How Much Climate Change Is Too Much? An Economics Perspective

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Contents

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Having risen from relative obscurity as few as 10 years ago, climate change now looms large among environmental policy issues. Its scope is global; the potential environmental and economic impacts are ubiquitous; the potential restrictions on human choices touch the most basic goals of people in all nations; and the sheer scope of the potential response—a significant shift away from using fossil fuels as the primary energy source in the modern economy—is daunting. The magnitude of these changes has motivated experts the world over to study the natural and socioeconomic effects of climate change as well as policy options for slowing climate change and reducing its risks. The various options serve as fodder for often testy negotiations within and among nations about how and when to mitigate climate change, who should take action, and who should bear the costs.

Lurking behind these policy activities is a deceptively simple question: How much climate change is acceptable, and how much is "too much"? (The other key questions are, Who is going to pay for mitigating the risks? What policies will be used for mitigation?) The lack of consensus on this issue reflects the uncertainties that surround it and differences in value judgments regarding the risks and costs.

In this paper, we review the economic approach to the question of how much climate change is too much. The economic perspective emphasizes the evaluation of benefits and costs broadly defined while addressing uncertainties and important considerations such as equity. We also consider some important criticisms of the benefit–cost approach. Then, we discuss the key factors that influence the benefits and costs of mitigating climate change risks. This discussion leads to a review of findings from the many quantitative "integrated assessment" models of climate change risks and response costs. This review does not lead to a simple answer to our

[*] This paper is adapted from Chapter 5 of *Public Policies for Environmental Protection* (Second Edition), edited by Paul R. Portney and Robert N. Stavins, published by Resources for the Future in 2000.

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overarching question about how much climate change is too much. But we do identify several good reasons for taking a deliberate but gradual approach to the mitigation of climate change risks.

The issues we cover are both diverse—ranging from the economics and philosophy of long-term cost-benefit analysis, to modeling strategies for representing climate change risks and greenhouse gas abatement costs—and, at times, somewhat complex. We have tried to be fairly comprehensive while seeking to make the discussion as accessible as possible.

Overview of the Risks and Response Costs

Life on Earth is possible partly because some gases such as carbon dioxide (CO_2) and water vapor, which naturally occur in Earth's atmosphere, trap heat—like a greenhouse. CO_2 released from use of fossil fuels (coal, oil, and natural gas) is the most plentiful human-created greenhouse gas (GHG). Other gases—which include methane (CH_4), chlorofluorocarbons (CFCs; now banned) and their substitutes currently in use, and nitrous oxides associated with fertilizer use—are emitted in lower volumes than CO_2 but trap more heat. Human-made GHGs work against us when they trap too much sunlight and block outward radiation. Scientists worry that the accumulation of these gases in the atmosphere has changed and will continue to change the climate.

The risk of climate change depends on the physical and socioeconomic implications of a changing climate. Climate change might have several effects:

Reduced productivity of natural resources that humans use or extract from the natural environment (for example, lower agricultural yields, smaller timber harvests, and scarcer water resources).

Damage to human-built environments (for example, coastal flooding from rising sea levels, incursion of salt water into drinking water systems, and damage from increased storms and floods).

Risks to life and limb (for example, more deaths from heat waves, storms, and contaminated water, and increased incidence of tropical diseases).

Damage to less managed resources such as the natural conditions conducive to different landscapes, wilderness areas, natural habitats for scarce species, and biodiversity (for example, rising sea levels could inundate coastal wetlands, and increased inland aridity could destroy prairie wetlands).

All of these kinds of damage are posited to result from changes in long-term GHG concentrations in the atmosphere. Very rapid rates of climate change could exacerbate the damage. The adverse effects of climate change most likely will take decades or longer to materialize, however. Moreover, the odds that these events will come to pass are uncertain and not well understood. Numerical estimates of physical impacts are few, and confidence intervals are even harder to come by. The rise in sea level as a result of polar ice melting, for instance, is perhaps the best understood, and the current predicted range of change is still broad. For example, scenarios presented by Working Group I of the Intergovernmental Panel on Climate Change (IPCC – see Suggested Reading) indicate possible increases in sea level of less than 20 cm to almost 100 cm by 2100 as a result of a doubling of Earth's atmospheric GHG concentrations. The uncertainty in these estimates stems from not knowing how temperature will respond to increased GHG concentrations and how oceans and ice caps will respond to temperature change. The risks of catastrophic effects such as shifts in the Gulf Stream and the sudden collapse of polar ice caps are even harder to gauge.

Unknown physical risks are compounded by uncertain socioeconomic consequences. Cost estimates of potential impacts on market goods and services such as agricultural outputs can be made with some confidence, at least in developed countries. But cost estimates for nonmarket goods such as human and ecosystem health give rise to serious debate.

Moreover, existing estimates apply almost exclusively to industrial countries such as the United States. Less is known about the adverse socioeconomic consequences for poorer societies, even though these societies arguably are more vulnerable to climate change. Economic growth in developing countries presumably will lessen some of their vulnerability—for example, threats related to agricultural yields and basic sanitation services would decline. But economic growth in the long term could be imperiled in those regions whose economies depend on natural and ecological resources that would be adversely affected by climate change. Aggregate statistics mask considerable regional variation: Some areas probably will benefit from climate change while others lose.

In weighing the consequences of climate change, it is important to remember that humans adapt to risk to lower their losses. In general, the ability to adapt contributes to lowering the net risk of climate change more in situations where the human control over relevant natural systems and infrastructure is greater. Humans have more capacity to adapt in agricultural activities than in wilderness preservation, for example. The potential to adapt also depends on a society's wealth and the presence of various kinds of social infrastructure, such as educational and public health systems. As a result, richer countries probably will face less of a threat to human health from climate change than poorer societies that have less infrastructure. Beyond this general point, the potential for adaptation to reduce climate change risks continues to be debated.

GHGs remain in the atmosphere for tens or hundreds of years. GHG concentrations reflect long-term emissions; changes in any one year's emissions have a trivial effect on current overall concentrations. Even significant reductions in emissions made today will not be evident in atmospheric concentrations for decades or more. This point is important to keep in mind in deciding when to act—we do not have the luxury of waiting to see the full implications of climate change before taking ameliorative action. Many observers characterize responding to the risks of climate change as taking out insurance; nations try to reduce the odds of adverse events occurring through mitigation, and to reduce the severity of negative consequences by increasing the capacity for adaptation once climate change occurs. The insurance analogy underscores both the uncertainty that permeates how society and policymakers evaluate the issue and the need to respond to the risks in a timely way.

In constructing a viable and effective risk-reducing climate policy, policymakers must address hazy estimates of the risks, the benefits from taking action, and the potential for adaptation against the uncertain but also consequential cost of reducing GHGs. Costs of mitigation matter, as do costs of climate change itself. One must consider the consequences of committing resources to reducing climate change risks that could otherwise be used to meet other human interests, just as one must weigh the consequences of different climatic changes.

Why Consider the Costs and Benefits of Climate Policy?

Responding effectively to climate change risks requires society to consider the potential costs and benefits of various actions as well as inaction. By costs we mean the opportunity costs of GHG mitigation or adaptation—what society must forgo to pursue climate policy. Benefits are the gains from reducing climate change risks by lowering emissions or by enhancing the capacity for adaptation. An assessment of benefits and costs gives policymakers information they need to make educated decisions in setting the stringency of a mitigation policy (for example, how much GHG abatement to undertake, and when to do it) and deciding how much adaptation infrastructure to create.

It is important to consider the costs and the benefits of climate change policies because all resources—human, physical, and natural—are scarce. Policymakers must consider the benefits not obtained when resources are devoted to reducing climate change risks, just as they must consider the climate change risks incurred or avoided from different kinds and degrees of policy response. Marginal benefits and costs reveal the gain from an incremental investment of time, talent, and other resources into mitigating climate risks, and the other opportunities forgone by using these resources for climate change risk mitigation. It is not a question of *whether* to address climate change but *how much* to address it.

Critics object to a benefit–cost approach to climate change policy assessment on several grounds. Their arguments include the following:

The damages due to climate change, and thus the benefits of climate policies to mitigate these damages, are uncertain and thus inherently difficult to quantify given the current state of knowledge. Climate change also could cause large-scale irreversible effects that are hard to address in a simple benefit–cost framework. Therefore, the estimated benefits of action are biased downward.

Climate mitigation costs are uncertain and could escalate rapidly from too-aggressive emission control policies. Proponents of this view are indicating a concern about the risk of underestimating mitigation costs.

Climate change involves substantial equity issues—among current societies and between current and future generations—that are questions of morality, not economic efficiency. Policymakers should be concerned with more than benefit–cost analysis in judging the merits of climate policies.

As these arguments indicate, some critics worry that economic benefit–cost analysis gives short shrift to the need for climate protection, whereas others are concerned that the results of the analysis will call for unwarranted expensive mitigation.

Both groups of critics have proposed alternative criteria for evaluating climate policies, which can be seen as different methods of weighing the benefits and costs of policies given uncertainties, risks of irreversibility, the desire to avoid risk, and distributional concerns. For example, under the *precautionary principle*, which seeks to avoid "undue" harm to the climate system, cost considerations are absent or secondary. Typically, the idea is that climate change beyond a certain level simply involves too much risk, if one considers the distribution of benefits and costs over generations.

Knee-of-the-cost-curve analysis, in contrast, seeks to limit emission reductions to a point at which marginal costs increase rapidly. Benefit estimation is set aside in this approach because of uncertainty. The approach implicitly assumes that the marginal damages from climate change (which are the flip side of marginal benefits from climate change mitigation) do not increase much as climate change proceeds and that costs could escalate rapidly from a poor choice of emissions target.

The benefit–cost approach can address both uncertainty and irreversibility. We do not mean to imply that estimates in practice are always the best or that how one evaluates and acts on highly uncertain assessments will not be open to philosophical debate. For example, as people become more informed about climate change, it is safe to presume that the importance they attach to the issue will change. Critics of the economic methodology argue that this process reflects in part a change in preferences through various social processes, not only a change in information. Moreover, under conditions of great uncertainty, the legitimacy of a policy decision may depend even more than usual on whether the processes used to determine it are deemed inclusive and fair, as well as on the substantive evidence for the decision.

But it is fundamentally inaccurate to see analysis of economic benefits and costs from climate change policies as inherently biased because of uncertainty and irreversibility. Nor should benefit–cost analysis be seen as concerned only with market values accruing to developed countries. One of the great achievements in environmental economics over the past 40 years has been a clear demonstration of the importance of nonmarket benefits, which include benefits related to the development aspirations of poorer countries. These values can be given importance equal to that of market values in policy debates.

Our advocacy that benefits and costs be considered when judging climate change policies does not mean we advocate a simple, one-dimensional benefit–cost test for climate change policies. In practice, decisionmakers can, will, and should bring to the fore important considerations about the equity and fairness of climate change policies across space and time. Decisionmakers also will bring their own judgments about the relevance, credibility, and robustness of benefit and cost information and about the appropriate degree of climate change and other risks that society should bear. Our argument in favor of considering both benefits and costs is that policy deliberations will be better informed if good economic analysis is provided.

The alternative decision criteria advanced by critics also are problematic in practice. The definition of “undue” is usually heuristic or vague. The approach is equivalent to assuming a sharp spike, or peak, in damages caused by climate change beyond the proposed threshold. It may be the case, but not enough evidence yet exists to assume this property (let alone to indicate at what level of climate change such a spike would occur). On the other hand, with knee-of-the-curve analysis, benefits are ignored so there is no assurance of a sound decision either.

Benefits and costs are unavoidable. How their impacts are assessed is what differentiates one approach from another. We maintain throughout this discussion that the assessment and weighing of costs and benefits is an inherent part of any policy decision.

Equity and Fairness Issues

The fairness of climate change policies to today's societies and to future generations continues to be at the core of policy debates. These issues go beyond what economic benefit–cost analysis can resolve, though such analysis can help illustrate the possible distributional impacts of different climate policies. In this section, we focus first on intergenerational equity issues. Then, contemporaneous equity issues are addressed.

Advocates of more aggressive GHG abatement point to the potential adverse consequences of less aggressive abatement policies for the well-being of future generations as a moral rationale for their stance. They assert that conventional discounting—even at relatively low rates—may be inequitable to future generations by leaving them with unacceptable climate damages or high costs from the need to abate future emissions very quickly. Critics also have argued that conventional discounting underestimates costs in the face of persistent income differences between rich and poor countries. Essentially, the argument is that because developing countries probably will not close the income gap over the next several decades, and because people in those countries attach higher incremental value to additional well-being than people in rich countries, the effective discount rate used to evaluate reductions in future damages from climate change should be lower than that applied to richer countries.

Supporters of the conventional approach to discounting on grounds of economic efficiency argue just as vehemently that any evaluation of costs and benefits over time that understates the opportunity cost of forgone investment is a bad bargain for future generations because it distorts the distribution of investment resources over time. These supporters of standard discounting also argue that future generations are likely to be better off than the present generation, casting doubt on the basic premise of the critics' concerns.

Experts attempting to address this complex mixture of issues increasingly recognize the need to distinguish principles of equity and efficiency, even though there is as yet no consensus on the practical implications for climate policy. We can start with the observation that anything society's decisionmakers do today—abating GHGs, investing in new seed varieties, expanding health and education facilities, and so on—should be evaluated in a way that reflects the real opportunity cost, that is, the options forgone both today and in the long term. This answer responds to the critics who fear a misallocation of investment resources if climate policies are not treated similarly to other uses of society's scarce resources.

Long-term uncertainty about the future growth of the economy provides a rationale for low discount rates on grounds of economic efficiency. The basic argument is that if everything goes well in the future, then the economy will be productive, the rate of return on investment will remain high, and the opportunity cost of displacing investment with policy today likewise also will be high. However, if things do not go so well and the rate of return on capital is low because of climate change or some other phenomenon, then the opportunity cost of our current investment in climate change mitigation versus other activities also will be low.

But economic efficiency only means a lack of waste given some initial distribution of resources. Specifically how much climate change mitigation to undertake is a different question, one that refers to the distribution of resources across generations. The answer depends on how concerned members of the current generation are about the future in general, how much they think climate change might imperil the well-being of their descendants, and the options at their disposal to mitigate unwelcome impacts on future generations. For example, one could be very concerned about the well-being of the future but also believe that other investments—such as health and education—would do more to enhance the well-being of future generations. Not surprisingly, experts and policymakers do not agree on these points.

We turn next to a brief discussion of international equity issues associated with climate change. The most immediate aspect of this debate involves the international distribution of responsibility for reducing GHGs and the associated costs. Developing nations have many pressing needs, such as potable water and stable food supplies, and less financial and technical capacity than rich countries have for mitigating GHGs. These nations have less incentive to agree to a policy that they see as imposing unacceptable costs.

Beyond this question are even more vexing issues surrounding the distribution of climate change risks. As already noted, it is likely that developing countries are both relatively more vulnerable to climate change than advanced industrialized countries and have less adaptive capacity; however, these disadvantages likely will be reduced in the future with further economic development. These differences are only beginning to be accounted for in climate change risks assessments. Analyses that consider only aggregate benefits and costs of climate change mitigation, without addressing the distribution of these benefits and costs, miss an important dimension of the policy problem. For example, the absolute magnitude of avoided costs from slowing climate change may be smaller in developing countries simply because per capita incomes are lower. But the implication that climate change mitigation should be given short shrift just because it mainly affects poorer people is ethically troubling.

Differences in perceptions about what constitutes equitable distributions of effort complicate any agreement. No standard exists for establishing the equity of any particular allocation of GHG control responsibility. Simple rules of thumb, such as allocating responsibility based on equal per capita rights to emit GHGs (advantageous to developing countries) and allocations that are positively correlated to past and current emissions (advantageous to developed countries) are unlikely to command broad political support internationally.

What Do Existing Economic Analyses Say?

Analyzing the benefits and costs of climate change mitigation requires understanding biophysical and economic systems as well as the interactions between them. Integrated assessment (IA) modeling combines the key elements of biophysical and economic systems into one integrated system (Figure 1). IA models strip down the laws of nature and human behavior to their essentials to depict how more GHGs in the atmosphere raise temperature and how temperature increase induces economic losses. The models also contain enough detail about the drivers of energy use and interactions between energy and economy that the economic costs of different constraints on CO_2 emissions can be determined.

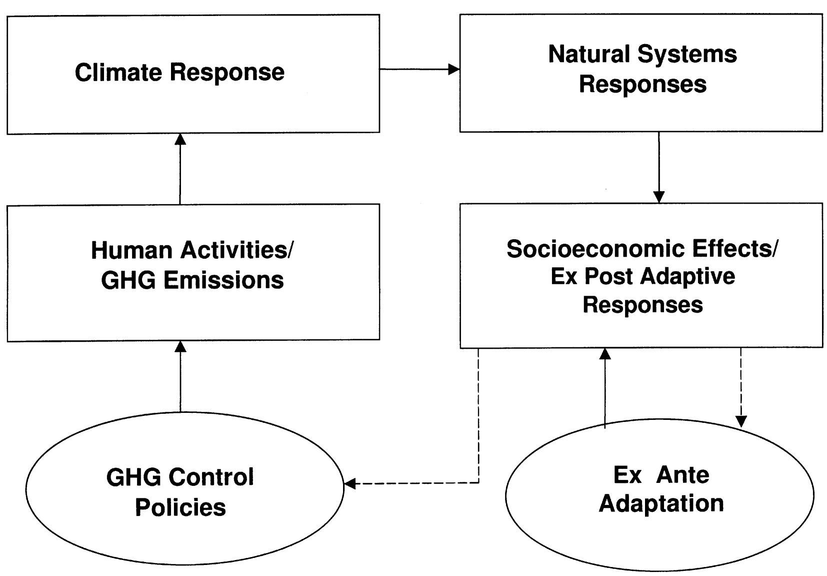

Figure 1. Climate Change and Its Interaction with Natural, Economic, and Social Processes.

Note: The key components of an integrated assessment model are illustrated. Solid lines represent physical changes; dotted lines represent policy changes. *Source:* Darmstadter and Toman (see Suggested Reading).

Researchers often use IA models to simulate a path of carbon reductions over time that would maximize the present value of avoided damages (that is, the benefits of a particular climate policy) less mitigation costs. As noted earlier, considerable controversy surrounds this criterion for evaluation.

A striking finding of many IA models is the apparent desirability of imposing only limited GHG controls over the next 20 or 30 years. According to the estimates in most IA models, the costs of sharply reducing GHG concentrations today are too high relative to the modest benefits the reductions are projected to bring.

The benefit of reducing GHG concentrations in the near term is estimated in many studies to be on the order of $5–25 per ton of carbon (see for example the papers by Nordhaus and Tol in Suggested Reading). Only after GHG concentrations have increased considerably do the impacts warrant more effort to taper off emissions, according to the models.

Even more striking is the finding of many IA models that emissions should rise well into this century. In comparison, the models indicate that policies pushing for substantial near-term control, such as the Kyoto Protocol, involve too much cost, too soon, relative to their projected benefits. Critics argue that IA models inadequately address several important elements of climate change risks: uncertainty, irreversibility, and risk of catastrophe. Assessing the weight of these criticisms requires us to explore the influences on the economic benefits and costs of climate protection.

Influences on the Benefits

The IPCC Second Assessment Report concluded that climate change could pose some serious risks. The IPCC presented results of studies showing that the damaging effects of a doubling of GHG concentrations in the atmosphere could cost on the order of 1.0–1.5% of gross domestic product (GDP) for developed countries and 2.0–9.0% of GDP for developing countries (see also Frankhauser and others in Suggested Reading). Reducing such losses is the benefit of protecting against the negative effects of climate change.

Several factors affect the potential magnitude of the benefits. One is the potential scale and timing of damages avoided. Although IA models differ greatly in detail, most have economic damage representations calibrated to produce damages resulting from a doubling of atmospheric GHG concentrations roughly of the same order as the IPCC Second Assessment Report. This point is worth keeping in mind when evaluating the results. The models increasingly contain separate damage functions for different regions. Generally, the effects in developing countries are presumed to be worse than those in the developed world, as in the IPCC Second Assessment Report. For the most part, these costs would be incurred decades into the future. Consequently, the present value of the costs would be relatively low today.

Assumptions about adaptation also affect estimates of potential benefits. Some critics of the earlier IPCC estimates argue that damages likely will be lower than predicted because expected temperature increases from a doubling of atmospheric GHG concentrations probably will be less than projected, ecosystems seem to be more resilient over the long term than the estimates suggest, human beings can adapt more than was supposed, and damages are not likely to increase proportionally with GDP. The implication is that the optimal path for GHG control (in a present value sense) should be even less aggressive than the IA results indicate. These new assessments remain controversial. One ongoing question concerns the cost of adjusting to a changing climate versus the long-term cost of a changed climate. Another is whether the effects of climate change (for example, in encouraging the spread of human illness through a greater incidence of tropical diseases, reducing river flows that concentrate pollutants, and increasing the incidence of heat stress) are being underestimated.

A third factor affects benefits: Damage costs not only are uncertain but also involve a chance of a catastrophe. However, a general finding from IA models is that GHG reductions should be gradual, even if damages are larger than conventionally assumed. A risk of catastrophe provides a rationale for more aggressive early actions to reduce GHG concentrations, but the risk has to be very large to rationalize near-term actions as aggressive as those envisioned in the Kyoto Protocol in a present-value IA framework. Part of the reason for this finding is that the outcome with the lowest cost also is the most likely to occur. IA models also do not incorporate risk-averse attitudes, which would provide a stronger rationale for avoiding large costs. Moreover, discounting in the models reduces the effective impact of all but the most catastrophic costs after a few decades.

Irreversibility of GHG emissions is yet another factor influencing the benefits of GHG abatement. Because GHG emissions persist in the atmosphere for decades, even centuries, the resulting long-term damages strengthen the rationale for early and aggressive GHG control. Moreover, given that some damage costs from adjusting to a changed climate depend on the *rate* of climate change, immediate action also might be valuable. To date, however, the importance of this factor has not been conclusively demonstrated; the gradual abatement policies implied by the IA models do not seem likely to greatly increase the speed of further climate change.

Finally, policies that reduce CO_2 also can yield ancillary benefits in terms of local environmental quality improvement, such as fewer threats to human health and reduced damage to water bodies from nitrogen deposition. The magnitudes of these ancillary effects remain fairly uncertain. They are lower to the extent that more environmental improvement would occur anyway, in the absence of GHG policy. They also depend on how GHG policies are implemented (for example, a new boiler performance mandate that encouraged extending the lives of old, dirty boilers would detract from the environment).

Influences on the Costs

Estimates of the cost of mitigating GHG emissions vary widely. Some studies suggest that the United States could meet its Kyoto Protocol target at negligible cost; other studies claim that the United States would lose at least 1–2% of its GDP each year. A study by the Energy Modeling Forum helped explain the range of results in assessing the costs to meet the Kyoto Protocol policy targets (see Weyant and Hill in Suggested Reading). For example, the carbon price (carbon tax or emissions permit price) needed to achieve the Kyoto Protocol emissions target in the United States with domestic policies alone ranges from about $70 per metric ton of carbon to more than $400 per ton (in 1990 dollars) across the models. The corresponding GDP losses in 2010 range from less than 0.2% to 2.0% relative to baseline. (The percentages of GDP are not reported in Weyant and Hill but implied from graphs presented there.) Carbon prices are put in perspective by relating them to prices for common forms of energy, as listed in Table 1.

Table 1. Implications of a Carbon Tax for U.S. Gasoline and Coal Prices.

Commodity	*Price ($) 1997 average*	*With $100/ton carbon tax*	*With $400/ton carbon tax*
Bituminous coal	26.16	87.94	273.28
Motor gasoline	1.29	1.53	2.26

Note: Coal price is national average annual delivered price per ton to electric utilities; gasoline price is national average annual retail price per gallon.
Sources: U.S. DOE (see Suggested Reading).

The results reported by Weyant and Hill and previous assessments of GHG control costs reflect different views about three key assumptions that drive the estimated costs of climate policy: stringency of the abatement policy, flexibility of policy instruments, and possibilities for development and diffusion of new technology. First, as one would expect, the greater the degree of CO_2 reduction required (because the target is ambitious, baseline emissions are high, or both), the greater the cost.

Costs of GHG control depend on the speed of control as well as its scale. Wigley and others (see Suggested Reading) showed that most long-term target GHG concentrations could be achieved at substantially lower present value costs if abatement were increased gradually over time, rather than rapidly, as envisaged under the Kyoto Protocol. Subsequent elaboration of this idea has shown that, in principle, cost savings well in excess of 50% could be achieved by using a cost-effective strategy for meeting a long-term concentration target versus an alternative path that mandates more aggressive early reductions (see the 1997 paper by Manne and Richels in Suggested Reading). These cost savings come about not only because costs that come later are discounted more but also because less existing capital becomes obsolete prematurely. There is an irreversibility problem associated with premature commitment to a form and scale of low-emissions capital, just as irreversibility is associated with climate change. The former irreversibility implies lower costs with a slower approach to mitigation.

Another important factor in assessing the costs of CO_2 control is the capacity and willingness of consumers and firms to substitute alternatives for existing high-carbon technologies. Substitution undertaken depends partly on the technological ease of substituting capital and technological inputs for energy inputs and partly on the cost of lower-carbon alternatives. Some engineering studies suggest that 20–25% of existing carbon emissions could be eliminated at low or negligible cost if people switched to new technologies such as compact fluorescent light bulbs, improved thermal insulation, efficient heating and cooling systems, and energy-efficient appliances. Economists counter that the choice of energy technology offers no free lunch. Even if new technologies are available, many people are unwilling to experiment with new devices at current prices. Factors other than energy efficiency also matter to consumers, such as quality, features, and the time and effort required to learn about a new technology and how it works. People behave as if their time horizons are short, perhaps reflecting their uncertainty about future energy prices and the reliability of the technology.

In addition, the unit cost of GHG control in the future may be lower than in the present, as a consequence of presumed continuation in trends toward greater energy efficiency in developed and developing countries (as well as some increased scarcity of fossil fuels). These trends will be enhanced by policies that provide economic incentives for GHG-reducing innovation. It is possible that the cost associated with premature commitment to irreversible long-lived investments in low-emissions technologies is more important in practice than climatic irreversibility, at least over the medium term. The reason is that sunk investments cannot be undone if climate change turns out to be less serious than might be expected, whereas society can accelerate GHG control if it learns that the danger is greater than estimated. The strength of this point depends in part on how irreversible low-GHG investment is and on the costs of irreversible climate change. In addition, critics of this view argue that without early action to reduce GHG emissions, markets for low-emission technologies would not develop and societies would lock in to continued use of fossil fuel–intensive energy systems.

Still another important factor is the flexibility and cost-effectiveness of the policy instruments imposed, both domestically and internationally. For example, Weyant and Hill's review showed that the flexibility to pursue CO_2 reductions anywhere in the Annex I countries (the industrialized countries that would cap their total emissions under the Kyoto Protocol) through some form of international emissions trading system could lower U.S. costs to meet the Kyoto Protocol target by roughly 30–50%. Less quantitative analysis has been done of alternative domestic policies. Nevertheless, it can be presumed from studies of the costs of abating other pollutants that cost-effective policies will lower the cost of GHG abatement, perhaps significantly. In contrast, constraints on the use of cost-effective policies—for example, the imposition of rigid technology mandates in lieu of more flexible performance standards—will raise costs, perhaps considerably. This factor often is neglected in analyses of domestic abatement activity that consider only the use of cost-effective policies such as emissions permit trading, although use of such policies is hardly foreordained. Ignoring this factor means that the costs reported in the economic models probably understate the costs societies will actually incur in GHG control. By the same token, studies of international policies that assume ideal conditions of implementation and compliance are overoptimistic.

A subtle but important influence on the cost of GHG control is whether emission-reducing policies also raise revenues (such as a carbon tax) and what is done with those revenues. When revenue generated by a carbon tax or other policy is used to reduce other taxes (a process commonly referred to as revenue recycling), some of the negative effect on incomes and labor force participation of the increased cost of energy are offset. However, it may be more effective at stimulating employment and economic activity in countries with chronically high unemployment than in the United States. The issue of revenue recycling applies also to policies that would reduce CO_2 through carbon permits or "caps." If CO_2 permits are auctioned, then the revenues can be recycled through cuts in existing taxes; freely offered CO_2 permits do not allow the possibility of revenue recycling. The difference in net social costs of GHG control in the two cases can be dramatic. Reducing CO_2 emissions with auctioned permits and revenue recycling can have net costs less than the benefits of GHG control indicated by the IA models (see Parry and others in Suggested Reading). In contrast, with a system of freely provided CO_2 permits, *any* level of emissions reduction yields environmental benefits (according to the IA models) that fall short of society's costs of abatement.

Most cost analyses presume that the relevant energy and technology markets work reasonably efficiently (other than the commonly recognized failure of private markets to provide for all the basic R&D that society wants, because this is a kind of public good). This assumption is more or less reasonable for most developed industrial economies. Even in these countries, one can identify problems such as direct and indirect energy subsidies that encourage excessive GHG emissions. Problems of market inefficiency are far more commonplace in the developing countries and in countries in transition toward market systems; accordingly, one expects incremental CO_2 control costs to be lower (even negative) in those countries. However, the institutional barriers to accomplishing GHG control in these economic systems may negate the potential efficiency gains.

Thus far, our discussion had focused on CO_2 control. Because CO_2 is only one of several GHGs, and because CO_2 emissions can be sequestered or even eliminated by using certain technologies, emissions targets related to climate change can be met in several ways. Some recent analyses suggest that the costs of other options alternatives compare very favorably with the costs of CO_2 reduction. For example, counting the results of forest-based sequestration and the reduction of non-CO_2 gases toward total GHG reduction goals could lower the cost to the United States of meeting its Kyoto Protocol emissions target by roughly 60% (see Reilly and others in Suggested Reading). But care is needed in interpreting some of the cost estimates. In particular, low estimates for the cost of carbon sequestration may not adequately capture all the opportunity cost of different land uses.

Uncertainty, Learning, and the Value of New Information

Another key factor in choosing the timing and intensity of climate change mitigation is the opportunity to learn more about both the risks of climate change and the costs of mitigation. Several studies show that the value of more and better information about climate risks is substantial. This value arises because one would like to avoid putting lots of resources into mitigation in the short term, only to find out later that the problems related to climate change are not serious. However, one also would like to minimize the risk of doing too little mitigation in the short term, only to find out later that very serious consequences of climate change will cost much more to avert because of the delay.

Manne and Richels and Kolstad showed that it generally pays to do somewhat less abatement in the short run under these conditions—to hedge against the downside without making too rapid a commitment. One virtue of some delay in emissions control is that it allows us to learn more about the severity of the risk of climate change and the options for responding to it. If the risk turns out to be worse than expected, mitigation can be accelerated to make up for lost time. To be sure, the strength of this argument depends on how costly it is to accelerate mitigation and on the degree of irreversibility of climate change. Analysts will continue to debate these points for some time to come.

Concluding Remarks

In this paper, we have explained that benefits and costs matter, for reasons of both efficiency and equity, and that benefits and costs must and can be considered in the context of the uncertainties that surround climate change. Economic analyses provide several rationales for pursuing only gradual abatement of GHG emissions. Because damages accrue gradually, catastrophes are uncertain and far off in the future, and unit mitigation costs are likely to fall over time (especially with well-designed climate policies), it makes sense to proceed slowly. To the extent that innovation is slower than desired with this approach, government programs targeted at basic R&D can help. The IA models indicate that rapid abatement does not maximize the present value of all society's resources.

We have not argued that current benefit–cost analyses are the last word on the subject. Opportunities certainly exist to improve the measurement of benefits and costs and to track the incidence of costs and risks across groups and over time. In practice, policy decisions will turn on a broader set of considerations than a single expected benefit–cost ratio. However, the arguments in favor of purposeful but gradual reduction in GHGs seem strong.

Economic analysis also could be used to justify not only a slower approach to GHG mitigation but also a less stringent long-term target. Here is where the potential conflict can arise between individuals' narrower economic self-interests and their concern for the well-being of future generations. Determining the right long-term policy goals ultimately requires us to address our attitudes toward intergenerational equity as well as to better understand the scale of environmental and economic risks that different climate policies imply for future generations. A more gradual GHG policy over the next 10–20 years does not preclude any but the most environmentally stringent targets, while potentially increasing the political acceptability of increasingly demanding mitigation measures. These considerations warrant renewed attention as the international community continues to grapple with the problem of finding a climate policy it can really live with.

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