggests there is a continuing need for evaluation of linkages of activities so as not to create a multipurpose spatial regime which is in practice merely eclectic. A spatial regime can serve usefully in delimitation of property rights, determining rights of access and limits of exploitation of resources in shared areas that are characterized by interdependent relationships. Having fulfilled this purpose, such a regime may become of questionable value. Morse (1977:19) gives the following case of functional versus spatial conflict:

> A food regime, for example, would involve some ocean space questions (fisheries), some trade issues (commodity agreements) and investment issues if its main purpose were to assume minimal equity in the distribution of food. The development of an adequate food regime would be impeded by the establishment of an all-encompassing "ocean space" regime. In terms of "functions," some aspects of ocean space would require little more than regulatory mechanisms—e.g., the establishment and maintenance of traffic patterns...

In the end, one might have a faulty commons and a dysfunctional management principle by simply emphasizing ocean space. There is no resolution to the debate other than, as Morse suggests, to continue to evaluate where the linkages in spatial terms are so strong that management from that point of view should dominate. In any case, one form of management need not preclude the other. Different angles of authority and function, if coordinated, might serve well.

In conclusion, one does get a sense from the broad kind of survey offered in this paper that several issues relating to the atmosphere have not received sufficient attention, definition, and comparison, and methods for development of relevant information and resolution of conflicts are insufficiently advanced. The most difficult questions all revolve around the massive return of residuals to the environment. The institutions of private property and exchange that are normally used for determining the value of resources and providing incentives for their efficient allocation do not, and perhaps cannot, function successfully for this purpose with respect to the atmosphere, as the atmosphere maintains many of the characteristics of a common property resource, at global and lower levels. The problem is compounded by the very poor information available and by equity questions, of spatial, as well as, intergenerational character.

Some experts have argued that a partial solution to the problem lies in giving preference to nondamaging uses of common property resources over damaging ones. Page (1973) has advanced an argument for justifying a hierarchy of rights based on the difference between rights to the use of the services of a common property resource which does not impair its substance, and rights to consumption, preemption, or destruction of the resource itself. While there are difficulties about information here, and ambiguities may arise, as, for example, with the contention that in some areas climate change may produce benefits, this would seem to be a persuasive argument, as long as there is some confidence in evidence or forecasts of detrimental effects. As Krutilla and Fisher (1977) comment, such arguments take one out of economics and into ethics.

Of course, it is precisely the ethical issues which are among the most compelling reasons for coming to terms with problems like climatic change, acid rain, and destruction of the ozone layer, since causing these problems is clearly not consistent with most concepts of environmental stewardship or the proper relationship of man to nature. But these concepts are philosophical and not economistic, and in spite of the inadequacy of economic analysis of the atmosphere, much of the battle over management of atmospheric resources will be fought out on economic (and political) issues and not ethical ones. Reducing residuals is expensive. It will add to the costs of production, slow exploitation of resources, and ultimately appear in the form of higher prices for consumers. Moreover, the costs of residuals control tend to rise steeply as targets for environmental preservation become more ambitious.

Given the scientific and economic uncertainties about many of the uses of the atmosphere, and the structure of control and management, or lack of it, both nationally and internationally, it is hard to believe that society will be able to come to grips in a decisive way with major atmospheric issues in the next decade. Even supposing, for example, unanimity among atmospheric scientists about the severity of CO_2 effects, much advanced work on the impacts of climate change and CO_2 enrichment of the atmosphere from ecologists, agronomists, and others, and more reliable analysis from economists, the underlying structural and philosophical reasons for present policies toward exploitation of atmospheric resources might well rule out successful preventive or compensatory action. Nonetheless, it is not a waste of effort to examine the possibilities for various control techniques for atmospheric issues, and for viable national and international regulation. But, it may be as important to continue to think about living with, and adjusting to, an ever more irrationally exploited and degraded atmosphere.

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