INTERNALIZING ENVIRONMENTAL COSTS:

A Survey of Progress in Estimating the External Environmental Costs of Electricity Production and A Review of Market-based Policies to Incorporate Them

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ABSTRACT

The production of electricity creates environmental insults whose costs are not fully reflected in the prices paid by consumers for electricity services. Failure to incorporate these external costs leads to economically inefficient production and consumption decisions. The present work reviews two related efforts to address this market distortion. The first concerns progress in estimating the un-internalized environmental costs of electricity production. The second concerns market-based approaches to internalizing these costs in electricity production and consumption decisions.

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EXECUTIVE SUMMARY

This report reviews progress in estimating the cost of environmental externalities associated with the generation of electricity and in applying market-based environmental policies to internalize these costs. The review is motivated by economic theories that suggest that private decisions to produce and consume electricity will better reflect society's desires for environmental quality by internalizing the external costs of electricity production.

We begin by describing an integrated framework to identify the source of particular environmental insults as well as identify points along the pathway from insult to damage where environmental policies can intervene.

In applying this framework to the environmental externalities from electricity production, we identify three general approaches to measuring the cost of these externalities. Indirect methods are used to measure the value of goods not traded in formal markets, such as human life, scenic, and recreational goods. Direct methods are used to measure goods for which economic costs can be readily assessed, such as the value of lost agricultural products, or the cost of repairing damaged goods. Methodological issues and data limitations complicate application of both approaches. When these problems are significant, proxy methods are used to measure the costs of avoiding the initiating insult rather than the cost of the damage created by the insult.

We find that significant progress has been made to quantify selected damages. These include, damage to health, agriculture, materials, and visibility from emissions of SO2, NOx, and particulates, routine and accidental radiation releases from nuclear powerplants (both during operation and decommissioning), and fabrication and operation of wind and solar photovoltaic electricity generators. Nevertheless, many other, potentially significant, aspects of certain fuel cycles remain un-analyzed.

Individually or when combined for a particular generating technology, we find that the estimates of the external environmental costs of electricity production often exceed the current price of electricity. This finding suggests that there is a large difference between the costs borne by private producers and consumers of electricity and the costs that these activities impose on society.

We also comment on important limitations of existing estimates by reviewing a recent major study of environmental (and other) externality costs in greater detail. In addition to identifying relatively straightforward limitations of the methodology and data used, our review raises important considerations for the use of quantitative information in measuring environmental costs. The net impact of these considerations is that current estimates of the environmental externality costs of electricity production are probably low.

The review of environmental externality costs sets the stage for a survey of market-based approaches to internalizing these costs. Market-based approaches differ from the regulatory approaches they replace because they allow for greater discretion in compliance for a polluter. Regulatory approaches typically mandate specific actions with little consideration of the cost of compliance (e.g., installation of best-available-control-technology on a plant that will be retired before the end of the useful life of the pollution control equipment), while market-based approaches provide some flexibility in the polluter's response.

Two market-based approaches are relevant to internalizing the external environmental costs of electricity production. The first is charges in which pollution fees or taxes are assessed based on the quantity of a given insult created by a polluter. Charges allow the polluter to choose between investment in pollution control or payment of the charge. The second is market-creation in which a fixed number of permits to pollute are issued and then sold, traded, or leased by polluters among themselves. Market-creation allows polluters to purchase abatement equipment (and sell their excess permits) or purchase permits from others. With charges, the value of the individual environmental externalities are determined administratively. With market-creation, these values are determined implicitly through the operation of the market.

Our survey confirms the relative newness of market-based approaches as instruments of environmental policy. Charges exist or are under discussion for SO2 (France, Sweden), NOx (Sweden), and CO2 (Sweden, Finland) emissions. Of these, the proposed charges for Sweden are considerably higher than those of France and Finland. In the United States, charges are rarely used to change the cost of electricity generating resources to the consumer, but they are being used in evaluations of the appropriate choice of future generating resources or conservation. Existing market-creation activities are limited to the U.S. for areas that have not yet met federal clean air standards. A market-creation policy for acid rain precursors is likely to be in place in the U.S. before the end of 1990.

We compare the estimates of environmental externalities with available pollution charges (since there are no comparable values available from market-creation activities) to provide some perspective on the levels of charges. While we find reasonable comparability between the charges and the damages they seek to internalize (especially, the proposed Swedish charges), we observe that the comparison is imperfect. We know from the start that the estimates of externality costs are probably low. In addition, there are often other influences on the price of energy, which reinforce or diminish the effects of charges that incorporate the costs of environmental damages. For both reasons, direct comparisons are of doubtful meaning. An additional comparison of charges with the costs of abatement highlights the apparent cost-effectiveness of abatement relative to most charges.

The comparison also raises a concern over the equity of such charges. That is, while the use of charges to internalize environmental externalities may increase the economic efficiency of electricity markets, they may be inequitable because to our knowledge in no case are charges being proposed for use in mitigating the environmental damage that is the basis for their collection.

The use of economic principles to guide environmental policies is a relatively new phenomenon. There are good reasons to believe that their use will lead society to attain its environmental quality objectives in a cost-effective manner. However, in the absence of economic quantities for many of the values that society holds dear, cost-effectiveness may be only a secondary consideration. We should not rely solely on monetary estimates of the value of environmental externalities to guide environmental policies (if only because we know these estimates are imperfect). Similarly, exclusive reliance on market-based approaches to internalize these costs will only yield efficiency benefits, if the markets themselves are workably competitive. Moreover, economic efficiency is not the only legitimate objective of environmental policies. This invisible hand is a powerful force for social organization, but let us not be afraid to bite or at least keep an eye on the hand that feeds us.

1. INTRODUCTION

Electricity generation imposes environmental costs on society that are not reflected in the prices paid for electricity services. In the absence of methods to reflect these costs in electricity prices, economists hold that decisions to produce and consume electricity may be inefficient from a societal point of view. The failure of electricity markets to reflect these costs is an important justification for market interventions to correct this deviation between society's and private decisionmakers' interests. Traditionally, policymakers have relied on regulations as the primary means for "internalizing" these external costs. Recently, market-based approaches, as opposed to traditional regulatory approaches, have been suggested as a superior alternative in view of their inherent efficiency properties.

In both approaches, the magnitude of these costs is an important consideration in judging the adequacy of the policy response. It is not in society's interest to pay too much or too little in protecting the environment. Yet, considerable uncertainty surrounds efforts to determine these costs, and it is likely that many important environmental externalities will never be adequately captured within an economic framework.

Despite the uncertainties, there is growing acknowledgment that these costs are significant. Their significance suggests that the use of even a limited measure of economic worth to guide policies would be an improvement over historic reliance on un-articulated, implicit measures of worth. Economists also suggest that market forces should be relied upon as instruments for incorporating these costs because doing so will ensure that the modifications to electricity production and consumption decisions will be economically efficient.

Whether or not these views are correct is beyond the scope of this study; we note only that they have become increasingly popular themes in environmental policy analysis. The goals of this study are to: 1) review progress in developing measurable economic costs for the environmental externalities associated with electricity production, and 2) survey market-based approaches for internalizing these costs. We do not consider environmental externalities associated with other energy supply technologies, nor do we consider non-environmental externalities arising from other government policies such as R&D subsidies, tax concessions, etc. Within the field of electricity, we focus on electricity generation technologies because they have been the primary focus of environmental costing efforts and remedial policies.

Measuring and internalizing the external environmental costs of electricity production is complicated by the myriad of costs involved and the many stages of the electricity production process from which these costs arise. It is instructive to systematize the sources and mechanisms by which these costs are incurred. Accordingly, we begin by describing a framework for integrated environmental assessments of electricity production and other technologies (Section 2).

This framework provides the basis for a review of efforts to measure the costs of selected environmental externalities (Section 3). We begin the review with a summary of major approaches for measuring environmental costs. The summary is followed by a presentation of available estimates. Where possible we express these estimates in comparable units of 1989 US mills per kilowatt hour of production ($ 0.001/kWh). We then discuss important limitations underlying current estimates by means of an in-depth review of a recent major study by O. Hohmeyer (1988).

Policies to internalize the environmental costs of electricity production are described in Section 4. We focus on emerging policies that rely on market forces rather than regulatory decrees to modify electricity production and consumption decisions. We pay special attention to the use of pollution charges because they make explicit the value placed on environmental goods. To gain some perspective on these policies, we then compare representative pollution charges with estimates of the environmental costs they seek to mitigate (described in the Section 3).

2. AN INTEGRATED FRAMEWORK FOR ASSESSING ENVIRONMENTAL EXTERNALITIES

Meeting consumers' demands for electricity services leads to the creation of undesired environmental consequences at every stage of the process (including harvesting or extracting, refining, and transporting fuels, converting them to electricity, distributing electricity to consumers, and finally using electricity to provide services). In order to organize existing estimates of the economic costs of the consequences of these activities and to assess market-based policies that seek to mitigate these costs, it is instructive to identify the individual steps by which they arise.

In the late 1970's, the significance of these and other un-internalized costs emerged as an important consideration for energy policies (Budnitz, Holdren 1976). As a result, the total cost (as opposed to just the capital and operating cost) associated with energy technologies became the subject of considerable study. The goal of these studies, which were called integrated technology assessments, was to catalog the entire range of environmental or social/macroeconomic impacts associated with individual energy technologies. At the time, it was acknowledged that many important impacts would be resistant to measurement. Thus, measurement, while desirable when possible, was recognized as only one component of an overall assessment. Similarly, the fact that some impacts might already be internalized in private producer costs (through, for example, regulations or standards) was of secondary importance. Many current estimates of environmental externality costs can be traced to this pioneering body of work.

Of particular significance for the present study was the conceptual development by Holdren (1978) of an all-encompassing analytical framework for organizing the causal linkages underlying the environmental impacts of any energy technology. The framework identifies five steps for organizing the components of the environmental effects of a technology.

1. Origins of environmental effects, meaning specific activities undertaken in the research, construction, operation, or decommissioning phase of finding, harvesting, processing, transporting, marketing, and using energy.
2. Insults to the immediate environment produced by these activities, meaning what is put into, taken out of, or otherwise done to the surroundings (including, for example, resource use, effluents, and direct physical transformations such as terrain modification and erection of structures).
3. Pathways by which these insults lead to stresses on (possibly remote) environmental components at risk, involving, for example, physical and chemical transformation.
4. Stresses, meaning altered environmental conditions (for example chemical concentrations, temperature, moisture, and

structure) at the point of potential vulnerability.

5. Damages associated with the responses of components of the environment to stresses imposed upon them (including, for example, direct production of injury and illness in humans, damage to economic or environmental goods and services, aesthetic losses, and psychological distress).

Holdren emphasizes that in addition to quantitative indices of harm the final category should also include: "a) the way in which damage distributes itself in space, time, and across classes of victims; b) the relative ease or difficulty of instituting technological or managerial controls to prevent some of the damage; c) the degree of irreversibility associated with the damage once it is done; d) how damage scales with increasing stress; and e) the degree of uncertainty associated with these characterizations."

In principle, every activity associated with each aspect of the production and use of electricity should be evaluated according to this framework. However, this ambitious program of study has never been and may never be fully carried out for at least two reasons. First, significant data limitations preclude definitive quantitative measurement of many environmental effects. As a result, many of the linkages described above cannot be established unambiguously (which emphasizes the importance of reporting the magnitude of relevant uncertainties). In many cases, our limited epistemological position is inescapable; indeed, data limitations are often the primary challenge for estimation of externality costs. These fundamental limitations are sobering considerations for policies that seek to internalize unknown or imprecisely measured environmental damage costs.

Second, there are often non-trivial methodological problems in developing appropriate system boundaries, which preclude meaningful comparisons. As an example, the construction of a power plant requires resources (such as concrete and steel), which, in turn, are the result of productive processes with environmental consequences of their own. At some point, an appropriate system boundary must be drawn, yet drawing any boundary is in some sense arbitrary. From the standpoint of evaluating the un-internalized economic costs of producing and using electricity, an expedient assumption is often made that "upstream" activities have in fact internalized all relevant costs. In other words, all environmental and other externalities associated with, say, the materials used in power plant construction, are already included in the prices paid for concrete and steel. The expediency of this assumption is not always warranted because the upstream (or downstream) activities may have significant additional un-internalized environmental costs of their own.

In the face of these difficulties and the sheer magnitude of the enormous range of activities associated with the production and use of electricity, efforts to date have taken a piecemeal approach. Individual effects are singled out based on their assumed significance. For example, evaluating various estimates of the environmental costs of an activity is often simply a matter of comparing the number of consequences considered.

For this reason, Holdren's framework provides an important means for organizing the information presented in this report. In reviewing estimates of environmental damage costs (Section 3), we will use the framework to differentiate between cost estimates by indicating which environmental damage is being considered and from what source or insult it arises. For example, we have found that few estimates consider the damage from every source in the total fuel cycle for a given electricity technology. Instead, they tend to focus on only those damages arising from generation.

For our survey of environmental policies (Section 4), the framework will help to identify precisely where in the causal chain (from source to damage) a given policy is designed to intervene. Environmental policies can in principle mitigate damage at any point in this chain and in fact often do. For example, damage from SO_2 emissions to lake ecosystems can be mitigated by policies which regulate sulfur content in fuels, SO_2 concentrations emerging from the smokestack, ambient SO_2 concentrations, or finally by the liming of lakes to lower their acidity.

3. MEASURING THE COST OF ENVIRONMENTAL EXTERNALITIES

The economic first principle of environmental policy development is that society should spend no more to mitigate an environmental externality than the cost of the damage that the externality causes it. Thus, the logical starting point for internalizing the external environmental costs of electricity production is the measurement of the economic value of the damage. In the context of the integrated framework presented in the previous section, we are concerned with only a subset of the effects that the framework is capable of addressing, namely the environmental damage that can be measured, but has not yet been internalized.

The absence of unambiguous monetary values for many important environmental effects raises two important questions for policies that seek to internalize the external costs of electricity production. The first is the technical question as to whether the estimates themselves are sound. The second is whether it is appropriate to develop policies on the basis of only an incomplete measure of the total external costs of an activity. While we will comment directly on the first question in Section 3.3, only a partial response to the second question is possible at this time.

We begin by observing that the adoption of an economic framework for evaluating environmental policies means that the assignment of some cost represents an improvement over the implicit assignment of no cost, which we know to be incorrect. However, it is also entirely appropriate to question the use of any economic framework for making environmental policy decisions when many costs are known to be highly uncertain and when others have not been (and may never be) adequately measured in economic terms. In this regard, while the use of economic arguments is an important component of environmental policy, we should acknowledge that economic considerations are but one of many justifications for the development of environmental policies. Nevertheless, to the extent that the activities environmental policies seek to modify are often driven by economic principles, it is essential that the damage created by these activities be measured in economic terms where possible. Crudely speaking, one should at least be prepared to fight fire with fire.

In this section, we describe the three major approaches used to estimate the costs of environmental externalities (3.1), review current applications of these approaches to the measurement of the un-internalized environmental costs of electricity production (3.2), and comment on important respects in which these efforts could be improved (3.3).

3.1 Methods for Measuring the Cost of Environmental Externalities

As a first approximation, methods to measure the cost of environmental externalities can be grouped into three categories: indirect, direct, and proxy. These categories are the subject of some confusion in the literature. Environmental economists sometimes refer to what we will call the indirect methods as "direct" and the direct methods as "indirect" (see, for example, OECD (1989)). Further complications arise when it turns out that some applications of the direct method rely on elements of the indirect method. We have chosen the three categories because they represent convenient groupings for the methods underlying the estimates we shall review in the next Section (3.2).

Indirect Methods

Indirect methods are based on the premise that careful analysis of individuals' behaviors can reveal the value that society accords a given good (such as clean air, scenic beauty, etc.) in the absence of formal markets where these goods can be valued explicitly. The methods establish this value either by examining surrogate markets for a good or by using experimental techniques to simulate such a market.

The surrogate market approach relies on the existence of markets where a primarily non-environmental good, which is linked to the provision of some environmental good, is bought and sold. The object of the analysis is to identify separately the aspects of the good that relate to the environmental impact under question. Hedonic property price techniques, for example, examine housing markets in polluted and non-polluted areas in order to estimate the premium attached with living in the non-polluted area. This premium is thus the cost of the pollution. Wage risk studies are another example in which the wage premium attached to riskier jobs is used to measure the value individuals implicitly are placing on their lives or health. A final surrogate market approach is the travel cost method in which the value of a given natural resource is estimated by the expenditures made by those who travel to visit these resources.

In the absence of formal markets where environmental goods are bought and sold, experimental approaches can be used to simulate these markets. Contingent valuation studies are the leading example of this experimental approach. These studies seek to measure the economic benefits or costs of a given activity by asking individuals how much they would be willing to pay to receive or forego a given benefit or cost. Questionnaires are typically used to elicit responses and there are elaborate theoretical considerations which differentiate between the significance of one's willingness to pay to acquire a benefit or prevent its loss and one's willingness to accept payment to forego a benefit or tolerate its loss.

The indirect methods have been criticized on several methodological grounds: A well-known failure of markets is the existence of imperfect information among participants. In this case, the individuals whose behaviors are being studied may not be aware of the environmental benefits being measured (as, for example, when someone does not recognize the damage to his property or himself caused by air pollution). Pre-existing biases also complicate the observation of revealed preferences (as, for example, when risk-takers choose to accept dangerous, low-paying jobs for which more risk-averse individuals might demand higher compensation). Finally, equity considerations are often overlooked (as, for example, when city parks are valued less highly because those who frequent city parks may not have and, in any case, do not expend their resources to travel to remote destinations).

With indirect methods it is also often difficult to separate the economic value of individual underlying influences from some more generally perceived environmental good (such as the relative contribution of individual air pollutants to the overall value placed upon clean air). For these reasons, direct methods offer some advantages over indirect methods. As we shall see, however, many direct approaches must also rely on indirect methods for specific aspects of the valuation process.

Direct Methods

Direct methods are favored by environmental scientists because they measure each causal link in the steps between sources and damages (see Section 2). In a typical analysis, a given insult is first identified, its pathways traced and the resulting stresses on various components measured. Next, through the use of dose-response relationships, damages are measured. In some cases, the value of the damage can be estimated directly (such as the economic value of damaged goods). In others, a hybrid approach, which combines aspects of the indirect methods, is used (such as in some approaches to valuing human life).

Three classes of damage are typically considered: 1) human health; 2) agricultural resources; and 3) materials degradation. Damage to human health includes loss of life (mortality) and illness (morbidity). Damage to agricultural resources includes loss of livestock, crops, forests, and ornamental plants. Damage to materials includes effects of corrosion and soiling.

Direct methods are particularly advantageous in those cases where the pathways between sources and damage are un-recognized by individuals. In addition, they offer the ability in principle to separate the effects of individual insults. For these reasons, direct methods dominate the studies we examine in the following Section (3.2).

The difficulty in using direct methods lies with the need to specify causal linkages explicitly. In the absence of sufficient data to establish these linkages, substantial uncertainty often surrounds dose-response and consequently damage estimates.

A major methodological issue for direct methods lies with the valuation of goods that are not commodities in formal markets. For example, damage to human health often considers the wages lost due to disability or loss of life. This approach assigns no value to illnesses and premature losses of life suffered by those who are unemployed (such as homeworkers, retired persons, children, etc.). For this and other reasons, the valuation component of causal methods often relies on the indirect methods described above. In this case the problems inherent in the indirect methods further compound those of the direct methods that adopt them.

Proxy Methods

The methodological and data limitations inherent in both the indirect and direct methods have led to the development of "shadow-pricing" or proxy methods. These methods do not estimate the cost of environmental damage directly, rather they estimate the cost of mitigating the damage. For example, due to the great difficulty of estimating the cost consequences of global warming due to increased CO_2 production, a proxy approach is often taken. In this approach either the cost of removing CO_2 from the combustion products of electricity production or the cost of removing CO_2 from the atmosphere through the planting of trees is estimated. (In fact, the cost of other carbon removal or avoidance strategies is often estimated as well and the least expensive is chosen; typically, the least expensive option is tree planting). When mitigation costs are mandated by regulatory authorities (such as the cost of scrubbers for powerplants), the shadow-price may be considered the revealed preference of the regulator acting on behalf of society. In this regard, some proxy methods may also be thought of as a type of indirect method.

The advantage of proxy methods is that, in many cases, the costs of mitigation are easier to estimate than the damage to be mitigated. The disadvantage is that it is precisely the cost of mitigation that the estimation of damage is to be compared against for the purposes of evaluating the economic justification for specific policies. In general, proxy methods are only used when the indirect or direct are incapable of producing meaningful estimates and when there is some confidence that the costs of mitigation are less than the damage they seek to mitigate.

3.2 The Cost of Environmental Externalities

The environmental externalities of electricity production have been examined by many, but quantified by only a few. With some exceptions, the studies we examined consider only those environmental insults arising from the generation of electricity at powerplants. For this particular source within the total fuel cycle, the studies typically examine only what are thought to be the most important environmental insults, such as the air polluting emissions of fossil-fuel combustion or the accidental release of radiation from nuclear powerplants.

The most comprehensive review of environmental externality costs is Ottinger, et al. 1990. In addition to reviewing existing numerical estimates, Ottinger's study provides an up-to-date guide to the literature for many environmental insults that have been studied but not yet quantified. We have relied extensively on this exhaustive work for the material in this Section.

The externality cost estimates we review can be divided into two categories: 1) those externalities that are common to several electricity generating technologies (for example, air pollution emissions common to all fossil fueled electricity generation); and 2) those externalities that are unique to particular generating technologies (for example, accidental radiation releases from nuclear powerplants). In the first case, estimates are usually developed independent of generating technology and are expressed on a 1989 US dollars per pound ($/lb) basis (see Tables 1-4). To facilitate comparison with externalities in the second category, these estimates must be re-expressed on a dollars per MWh basis (see Tables 6-9). We have adopted a common set of conversion factors based on the published characteristics of various electricity generating technologies in order to standardize this process (Table 5).

Tables 1, 2, and 3 present estimates of the environmental costs of SO2, NOx, and particulates, respectively. The studies prepared by ECO Northwest were prepared for the Bonneville Power Administration (BPA). They examined the direct impacts of powerplant emissions from an existing coal-fired powerplant in Oregon (ECO 1983), an existing gas and oil-fired powerplant in Washington (ECO 1984), and generic coal-fired powerplants located in several Northwestern locations. Krawiec (1980) is based on previous epidemiological studies. Mendelsohn (1979) examines emissions from an uncontrolled coal-fired powerplant in Connecticut.

With the exception of Chernick and Caverhill (1989), these studies rely on direct methods to develop estimates for health and material damage and on indirect methods to develop visibility damage (typically, hedonic property prices). Chernick and Caverhill (1989) use a proxy approach in which the costs of abatement are estimated. Ottinger, et al. (1990) rely on all of the studies (except Chernick and Caverhill (1989)) to develop a "best" and "high" estimate. These estimates often differ from those found in the studies they review because efforts were made to extrapolate values for use in the Northeast. Several of the studies were originally developed using assumptions characteristic of the Northwest (in particular, lower population densities).

To facilitate comparisons of estimates from different studies, Ottinger, et al. (1990) used common assumptions for the value of human life ($4,000,000) and major illness ($400,000) to re-derive costs from each study. In addition, all costs were expressed in 1989 dollars. We have relied on these modified values in Tables 1, 2, and 3.

Table 4 presents various proxy estimates for the environmental costs of CO_2. It is generally agreed that application of the direct methods is un-workable for estimating these costs due to the difficulty in determining the impacts of increased CO_2 levels with precision. (An exception is Hohmeyer (1988) who takes a 1 meter rise in sea level as given and then calculates the cost of raising German sea walls by 1 meter.) As a result, the cost of planting trees has been widely used as a proxy that measures the cost of removing CO_2 from the atmosphere.

Ottinger, et al. (1990) review a large number of tree planting studies. Their review dismisses many of the lower estimates found in the literature due to acknowledged difficulties in replicating these costs elsewhere. For example, the widely cited efforts by Applied Energy Systems to reforest parts of Guatemala are not included because they relied on unrealistically low (or, more importantly, unreplicable in other locations) cost assumptions (Trexler, et al. 1989). The work by Akbari, et al. (1988) is interesting because it examines tree planting in urban settings. Since these plantings have the effect of reducing building cooling loads, they save energy in addition to sequestering carbon. These savings effectively offset the entire cost of the planting, which makes the cost of removing carbon free or a negative net cost. Nevertheless, these costs would only be applicable for urban tree plantings. Another study in which carbon removal is but one of several benefits (and consequently gets assigned only part of the cost) of tree-planting is Dudek (1989), which examines tree planting in conjunction with efforts to halt soil erosion. The remaining studies examine commercial re-forestation at particular locales in the Northwest (Buchanan (1989) and Reichmuth and Robison (1989)). Chernick and Caverhill (1989) analyze these and other studies to derive a much higher estimate.

Table 5 presents conversion factors for combining the costs of individual air emissions (Tables 1-4) into a single value for various fuel and electricity generation technology combinations. These data are taken mainly from U.S. Department of Energy technology characterizations.

Table 6 presents estimates of the environmental cost of major fossil fuel and waste-to-energy electricity generation technologies. These estimates are calculated using the "best" and "high" costs estimated by Ottinger, et al. (1990) for individual air emissions (from Tables 1-3) and the conversion factors from Table 5. In the case of CO2, a range of $20/ton to $80/ton is used.

Table 6 also includes environmental costs estimated by Hohmeyer (1988). These values were not derived separately for individual air emissions, fuels, or generation technologies. Consequently, only a final estimate representing the aggregate environmental costs for all fossil fuel electricity generation can be presented. The damages included in Hohmeyer's estimates include health, agriculture, and materials, but are restricted to damage that occur within German borders. (See the following Section for a more in-depth review of Hohmeyer's estimates.)

In reviewing the environmental cost estimates for waste-to-energy facilities presented on Table 6, it is important to recognize that only the costs for the air emissions on Tables 1-4 are being considered. A more comprehensive estimate would also consider air emissions of heavy metals and other pollutants, which are not associated with conventional fossil fuel electricity generation.

Table 6 also presents the average retail price of electricity as a yardstick for comparison with the externality cost estimates. We find that for many fuels and technologies the externality costs exceed the average price paid for electricity; in several cases, the differences are an order of magnitude. The size of these differences suggests that the societal cost of producing electricity is significantly greater than that of private producers'.

We also find that the magnitude and variation in externality costs across generating technologies can dramatically affect cost differences between technologies based on capital or operating cost. For example, considering the average price paid in 1988 for coal (1.47 $/MBtu) and petroleum (2.44 $/MBtu) from EIA (1989), and assuming a heat rate of 10,000 Btu/kWh, the difference in fuel costs for coal and petroleum electricity generation is 10 $/MWh. The significance of this finding is that consideration of environmental externality costs could have a major impact on utility resource acquisition decisions because externality costs can be much greater this difference in fuel prices.

Table 7 presents total cost estimates for nuclear electricity generation. The first set of estimates was developed in Ottinger, et al. (1990) based on an extensive review of the literature. We do not present the underlying assumptions from which this estimate was drawn due to significant differences among these studies, which makes direct comparisons difficult. Many of these studies examine radiation damage from any source and must be combined with additional assumptions to arrive at an estimate unique to nuclear electricity generation. An exception is Hohmeyer (1988), which examines damage stemming from an accidental release, such as Chernobyl. The Ottinger estimate is unusual relative to previous estimates in that the decommissioning phase is also considered (although, as with most studies, the front end of the fuel cycle is not included). Since limits on decommissioning costs have been established (and are thus included in existing powerplant cost estimates), Ottinger considers only those additional costs, which have been estimated to exceed this limit. Separate estimates are presented based on type of generating technology (boiling water versus pressurized water reactors).

The studies by Ottinger, et al. (1990) and Hohmeyer (1988) are also the source for estimates of the environmental externality costs of renewable energy sources for electricity generation (Table 8). Renewable electricity sources differ considerably from combustion and nuclear technologies in that the "fuels" and their conversion to electricity are relatively benign. For example, none of the air emissions considered to this point are associated with renewable electricity generating sources. Studies of the environmental impacts of renewable electricity typically consider other aspects of the fuel cycle. These include land and material use associated with the construction of renewable electricity plants. These insults are usually not considered for conventional powerplants because land use requirements are often modest in comparison. In addition, it is generally assumed that environmental impacts are already incorporated in the prices paid for land and materials and are thus not externalities. This issue also arises for renewable electricity technologies because it is often difficult to determine what fraction of environmental costs have, in fact, already been internalized.

Ottinger, et al. (1990) base their estimates for large hydroelectric plants on earlier studies prepared for BPA for the Northwest (BPA/ECO 1986). These studies consider primarily impacts on lost recreation opportunities (including fishing and hunting). Hohmeyer (1988) examines both the land use impacts of solar photovoltaic electricity in which generation is assumed to be geographically dispersed as well as accidents that would arise from the maintenance of these installations. Ottinger, et al. (1990) considers these costs, as well as those associated with the fabrication of photovoltaic cells. It is generally acknowledged that the fabrication process is the source of the most significant environmental impacts of photovoltaics (which are nonetheless low by comparison to those of conventional electricity generating technologies). Hohmeyer's (1988) estimate for wind generation uses assumed reductions in property prices (i.e., an inferred hedonic property price) to measure the environmental cost of noise and visibility impacts. Ottinger, et al. (1990) base their estimate on Hohmeyer (1988) and on two additional studies (BPA/ECO (1986) and

Shuman and Cavanagh (1984)), the latter of which also examines occupational impacts. Ottinger, et al. (1990) also develop an estimate for biomass, which is based largely on a BPA study for biomass cogeneration (BPA/ECO 1986).

Comparisons of the figures on Tables 7 and 8 with the average retail price of electricity (See Table 6) suggest that the differences between societal and private producer costs are smaller than those found for fossil fuel generating technologies. For nuclear electricity, these costs nevertheless represent a significant fraction of the average price of electricity. Similarly, our earlier findings regarding the effect of externality costs on the cost differences between generating technologies is reinforced, in particular by the low environmental externality costs for renewable electricity generation.

Table 1. Environmental Externality Costs for SO2 (1989 US$/lb)

	Method	Damage	Estimates Best	High
ECO 1987	direct	H,M	1.79	
ECO 1984	indirect	V	0.14	
Mendelsohn	direct/ indirect	H,M,V	4.53	
Krawiec	direct	M	0.34	
Chernick-Caverhill	proxy	n/a	0.88	
Ottinger, et al.	n/a	H,A,M,V	1.79	7.10

Notes:
1. Damage: H-Health; A-Agriculture; M-Materials; V-Visibility; O-Other.
2 All health damage adjusted from original studies using 4.0E6$/life and 0.4E6$/illness (from Ottinger, et al. 1990).
3. Ottinger, et al. costs developed from review of other studies.

Table 2. Environmental Externality Costs for NOx (1989 US$/lb)

	Method	Damage	Estimates Best	High
ECO 1987	direct/ indirect	H,M,A,V	0.02	0.43
ECO 1984	direct/ indirect	H,V	0.18	
ECO 1983	direct/ indirect	A,V	0.00	
Chernick-Caverhill	proxy	n/a	1.50	
Ottinger, et al.	n/a	H,A,M,V	0.53	1.05

Notes:
1. Damage: H-Health; A-Agriculture; M-Materials; V-Visibility; O-Other.
2 All health damage adjusted from original studies using 4.0E6$/life and 0.4E6$/illness (from Ottinger, et al. 1990)
3. Ottinger, et al. costs developed from review of other studies.

Table 3. Environmental Externality Costs for Particulates (1989 US$/lb)

	Method	Damage	Estimates Best	High
ECO 1987	direct	H	0.20	0.36
ECO 1983	direct/ indirect	H,V	0.86	
Ottinger, et al.	n/a	H,V	1.18	2.36

Notes:
1. Damage: H-Health; A-Agriculture; M-Materials; V-Visibility; O-Other.
2 All health damage adjusted from original studies using 4.0E6$/life and 0.4E6$/illness (from Ottinger, et al. 1990).
3. Ottinger, et al. costs developed from review of other studies.

Table 4. Environmental Externality Costs for CO_2 (1989 US$/ton)

	Method	Estimates Best	High	Comments
Buchanan	proxy	19.5	47.5	commercial douglas fir trees
Reichmuth-Robison	proxy	19.0	25.0	temperate forests
Dudek	proxy	21.5	24.0	conservation resource program planting silver pines
Akbari, et al.	proxy	-0.0	26.0	urban tree planting could have negative cost
Schilberg, et al.	proxy	54.0		
Chernick-Caverhill	proxy	80.0	120	based on analysis of available estimates

Table 5. Conversion Factors for Fossil Fuel Environmental Externality Costs

	Assumptions Heat Rate (Btu/kWh)	Fuel Sulfur (%)	Emission Factors (lb/MWh) SO2	NOx	Part.	CO2	Sources
Coal							
ST no control	9400	2.5	46.5	9.40	0.940	1,960	A
FGD	9400	2.5	4.7	9.40	0.940	1,960	A
AFBC	9400		4.7	3.76	0.282	1,960	A
IGCC	9000		1.3	0.45	0.090	1,880	A
Natural Gas							
ST	9224		0.0+	6.23	0.293	990	B
/CC	9000			3.78		990	C
CC w/BACT	9000			0.25		990	C
Oil							
ST	9840	2.0	25.4	2.95	2.800	1,650	B
CT	13600	0.3	4.4	6.77		2,190	C
Waste to Energy			20.0	2.00	0.750		D

Notes:

1. Technologies: ST - steam turbine; FGD - flue gas desulfurization; AFBC - atmospheric fluidized bed combustion; IGCC - integrated gasification combined cycle; CC - combined cycle; CC w/BACT - combined cycle with best available control technology; CT - combustion turbine.
2 Sources: A - DOE (1988); B - DOE (1983); C - Chernick and Caverhill (1989); D - Ottinger, et al. (1990).

Table 6. Environmental Externality Costs for Fossil Fuel Electricity (1989 $/MWh)

	Best	High	Percentage of Best Estimate Represented by SO2	CO2
Coal				
ST w/o control	108	421	77%	18%
FGD	33	124	25	60
AFBC	30	116	28	66
IGCC	21	85	11	88
Natural Gas				
ST	13	47	0	75
CC	12	44	0	83
CC w/BACT	10	41	0	99
Oil				
ST	64	256	72	26
CT	33	132	23	66
Waste to Energy	47	185	77	21
Hohmeyer	8	48		
US Average Electricity Price		64		

Notes:
1. Based on the ranges of costs developed by Ottinger, et al. (1990) from Tables 1, 2, 3, and 4 and the conversion factors from Table 5. For CO2, a range from 20 to 80 $/ton was used.
2. Hohmeyer examines health, agricultural, and material damage, but does not assign unique values for individual fuels or technologies.
3. US average electricity price taken from EIA (1989).

Table 7. Environmental Externality Costs for Nuclear Electricity (1989 $/MWh)

	Damage	Low	High
Ottinger, et al.			
routine operation	H,A	1	
accident	H,M	21	
decommission	proxy	2	3
total		24	26
Hohmeyer			
accident	H,A	8	84

Notes:
1. Damage: H-Health; A-Agriculture; M-Materials; V-Visibility; O-Other.
2. Ottinger, et al. gives separate estimates for the incremental decommissioning costs of pressurized water reactors (PWR) and boiling water reactors (BWR).

Table 8. Environmental Externality Costs for Renewable Electricity (1989 $/MWh)

	Damage	Low	High
Ottinger, et al.			
Large Hydro	A	11	12
Solar Thermal & Photovoltaic	H,O	0	4
Wind	O	0	1
Biomass		0	7
Hohmeyer			
Photovoltaic	H,O	0	3
Wind	O	0	0+

Notes:
1. Damage: H-Health; A-Agriculture; M-Materials; V-Visibility; O-Other.
2. Hohmeyer's estimate for wind electricity generation is less than 0.5 mills/kWh.

3.3 Assessing the Estimates

Efforts to measure the cost of the environmental externalities of electricity production technologies remain in their infancy. Important progress has been made as evidenced by the estimates presented in the previous Section, but much work remains. As an example, we examine one of the most comprehensive, independent studies of environmental externality costs, that developed by Hohmeyer (1988).

Estimation Methods

Hohmeyer begins with an assessment of the data available to support analyses of the external costs of electricity production. (His scope is somewhat broader than that of the present study because he is also concerned with non-environmental externalities.) Based on this assessment, individual external effects are identified for examination separately for each electricity generating technology (fossil fuel, nuclear, wind, and photovoltaic). The costs are annualized and then unitized by kWh (although temporal variations in kWh output are suppressed for renewable technologies). The effects considered and costing methods vary somewhat for each technology.

Fossil fuel electricity. Air pollution damage from power plant emissions of CO, particulate matter, NOx, SO2, and volatile organic compounds is measured in two steps. First, the relative emissions of powerplants, combined heat and power stations, and district heating plants (not including railway electricity generation) are multiplied by "toxicity factors," which equates damage from each of the five pollutants (e.g., NOx is 128 times worse than CO on a per ton basis). These factors are multiplied and summed over all pollutants and then compared to the corresponding sum from all other sources of these emissions to estimate the fraction of damage attributable to electricity production (estimated at 28%). Second, this fraction is applied to annual total damage estimates for German flora, fauna, people, materials, and climate. Damage to German flora includes forest (5.5-8.8 G DM/yr) and agricultural crop damage (1.0 G DM/yr). Damage to German fauna is estimated to be 100 M DM/yr. Damage to the people of Germany is based on productivity losses due to increased respiratory diseases (1.6 to 40.4 M DM/yr). Damage to German materials consists of corrosion and weathering of man-made structures (2.3-4.2 M DM/yr). The effect on climate considers the costs of raising German dikes by 1 meter (1.0-2.0 M DM total). The damage ranges from 8 to 48 $/MWh in 1989 US dollars.

Nuclear electricity. Using data from the Chernobyl accident, the costs of a large nuclear powerplant meltdown are estimated. The estimation requires several components: the cost of German health damage resulting from a meltdown times the probability of a meltdown normalized by electricity production from nuclear powerplants. The value of health damage is the product of the radiation emitted by a Chernobyl-like accident (240 M person rem), a dose-response rate (200-3,700 cancer incidents per 1 M person rem), and a productivity loss per cancer incident (750 k DM total per cancer incident, based on 50% deaths at 1 M DM + 50% non-fatal at 0.5 M DM). However, the Chernobyl emissions are modified to account for different quantities of release per meltdown and for releases in more densely populated areas. As a result, a range of 30 M person rem to 30,000 M person rem per meltdown is estimated. The range of meltdown probabilities is 2,000 to 20,000 reactor-years of operation per meltdown. Ultimately, a much narrower range is estimated based on a high and low population density estimate (differing by a factor of 10), the Chernobyl release of 240 M person rem, the assumption that the Chernobyl incident is statistically representative of the probability of reactor meltdowns (i.e. one meltdown for 3000 observed reactor-years of operation) and a mid-point assumption of 1000 cancer incidents per 1 M rem. The damage ranges from 8 to 84 $/MWh in 1989 US dollars.

Photovoltaic electricity. Accident risk to maintenance personnel of decentralized photovoltaic installations and the cost of land not included in real estate prices are estimated. Accident risks are based on 423.5 lost person hours and 0.0085 fatal accidents per PJ (280 GWh) of electricity produced. They are valued using the same productivity assumptions used to calculate the costs of nuclear electricity. The "opportunity" costs of real estate are assumed to be 10% of the price of the real estate. The damage is estimated to be 3 $/MWh in 1989 US dollars.

Wind electricity. The decrease in property rental value due the noise increases associated with windmill operation are estimated. The decrease is assumed to be 3% for a noise level of 30-35 dB. This decrease affects only the 10,000 residential units, which rent for 500 DM/month, in the area of Germany where windpower is assumed to develop. The damage is estimated to be 0.09 $/MWh in 1989.

In addition, several non-environmental external costs are estimated. For the renewable technologies, these include net positive costs for the combined impacts on gross value added, savings, and employment. For the non-renewable technologies, these include depletion surcharges. Finally, government subsidies for publicly supplied goods and services, direct monetary subsidies, and public R&D are estimated.

Critique

Considering only the environmental external cost estimates, reference to Holdren's work on the pitfalls associated with integrated assessments (1980) provides several organizing themes: inconsistent boundaries, confusing average with marginal effects, illusory precision, the introduction of hidden values, and mistaking what's countable for what really counts.

Inconsistent boundaries. An integrated assessment of the environmental impacts of energy technologies should consider all impacts from all stages of a given fuel cycle. In this regard, Hohmeyer's work represents an important contribution to the determination of the costs of selected stages of particular fuel cycles but not a complete survey for all stages of these fuel cycles. Restricting the analysis to selected stages of a fuel cycle is understandable given significant data limitations. However, several omissions are especially glaring:

The assessment of fossil fuel and nuclear electricity production considers only the electricity generation component of these fuel cycles. Within this stage of the fuel cycle, only the external costs of air borne pollutants (routine in the case of fossil fuels, and extraordinary in the case of nuclear) are estimated. For fossil fuels, mitigation of sea level increases through seawall reinforcements are the only effect measured for climate change. The upstream costs of fuel harvesting/extraction, processing, and transportation are ignored as are the downstream costs of decommissioning for nuclear electricity. Non-air borne emissions are not considered despite the fact that thermal and effluent discharges into waterways can be significant. For photovoltaic technologies, limiting analysis to the generation stage of the fuel cycle is especially misleading because the major environmental insults associated with photovoltaic cells arise during their fabrication.

Confusing average with marginal. Depending on the objective, either effect can be the appropriate subject of investigation. Average refers to what's currently in place as a snapshot of the present situation. Marginal refers to the last or next incremental addition to what's in place. However, the rhetorical objective of Hohmeyer's work lies with making the case for development of more environmentally benign sources of electricity. Thus, it is misleading to estimate the external costs associated with air emissions from the current stock of electricity producing powerplants for use in comparison with renewable technologies. The correct comparison is with emissions from new fossil fuel or nuclear powerplants. These often take advantage of recent technological improvements that mitigate emissions with respect to what's currently in place.

Illusory precision. Given the complexity of the topic of the external (i.e., not currently counted) costs of electricity producing technologies, it should come as no surprise that the data and analytical methods used to measure these costs are subject to great uncertainties. It is, however, misleading to suggest that these uncertainties are any smaller than they actually are. Indeed, the fact that the uncertainties are great is an important "cost" associated with the choice of technologies. Hohmeyer wisely avoids the fiction of providing median values by giving ranges for many of the estimates. However, in the case of the risks associated with a nuclear powerplant meltdown, the range presented is unrealistically narrow, spanning only one order of magnitude. Hohmeyer previously acknowledges that a more realistic range spans at least 6 orders of magnitude. To suggest that the range is any narrower than this does a disservice to those who seek to use these costs in decision-making.

The introduction of hidden values. The significant data limitations on the subject of the external costs of electricity producing technologies make reliance on judgments inevitable. Many significant environmental insults cannot be examined and large assumptions must often be made when analyzing those which are examined. While Hohmeyer is more or less candid when making these judgments, several of them bias his results and should be the subjects of re-examination. We restrict our attention, not to the environmental insults overlooked, but rather to the analysis of those insults for which costs are estimated.

Assessing the external costs to Germany alone of various technologies places important restrictions on the transferability of Hohmeyer's results. However, it creates an even greater problem for the analysis of inherently trans-national external costs. To take advantage of information on damage to German flora, fauna, population, and climate, Hohmeyer assumes that the amount of air borne pollutants emitted and exported by German sources is equal to the amount imported from non-German sources. By this equivalence, the damage to German flora, fauna, population, and climate can then be used to assess the damage caused by German emissions of air borne pollutants. While this equivalence may be correct, the absence of documentation to support the claim leaves it open to suspicion as being merely convenient, yet potentially biased. It is particularly suspect when used to assign the costs of global warming to powerplants since CO_2 is not even included in the list of emissions combined through the use of toxicity factors (although NO_x, another greenhouse gas, is included).

Toxicity factors are used to combine the relative damage caused by various air borne pollutants into a single measure of damage. Such a measure provides a convenient method for allocating the damage from all sources of these pollutants to those from the powerplant sources of these pollutants because the emissions from the powerplant sources can be combined separately and expressed as a fraction of the total. The weights used to combine the emissions were developed to set maximum permissible pollutant concentrations for German workplaces. It is not obvious that weights used to set occupational air quality standards are in any way related to non-occupational damage to flora, fauna, and climate (although it is presumably related to the reduced worker productivity calculations of damage to the German population). Again, absence of documentation to support this assumption weakens its credibility.

We have already described how the decision to focus on the external costs associated with the generation stage of the fuel cycle rules out consideration of the most environmentally damaging stage of photovoltaic electricity, namely fabrication. However, part of the justification for not examining this aspect of photovoltaic is Hohmeyer's "suggestion" that the industry should not concentrate future development on the more environmentally risky photovoltaic technologies, such as gallium arsenide, but rather the less risky silicon-based technologies. It seems presumptuous or at least out of place for an analyst to tell the photovoltaic industry how it should conduct its affairs on the basis of an assessment of the technologies' environmental consequences.

Mistaking what's countable for what really counts. The greatest danger in Hohmeyer's work lies not so much with the analysis it contains, but rather with the possibility of uncritical use of estimates, which it presents, to make the case for various types of energy policy decisions. In the political realm in which these decisions take place, any quantitative estimate is viewed as superior to no quantitative estimate and there will be a tendency to use Hohmeyer's work to argue for or against various policies independent of the context in which his estimates were developed. The fallacy lies in presuming: 1. that the estimates are complete and correct; and 2. that quantitative estimates, so defined, are the only appropriate yardstick. In the preceding paragraphs, we have made suggestions as to how the estimates, themselves, could be improved. (However, as we have stated earlier, the absence of any estimate at all is equivalent to assuming that an externality has zero cost, which is clearly incorrect.) We turn now to the important respects in which the quantitative estimates, alone, may be insufficient for making informed decisions. The global warming estimate for fossil fuel electricity will be the basis for this discussion, but it should be emphasized that each environmental insult considered by Hohmeyer is vulnerable to these considerations.

One of the most important caveats to be considered in evaluating Hohmeyer's work is his focus on the external costs to Germany. Taken literally, as it should be, this caveat means that application of the estimates to policy contexts other than Germany is either wrong or subject to significant conditions. We have already described how the estimation of damage from the air borne pollutants emitted by fossil fuel powerplants are estimated by damage to German flora, German fauna, German population, and German climate. The damage to German climate, in particular, is estimated by considering only the costs of raising German sea walls in response to rising sea levels due to global warming. Surely this cost is of no relevance for countries lacking a sea coast, but can it also be relevant for countries with very different coastal geographies than Germany?

More to the point, the fact that some of the external costs of electricity producing technologies are more amenable than others to measurement does not mean that the most important costs have been captured. Indeed, many of the costs most resistant to measurement may well be the most important costs of all and ought therefore be the proper subjects for political decisions. For example, apart from rises in sea level resulting from global warming, dramatic changes in agricultural productivity can be expected. These changes have so far been difficult to measure because of the significant uncertainties inherent in modelling climates. Yet these changes portend far greater economic consequences than do the costs of raising German dikes by 1 meter.

The agricultural changes resulting from global warming also point to the important need to consider the equity or distributional impacts of environmental insults in addition to measuring net costs. Global warming can be expected to improve the agricultural productivity of some areas, while simultaneously decreasing that of others. Explicit consideration of equity, as an aspect of overall measurement, is required to develop appropriate responses to these aspects of global warming.

Summary

Hohmeyer has made an important contribution to the debate over the appropriate basis for choosing between future electricity producing technologies. While limited to analyses of selected external costs and their impacts on Germany, the basic analytical approach is sound. Significant improvements to individual costing approaches can be made and expansion of the applicability of the results is warranted. It would be dangerous, however, to use Hohmeyer's results uncritically in inappropriate contexts and to fail to recognize the important limitations faced by strictly quantitative approaches for developing information on which to base energy policy decisions.

3.4 Conclusion

Significant progress has been made in developing quantitative estimates of the un-internalized environmental costs of electricity production. For goods that are formally traded in markets, the market value of damages from environmental insults can be measured provided a meaningful causal chain can be identified linking the insult to the damages. In the absence of formal markets, surrogate or simulated markets can be examined to establish values for environmental goods. Finally, when well-defined links between insults and damages are not available, proxy methods can be used to estimate the cost of avoiding the insult, rather than measure its damages.

The estimates available at this time suggest that there are often significant differences between the private producer's cost of electricity generation and the costs imposed upon society by these activities. These differences, if incorporated into the prices paid for electricity, would lead to very different choices for future electricity supply options; moreover, they might also lead to increased emphasis on non-electricity generating alternatives such as increased end-use efficiency.

The estimates available at this time are nevertheless only partial measures of the un-internalized environmental costs of electricity production. Our review of a recent well-publicized study suggests that there is ample room for improvement in most current estimates. Typically, significant data limitations preclude more precise measurement of many insults and many other important insults have not been measured at all. This latter category includes the environmental costs associated with global warming, the front-end of the nuclear fuel cycle, and the costs of nuclear terrorism. It is safe to say that current estimates are on the low end of the total environmental costs of electricity production, given the absence or imprecision of current estimates.

In the limited epistemological state in which we find ourselves, it is also worth remembering that numerical estimates of the economic value of environmental "goods" are only one measure of the value society places on the environment. We have already illustrated this point by highlighting the significance of distributional issues. To this we add a final sobering thought that the economic paradigm, itself, is inherently incapable of addressing many important but intangible societal values because these values have not been and, perhaps, cannot be measured in economic terms.

4. MARKET-BASED APPROACHES FOR INTERNALIZING ENVIRONMENTAL EXTERNALITIES

Regulation has been the dominant approach for internalizing environmental externalities (see, for example, Haigh 1989). The command and control nature of this approach is both its strength and weakness. The strength derives from the certainty gained by the prescription of particular forms of behavior (e.g., abatement technologies, emission limits, etc.). The weakness lies in the inflexibility of these prescriptions, which hinders the development or precludes the use of equally effective, yet potentially cheaper, alternatives.

Economists have suggested that market-based alternatives to regulation offer the flexibility absent from regulatory approaches while preserving the certainty that specific environmental quality objectives will be met (OECD 1988). As a result, they maintain that market-based approaches can meet society's desire for a cleaner environment in an economically efficient manner.

Consider, for example, the environmental damage caused by the acid rain precursors (SO2 and NOx) emitted by powerplants. Among other things, the regulatory approach has prescribed the use of best-available-control-technologies, limitations on the sulfur content of fuels, and limitations on the rate of emissions (see the example at the end of Section 2). These regulations are often applied independent of the economic costs to the polluter of compliance, for example, when expensive modifications are required for a plant that is to be retired before the modifications can be amortized. A market-based approach, on the other hand, might instead simply set a ceiling on the total quantity of emissions for an air basin (or more widely geographically defined source of these emissions). Within the air basin, marketable permits to emit a fixed quantity of these pollutants are issued. These permits allow those polluters with access to inexpensive mitigation options (such as fuel-switching, plant retirement, etc.) to sell or lease some or all of their permits to those for whom the purchase of a permit represents a lower cost option than reductions at their own facility. In this way, it is claimed, a known, fixed amount of pollution will be emitted in a cost-efficient manner. (This example is, in fact, a sketch of the changes currently envisioned for the amendments to the Clear Air Act in the U.S.)

In this Section, we describe several market-based approaches for internalizing environmental externalities (4.1), report on the use of these approaches for electricity production (4.2), and, for those policies that rely on charges, begin to evaluate them by comparison with the cost estimates of the damage they seek to internalize (4.3).

4.1 Market-Based Approaches

We have indicated that market-based approaches represent a marked departure from traditional regulatory approaches to internalizing environmental externalities. In fact, the distinction is not unambiguous from both a definitional and institutional standpoint. In this Section, we develop this distinction more precisely and illustrate it with descriptions of approaches that we consider market-based.

Strictly speaking, regulatory approaches are distinct from market-based approaches because they prescribe specific forms of behavior such as limits on fuel sulfur content, use of particular abatement technologies, etc. In these cases, the affected party has little or no discretion as to the means for compliance; non-compliance is typically subject to penalties or fines. Market-based approaches, by contrast, are intended to stimulate voluntary responses to financial stimuli, which permit substantial discretion on the part of the regulated parties. However, to the extent that non-compliance with a regulation is in some sense voluntary (one can always choose to accept the penalties for non-compliance) and that these penalties are monetary, regulatory approaches, too, could be included under a very broad definition of market-based approaches.

From an institutional standpoint, the distinction between types of approaches is also obscured by the often overlapping nature of regulatory and market-based approaches. It is not unusual to find overlapping regulatory approaches, as exemplified by the simultaneous regulation of fuel sulfur content, emission rate, and abatement technology. Market-based approaches, too, must operate against a background of other (probably, non-market-based) regulations. While this situation does not change the nature of the market-based approach directly, it can affect the range of responses available (it also exacerbates the difficulties in assessing the effectiveness of the market-based approach).

Definitional imprecision and overlapping regulations notwithstanding, it is possible to identify several classes of policies that rely primarily on market forces to stimulate environmentally responsive behavior. OECD (1989) identifies four classes of what it terms "economic" approaches for environmental protection: 1) charges; 2) market-creation; 3) subsidies; and 4) deposit-refund systems. From the standpoint of policies to address the environmental externalities of electricity production, charges and market-creation are the two most important instruments.

Charges

Charges are perhaps the most direct approach for internalizing externalities. A charge is essentially a price that must be paid for permission to pollute. This price is first incorporated into producers' decisions regarding the cost-effectiveness of various mitigation strategies and then reflected in the prices paid by consumers of the product. Charges are typically levied on the insults produced by a given source (e.g., a tax on SO2 emissions), but they can also be levied on the basis of the usage of an environmental good (e.g., water treatment fees), or the product produced (e.g., a gasoline tax). Charges can also be designed so that they are revenue neutral (Koomey and Rosenfeld 1990).

Several considerations complicate the effectiveness of charges. First, the level of the charge may be set so as to provide incorrect incentives to modify behavior. (This is related to the presence of overlapping regulations, which may already limit the range of possible responses.) On the one hand, the primary purpose of the charge may have little to do with environmental protection directly (e.g., the raising of funds to provide general revenues). On the other hand, the charge may bear little relationship to the monetary value of the damage caused by the environmental insult to which it applies. (We shall examine this final issue in Section 4.3.)

Second and again related to the presence of overlapping (in this case, non-environmentally motivated) regulations or policies, other considerations often influence the prices paid for goods. For example, general commodity taxes or price supports to promote economic development are popular policy instruments that have the effect of distorting the "true" market price of goods. [See OECD (1990) for an tabulation of these distortions for OECD countries by energy source and Steenvlik and Wigley (1990) for a discussion of how these distortions can be measured for coal.] The presence of pre-existing price distortions can either amplify or dampen the effect of additional charges designed to internalize environmental externalities. In either case, it is difficult to determine the effectiveness of charges to correct one price distortion (un-internalized environmental damage) in the presence of other, often significant price distortions.

Finally, the introduction of charges can also lead to short-term dislocations and inefficiencies. This phenomena is particularly significant in the electricity production industry where the turnover of capital stock is relatively slow. It is also true for long-lived electricity consuming durables, such as buildings.

Market-Creation

Markets can be created artificially to provide a mechanism for the buying and selling of pollution "rights." The most well-known application of this approach is the creation of permits for air emissions of pollutants (to be described in Section 4.2). In its simplest form, a limited number of emission permits is created based on some determination of the total permissible/tolerable level of emissions for a given geographic region. These are then distributed to polluters who can either retain them for themselves or, if they can reduce their emissions, sell them to others. Those who purchase these permits are either newcomers or existing polluters from whom the permits represent a lower cost option than other means for reducing emissions. The total level of emissions is fixed, but it is left to the polluters to determine how best to meet this level by either reducing their own emissions or by purchasing from others the right to emit in excess of their original allocation.

One of the primary advantages of market-creation is that markets create their own prices for goods. In contrast to the administrative determination of environmental externality costs for use in charges, markets reveal prices automatically. From a theoretical perspective, the values derived from efforts to measure environmental damages administratively are either incorrect or meaningless in a market economy for these environmental goods.

The difficulties in creating markets to pollute include determining an acceptable amount of total emissions, distributing permits equitably to polluters, and enforcing rights to pollute. Given significant data limitations, which complicate the attribution of causality to particular insults, and very real disputes over the consequent damage caused by these insults, it is often far from clear what the maximum level of emissions should be. Resolution of this issue may be based on an environmental cost-benefit analysis relying on cost estimates of environmental damage (and reviewed in Section 3). Having somehow determined an acceptable level of pollution, it is likely that previous environmental regulations have resulted in varying degrees of mitigation activities by existing polluters. This situation raises concerns that an allocation of permits based on present levels of emissions may be inequitable. Having issued the permits, some degree of enforcement is required to ensure that the permit process is meaningful to the polluters. (This concern is one of the important advantages of regulations that, for example, prescribe the use of certain abatement technologies).

Finally, other real-world distortions that prevent markets from operating efficiently (such as un-equal access to information or capital, and anti-competitive practices) will also serve to reduce the efficiency benefits of market-creation.

Subsidies and Deposit-Refund Systems

Subsidies are efforts to persuade polluters to modify their behavior by encouraging them to invest in a specific pollution control practice or technology for which some part of the costs are paid for by others. They may take the form of grants, interest rate reductions, or tax allowances.

Strictly speaking, subsidies distort the market forces, which might otherwise be used to incorporate environmental externalities, because they shield the polluter from some fraction of the total cost of the polluting activity. In most cases, subsidies are justified on equity considerations, such as the need to assist distressed industries in complying with regulations. From the standpoint of our survey, they represent a market-based approach whose use acts to reduce the effectiveness of the other market-based approaches we shall examine.

Deposit-refund systems are surcharges assessed at the time of purchase of a potentially polluting product (e.g. glass or aluminum beverage containers). When it has been demonstrated that the pollution has been avoided (e.g., the bottle or can is returned), the charges are refunded. This system, too, is of little direct relevance for our survey and will not be discussed further.

4.2 A Survey of Market-Based Policies

The use of charges and market-creation to internalize the environmental externalities of electricity production are relatively new instruments for environmental policy. We are aware of only one operating market-creation policy, although at least one more appears imminent (by the end of 1990); both are from the United States (US). Charges for specific environmental insults resulting from electricity production are only operating in France and Finland, although several European countries are in the process of adopting them. As their use appears to be more widespread, we begin by discussing the use of charges, focussing first on activities in countries that are members of the European Community (EC). It should be remembered that most efforts are in the process of development so our survey can only be regarded as a snapshot of activities as of the middle of 1990. Where possible, we re-express charges unique to electricity production in units comparable to those used in Section 3 using 1989 US dollars. Table 9 summarizes these findings.

The Use of Charges in EC Member Countries

We are aware of only one EC member country, France, where charges are currently being applied to the emission of specific environmental insults associated with the production of electricity. Created in 1985, Decree No. 85-582 (7 June 1985) levied a charge of 19 ECU per ton on SO2 emissions ($ 0.01/lb). The charge was applicable to industrial firms that had power generation capacities of 50 MW or more, or discharged more than 2,500 tonnes of sulfur oxides or nitrogen oxides per year. The charge was criticized for being too low to have any incentive impact, for returning 90 percent of collected revenues as subsidies to the polluters for the purchase of abatement equipment, and for affecting only 400 firms (OECD 1989). In 1989, these concerns were partially addressed by the raising of the charge to FFr300 per tonne ($ 0.03/lb) and the lowering of the eligibility criteria so as to double the number of affected firms (EER 1990a). Related changes to the Decree also add charges for emissions of other pollutants (including non-methane hydrocarbons, solvents, volatile organics, and dust).

Denmark has proposed, but not implemented, charges on CO2 and SO2 emissions in its recent energy policy plan, Energy 2000 (EER 1990b). Critics of the plan estimate that the charges amount to DKr 0.22 per cubic meter of natural gas, DKr 294 per tonne of LPG, DKr 315 per tonne of gasoil, DKr 619 per tonne of fuel oil, DKr 485 per tonne of coal, and DKr 0.18 per kWh ($ 30/MWh) for electricity.

The governments of Netherlands, Italy, and Germany have also discussed charges. In Germany, charges for air pollution were proposed but not adopted, in part due to existing regulations, which already strictly limit emissions (OECD 1989). Details of the discussions in the Netherlands and Italy are not known at this time.

The European Commission itself appears to be interested in charges for carbon (EER 1990c). While no information is available on what the level of the charge might be, several estimates have been made (independent of official Commission activities). These estimates range from $ 5 per ton of CO_2 (Economist 1990a) to $ 13 per ton (Economist 1990b). A recent IEA study estimated that charges of $ 50 per ton of coal, $ 8 per barrel of oil, and $ 1 per MBtu of gas would be necessary to cut OECD CO_2 emissions by 13% (EER 1990d). Assuming an electricity conversion efficiency of 34% (10,000 Btu/kWh), these charges would increase the cost of producing electricity from coal, oil, and natural gas by 226, 127, and 100 $/MWh, respectively.

The Use of Charges in Other Countries

Finland is the first country to enact charges for CO_2 emissions. The charge, which took effect in January 1990, is based on the carbon content of fossil fuels. It has been set at a rate of $ 6.10 per tonne of CO_2 ($ 5.5/ton) (Economist 1990c).

Sweden has announced charges for sulfur, NOx, and CO_2. The charges are scheduled to take affect in 1991. They are set at SKr 30 per kilo of sulfur ($ 5.6/lb), SKr 40 per kilo of NOx ($ 7.5/lb), and SKr 0.25 per kilo of CO_2 ($ 39/ton) (Economist 1990c). The CO_2 charge is nearly seven times greater than that in Finland.

In the United States, the use of charges is taking place at both the federal and state levels. At the federal level, the US Congress is discussing a proposal that would levy charges on carbon that would be equivalent to $ 15 per ton of coal, $ 3.25 per barrel of oil, and $ 0.40 per thousand cubic feet of natural gas (Electricity Journal 1990). Again, assuming a conversion efficiency of 34% (10,000 Btu/kWh), these charges would raise the cost of producing electricity from coal, oil, and natural gas by 68, 52, and 39 $/MWh, respectively.

At the state level, many state commissions, which are the primary regulatory authority for investor-owned utilities, now require formal consideration of environmental externality costs in electricity planning activities (Cohen, et al. 1990). In several states (California, New York, Oregon, New Jersey, and Colorado) explicit monetary values are being added to the costs of new generating resources at the planning stage. However, unlike their European counterparts, the "charges" are never actually collected, instead they are used as inputs to the evaluation of future resource acquisitions. In other words, the cost of the resource to society and the price of electricity it generates are unaffected; only the choice of and timing for the acquisition of generating resources are affected.

In California, the Energy Commission, which has responsibility for determining the need for and the siting of new generating resources, has established values of \$ 5.80/lb for SO_2, \$ 5.75/lb for NO_x, \$ 3.90/lb for particulates, and \$ 7/ton for CO_2. In New York, the values, which are based on the costs of mitigation (the proxy approach), are expressed as a credit of up to 14 \$/MWh depending on the degree to which a resource option avoids emissions of SO_2, NO_x, particulates, and CO_2, as well as minimizes land use and water impacts. In Oregon, a combustion tax of 10 \$/MWh (without reference to any particular environmental insult) has been used in a sensitivity analysis of planning results, which were first developed without formal consideration of environmental externalities. New Jersey and Colorado assign points, not monetary values, to resources that avoid selected environmental externalities. These points are used in evaluating offers by third parties to supply power. The monetary value of these points cannot be determined without simultaneous evaluation of the actual distribution of offers, to supply power, received by the utilities.

Values for environmental externalities also enter the resource planning process in Wisconsin, Vermont, and the regional Northwest Power Planning Council, but in a somewhat different manner. In these states or planning regions, externalities are assigned a value that depends on the capital cost of generating resource options under study. The amount is based on a fixed percentage of the capital cost of the resource which then is added to the total cost of the resource for purposes of the evaluation. This procedure has the effect of increasing the apparent cost of generating resources relative to non-generating resources. In Wisconsin the adder is 15%. For Vermont and the Northwest Power Planning Council, the adder is 10%. Koomey (1990) has shown that the use of percentage adders can lead to perverse biases in the resource selection process because environmental externalities are not correlated with the capital costs of most generating technologies.

Despite the potential biases inherent in the use of percentage adders, several states (Connecticut, Kansas, and Idaho) use them to reward conservation activities by the utilities. The adders can range up to 5% increase in the rate of return earned on conservation investments. They are explicitly linked to the relative environmental benefits of conservation over the alternative of increased generation. Unlike the methods described previously, they have the effect of increasing utility earnings (and raising electricity rates). Again, it is difficult to express these adders as unique monetary values for selected environmental insults because it is not possible to know in advance precisely what types of generating resources (and, hence, environmental insults) are being avoided by the conservation activities.

The Use of Market-Creation

The United States is unique in its reliance on market-creation as an approach for mitigating the environmental externalities of electricity production (among other activities). At the present time, there is an emissions trading policy in effect for air quality control areas that have not attained the National Ambient Air Quality Standards (NAAQS). In the very near future (sometime before the end of 1990), the US Congress is expected to pass revisions to the Clean Air Act that will create markets for SO_2 and NO_x emissions.

The current emissions trading policy is the result of continuing difficulties that states have had in bringing certain air quality control areas into attainment with NAAQS (OECD 1988). Initially, regulations required use of "best-available-control-technologies" (BACT) regardless of cost considerations. Subsequently, cost considerations were allowed to enter into decisions for certain non-attainment areas. Soon, approvals were given when polluters were able to demonstrate that emissions equal to the reductions achieved with BACT could be realized (at lower cost to the polluter) without BACT. Policy shifts to the establishment of "bubbles" (areas within which attainment with some emission target must be demonstrated) and the allowance of "banking" (in which emission reductions can be held for future use against some over target level) followed shortly and are now accepted practice.

The existing policy has been criticized because it leaves the final state of the environment somewhat ambiguous. The determination of the ambient level of air quality to be maintained has been especially contentious. Further, in the absence of significant monitoring, the actual air quality of the air basins has never been rigorously determined. There is justifiable concern that the emissions trading policy has merely been a legitimation for a failed policy.

More recently, use of tradable permits for NO_x and SO_2 has been proposed as the cornerstone of the 1990 revisions to the Clean Air Act (Bupp and Hansen 1989). The goal of the revisions is to achieve significant reductions to NO_x and SO_2 emissions (which result largely from electricity production). The policy approach for achieving these reductions is the creation of a market for the buying and selling of permits to emit these pollutants. Requiring an absolute reduction in total emissions is intended to be the guarantee for environmental improvement missing from the existing emissions trading policy for non-attainment areas. Extensive monitoring and escalating fines are also part of the proposal; again, to rectify some of the perceived shortcomings of the existing emission trading policy. See Tietenberg (1989) for an interesting review of important lessons learned from earlier market-creation activities and their implications for the current proposal.

Market-creation has also been suggested as a desirable policy for limiting CO_2 emissions (Grubb 1989). Grubb argues that the global scale of an appropriate response to dangers of the greenhouse effect renders charge schemes un-workable. Instead, Grubb maintains that a negotiated carbon target allocated on a per capita basis represents a more pragmatic and equitable approach for managing carbon emissions.

Table 9. Environmental Externality Charges

Country	Insult	Charge	US $	Notes
EUROPEAN COMMUNITY				
France	SO2	300 FFr/tonne	0.03 /lb	operating
Denmark	CO2&SO2	0.18 DKr/kWh	30 /MWh	proposed
non-govt	CO2	5 $/ton	5.0 /ton	EC 1990a
	CO2	23 UK/tonneC	12.7 /ton	EC 1990b
NON-EUROPEAN COMMUNITY				
Finland	CO2	6.1 $/tonne	6.7 /ton	operating
Sweden	SO2	30 SKr/kgS	5.62 /lb	proposed
	NOx	40 SKr/kg	7.50 /lb	proposed
	CO2	0.25 SKr/kg	38.7 /ton	proposed
USA				
Calif.	SO2		5.75 /lb	evaluation
	NOx		5.80 /lb	evaluation
	PM		3.90 /lb	evaluation
	CO2		7.00 /ton	evaluation
New York	SO2,NOx,PM			
	CO2,land,water		14 /MWh	evaluation
Congress	CO2		15.0 /ton	proposed

Monetary conversion factors:

	unit/US$
France	5.394
Denmark	6.136
England	0.542
Finland	3.774
Germany	1.610
Sweden	5.867

4.3 Economic Evaluation of Environmental Externality Charges

Charges designed to internalize the environmental externality costs of electricity production can be evaluated in two ways. First, we can compare the charges to estimates of the environmental damage they seek to offset (which were reported in Section 3.2). This comparison is in principle a measure of the extent to which the policies reflect the damage they seek to internalize. Second, we can compare the charges to the costs of abatement using currently available technologies. This comparison is one measure of the cost-effectiveness of abatement technologies (another, more direct measure would compare the damage estimates to these abatement costs). Closer examination of both these issues suggests that at this time both comparisons are necessarily incomplete.

The relative scarcity of environmental policies that rely on charges limits our evaluation to SO2, NOx, and CO2. In the case of CO2, only one comparison is possible since the environmental damage costs are estimated (in Section 3.2) using abatement costs as a proxy (instead of, say, a more direct measure of the damage caused by CO2). The results are presented in Table 10.

Comparison of the charges for SO2 emissions to the estimates of SO2 damage and abatement costs confirms the low incentive value of the French charges for SO2. The charge proposed for Sweden is close to the high end of the range of damage cost estimated by Ottinger, et al. (1990) and exceeds the estimated cost of abatement. Both NOx charges (from California and Sweden) exceed the range of current damage estimates; they also exceed the cost of abatement. The Finnish CO2 charge is less than the low end of range of estimates of the cost of planting trees to sequester carbon. The proposed Swedish charge falls close to the middle of this range.

Drawing conclusions regarding the appropriateness of the charges, for example, that the California and Swedish NOx charges are unreasonably high relative to current damage cost estimates, is complicated for several reasons. First, as noted in Section 3, existing efforts to measure the value of environmental externalities are incomplete. Many sources within a given fuel cycle have never been examined, many associated insults from sources which have been examined remain un-investigated, and great uncertainties surround those estimates which are available. In the absence of complete measures of the total cost of all the environmental externalities associated with the production of electricity, it is likely that existing estimates of these costs are low.

Second, charges for environmental externalities cannot be evaluated independently of pre-existing distortions in the prices of energy. These distortions can either amplify or dampen the effect of environmental externality charges. They may take the form of either government policies to manipulate the price of electricity artificially (as described in Section 4.1) or un-internalized non-environmental externalities. For example, Hohmeyer (1988), considers a number of non-environmental externalities, which in the case of nuclear electricity jointly exceed the sum of environmental externalities for this source of electricity.

A final consideration goes to the issue of whether comparison of environmental charges with environmental damage estimates is meaningful outside a narrow measure of economic efficiency. It is that we are unaware of a single "environmental" charge whose sole intent is the direct mitigation of the damage whose costs they seek to internalize. Generally speaking, it appears that the revenue from charges goes to the general treasury of the country where it is spent on the general welfare (e.g., defense, social programs, etc.). In several cases, charges have been announced and explicitly linked with reductions in other, energy or non-energy related taxes. But, in no case are we aware of efforts to compensate the affected parties (animate or inanimate) directly for the damage caused by the insults which are the basis for the charges. The French SO2 charge comes somewhat closer in this respect since the revenues are used to subsidize pollution abatement equipment for the contributors.

Thus, we are left with an interesting compromise. Charges raise prices to consumers and producers, internalizing environmental costs to some extent and modifying behavior as a result. Yet, the compensation flows at best only indirectly to those who are affected. Economic efficiency is improved incrementally, but equity remains largely unaffected.

Comparison of environmental charges with abatement costs is more straightforward. In general, the charges in operation or under consideration tend to exceed the costs of abatement. In this situation, polluters will find it cost-effective to invest in pollution abatement equipment in lieu of paying the charge. Until the marginal costs of abatement increase (which they surely must, although we have not commented on the steepness of this cost curve), absolute levels of emissions should decrease in response to the charges. Finally, to the extent that the estimates of environmental external costs are low, the fact that they also tend to exceed the cost of abatement (in the case of SO2 and NOx) suggests that these costs are also justifiable from a societal perspective.

Table 10. Economic Evaluation of Environmental Externality Charges

	Low	High	Notes
SO_2 (1989 US$/lb)			
Policy	0.03	5.62	France(low), Sweden(high)
Damage	1.79	7.10	Ottinger, et al. (1990)
Abatement	3.50		Chernick/Caverhill (1989)
NO_x (1989 US$/lb)			
Policy	5.80	7.50	Calif.(low); Sweden(high)
Damage	0.53	1.05	Ottinger, et al. (1990)
Abatement	1.50		Chernick/Caverhill (1989)
CO_2 (1989 US$/ton)			
Policy	7	39	Finland(low), Sweden(high)
Damage Proxy	20	80	derived from Table 4.

4.4 Conclusion

Market-based approaches for internalizing environmental externality costs are becoming increasing popular instruments of public policy. Two types of market-based approaches are relevant for internalizing the external costs associated with electricity production. The first is charges, which are assessed based on the quantity of particular environmental insult created by a polluter. The second is market-creation, in which a fixed quantity of permits to create environmental insults are issued for trade, sale, or lease among polluters.

Charges are in place or being developed in several European countries. In the United States, numerical environmental externality values are used primarily by state regulatory authorities in electricity resource planning; only rarely do they enter into the actual costs paid by society for resource acquisitions. The US, however, leads the world in the use of market-creation. While the current use of market-creation for areas that fail to meet federal air quality standards has been criticized, the lessons learned from this experience have prompted the US to propose a more aggressive market-creation approach for reducing emissions of acid rain precursors (primarily, $SO2$ and NOx).

Direct comparison of existing and proposed environmental charges with the damages they seek to mitigate is also problematic. On the one hand, we know that externality costs estimates are imperfect and probably low. On the other hand, other distortions in the price of energy can amplify or dampen the "signal" charges are intended to send. In addition, unless the revenues collected through environmental charges are used to mitigate the environmental damages incurred, economic efficiency may enhanced at the expense of equity. The costs of abatement are generally less than most proposed charges and thus represent a cost-effective means for reducing the absolute level of emissions.

The newness of market-based approaches (indeed, few are actually in operation) means that little or no empirical evidence is available to evaluate their performance. When this evidence becomes available, the primary issue will be whether or not the efficiency benefits from reliance on market mechanisms have, in fact, been realized. That is, markets must be workably competitive, if their efficiency benefits are to be captured. To the extent that few non-environmental commodities are currently traded in perfectly competitive markets, it is an open question whether environmental goods will be any more fortunate.

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