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NORMATIVE CRITERIA FOR CLIMATE CHANGE POLICY ANALYSIS

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ABSTRACT

This paper explores the implications of three normative frameworks—cost-benefit analysis, classical utilitarianism, and the precautionary principle—for policy choices in a stylized model of interactions between climatic systems and the world economy. Under the assumptions of the model, cost-benefit analysis supports only modest steps to abate carbon dioxide emissions, allowing a long-run increase in mean global temperature of 7.4 percent Celsius (%C) relative to the preindustrial norm. Under classical utilitarianism, in contrast, emissions-abatement rates rise from 51 percent to 76 percent over the next century, with a long-run warming of 4.3%C. The precautionary principle may be taken to imply the restriction of greenhouse gas concentrations to no more than a doubling relative to preindustrial levels to "prevent dangerous anthropogenic interference with the climate system" under the Framework Convention on Climate Change. This policy scenario allows a long-run temperature change of no more than 2.9%C, with optimal emissions-abatement rates that rise from 31 percent to 85 percent between the years 2000 and 2105.

I. INTRODUCTION

Debates over climate change involve disagreements over both the facts and values surrounding this emerging policy dilemma. In U.S. policy discourse, skeptics combine doubts about the reality of climate change with libertarian social norms to argue that costly efforts to reduce greenhouse gas emissions are politically unwarranted (Lindzen 1990; Gray and Rivkin 1991). According to this view, greenhouse gas emissions are the by-product of certain activities—driving, space conditioning, lighting, appliance use, manufacturing, and land-use practices—that individuals and firms are entitled to pursue without undue government intervention. Based on the perception that emissions abatement might entail substantial economic costs, skeptics argue that aggressive climate-stabilization policies are unjustified in the absence of conclusive evidence that they would generate significant social benefits.

The factual assumptions behind this line of reasoning are partially confirmed and partially rejected by an assessment of the scientific and economic literature on climate change. The Intergovernmental Panel on Climate Change (IPCC 1996a), for example, confirms that efforts to stabilize greenhouse gas emissions at 1990 levels would yield long-run economic costs of up to 2 percent of gross world output. At the same time, however, the IPCC (1996b) concludes that a broad scientific consensus exists concerning the basic physical processes that drive climate dynamics, and that "the balance of evidence suggests a discernible human influence on global climate." In the absence of efforts to abate greenhouse gas emissions, the IPCC gauges that mean global temperatures would rise by 1 to 3.5%C by the end of the next century, with larger increases in the further future. Such changes would be accompanied by environmental impacts such as a rise in the sea level, the proliferation of tropical diseases, changes in the level and distribution of precipitation, possible reductions in agricultural production, and the pervasive disruption of natural ecosystems. Economic studies suggest that these impacts would impose net monetary costs of 1.5 to 2.0 percent of gross world output for a 2.5%C temperature change (IPCC 1996a).

The IPCC assessment suggests that contrasting the presumed rights of polluters with the hypothetical nature of climate forecasts "misframes" the essential trade-offs involved in climate change policy choices. Climate change, in this emerging view, pits the freedom of present-day economic actors—those who enjoy the benefits of greenhouse gas emissions—against the freedom of future generations to enjoy the benefits of a stable climate. If one accepts Thomas Jefferson's aphorism that "the Earth belongs in usufruct to the living" (see Page 1997) then the moral force of libertarian arguments against climate stabilization is cast into doubt. In place of a strong presumption against policy intervention, one is forced to identify principles that balance the interests of present and future generations.

The dominant approach to this problem in formal policy modeling involves the application of standard cost-benefit analysis to climate change mitigation strategies (Cline 1992; Nordhaus 1994; Fankhauser 1995). In this setting, analysts construct monetary estimates of the costs and benefits of greenhouse gas emissions abatement. A policy portfolio is then chosen to maximize the present-value net benefits of emissions control. This approach is defended on the grounds that cost-benefit analysis is based on revealed social preferences regarding the relative value of environmental and economic goods. The approach is criticized, however, because the discounting procedures that are essential to cost-benefit analysis suggest a possible bias against the needs and interests of future generations.

Classical utilitarianism offers a second approach to climate-stabilization policy that has been explicitly embraced by a range of prominent scholars (Broome 1992). Utilitarians take human *utilty* or *welfare* (not monetary benefits) as the basic unit of account on which social decisions should rest. They further stipulate that just decisionmaking requires that equal weight be placed on the needs and interests of every individual. In this view, the practice of discounting the future is morally inappropriate. Utilitarians therefore suggest that climate change policies should be designed to maximize the summed utility of all present and future persons.

Neither cost-benefit analysis nor classical utilitarianism captures the apparent intent of the United Nations Framework Convention on Climate Change, which calls for:

> [the] stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

Although this language does not challenge published estimates of the costs of climate change, it emphasizes the core uncertainties that surround such estimates, as well as the possibility that climate change will engender unexpected—and potentially highly undesirable—effects.

In developing this theme, the IPCC (1996b) identifies several processes though which climate change might generate truly catastrophic environmental impacts: the disruption of ocean circulation patterns, the release of large quantities of methane stored in terrestrial and marine sediments, and the possible collapse of the West Antarctic ice sheet. Although none of these scenarios is judged probable given the current state of scientific understanding, the IPCC notes that climatic systems are complex, nonlinear, and only partially understood—and hence vulnerable to problems of unpredictability and surprise. Under such circumstances, some observers have called for the use of the *precautionary principle*—"the commitment of resources now to safeguard against the potentially adverse future outcomes of some decision" (Perrings 1991)—as a guide to policy formulation. The language of the Framework Convention is generally consistent with this approach.

This paper presents an analysis and discussion of these three main approaches to climate change policy choices with a focus on their operational implications for formal policy modeling. The analysis begins by describing a framework for evaluating the economic impacts of climate change and the costs of reducing greenhouse gas emissions in a numerical simulation model. It then proceeds with an analysis of the optimal policy choices that emerge for this model under cost-benefit analysis, classical utilitarianism, and the precautionary principle, while simultaneously discussing the relative merits of each approach. It concludes with a summary and interpretation of the principal findings.

II. A STYLIZED MODEL OF CLIMATE-ECONOMY INTERACTIONS

The analysis employs a stylized model of the links between climate change and the world economy that was developed by Howarth (1998). The model is numerically calibrated based on the well-known work of Nordhaus (1994), who provides a concise representation of climate dynamics and the technical determinants of economic growth. Although Nordhaus focuses on an optimal growth model in which the welfare of a single, infinitely lived agent is maximized through time, Howarth implements an overlapping-generations specification in which decentralized producers and consumers interact in a market setting. This approach allows the explicit analysis of normative questions that are generally suppressed in optimal growth models. Since this paper's focus is on the qualitative implications of alternative normative criteria for climate change policy choices, attention is limited to a verbal sketch of the essential elements of the model. See Howarth 1998 for a complete technical description.

The model considers a competitive economy in which a homogeneous consumption-investment good is produced using inputs of capital and labor according to a Cobb-Douglas production function. The parameters of the production function are chosen to match the stylized fact that labor accounts for three-quarters of the value of economic output while capital accounts for the remainder. Beginning with the year 2000, the model assumes that technological change augments total factor productivity at an initial rate of 1.1 percent per year. The rate of technological change falls gradually over time, so that the long-run improvement in total factor productivity is limited to 153 percent. Economic output is divided between consumption, gross investment, and capital depreciation. Capital assets depreciate at a fixed rate of 10 percent per year.

In line with standard demographic projections (Bulatao et al. 1990), human population rises from 5.93 billion persons in the year 2000 to 10.54 billion in the long-run future. Population growth is concentrated in the next one hundred years, during which four-fifths of the total increase occurs. The model assumes that the supply of labor is proportional to total population. A typical person is endowed with labor services that she supplies to the production sector in exchange for wage income.

Savings-investment decisions are managed by private individuals to achieve a desired distribution of consumption over their life spans. A typical person lives for seventy years, investing part of his income in youth to finance increased consumption in old age. Capital assets are rented to firms at the prevailing interest rate, which reflects both the marginal productivity of capital and the marginal time preference of individuals. In order to match expected rates of capital accumulation, the model represents individual preferences using a utility function that increases in proportion with the logarithm of personal consumption. Individuals seek to maximize the present-value sum of their lifetime utility stream with a pure rate-of-time preference of 0.5 percent per year.

The model represents net emissions of carbon dioxide as proportional to gross world output. In the absence of emissions-abatement policies, emissions in the year 2000 amount to some 0.37 kilograms (kg)-carbon per dollar of economic output.[1] Due to technological innovation, the ratio of emissions per unit output falls at an initial rate of 0.55 percent per year. with a long-run decline of 51 percent. The model assumes that emissions abatement, although technologically feasible, is economically costly. A 50 percent reduction in carbon dioxide emissions entails a 0.93 percent reduction in gross world output, while costs rise to 6.86 percent of economic activity when emissions are fully controlled.

The model rests on a simple, but analytically tractable, representation of climate dynamics. Approximately two-thirds of carbon dioxide emissions are directed to the atmosphere, while the remaining third is taken up by short-run processes involving the oceans and biota. Once in the atmosphere, the residence time of carbon dioxide molecules is 120 years. Thus anthropogenic emissions of carbon dioxide are removed from the atmosphere to the deep ocean at an effective rate of 0.833 percent per year.

Climate change is driven by the accumulation of both carbon dioxide and other greenhouse gases in the atmosphere. The model treats stocks and flows of non-CO_2 greenhouse gases as beyond the control of policy decisions; together these gases (which include chlorofluorocarbons, nitrous oxides, and methane) elevate mean global temperature at a rate that rises from 0.47%C in the year 2000 to 1.0%C in the long-run future. The impacts of these gases, however, are small in magnitude when compared with the influence of carbon dioxide. The model assumes that mean global temperature increases in proportion with the logarithm of carbon dioxide concentrations. A doubling of carbon dioxide concentrations relative to the preindustrial norm (i.e., the prevailing conditions of the late nineteenth century) causes a net temperature increase of 2.91%C.

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[1] Monetary units are denominated in 1989 U.S. dollars throughout the analysis.

A critical aspect of the model relates to its assumptions concerning the damages imposed by climate change. Following Nordhaus (1994), the model represents climatic damages as a production externality, in which a 3.0%C temperature increase causes a 1.33 percent reduction in gross world output. The level of damages is proportional to economic activity and increases with the square of the temperature change caused by anthropogenic greenhouse gas emissions.

To complete the description of the model it is necessary to discuss the role of government policies in shaping the behavior of producers and consumers. As was noted above, the model assumes that decisions about savings and investments are managed by the private sector. The externalities associated with climate change, however, suggest a positive role for policy intervention. In the model, the government taxes greenhouse gas emissions to balance the present benefits and future costs they impose on economic and environmental systems. Tax revenues are returned to consumers in equal lump sums that augment earnings on labor and capital.

III. COST-BENEFIT ANALYSIS

The basic theory behind cost-benefit analysis is widely known if broadly misunderstood (Just et al. 1982; Friedman 1984). Suppose that the benefits generated by a policy change, measured in monetary units, exceeded the costs of its implementation. Then those benefiting from the policy could, in principle, compensate the losers so that all affected parties were made better off. Alternatively, one might begin with the observation that maximizing the net benefits of public policies leads to a Pareto-efficient resource allocation. From an efficient allocation, it is impossible to identify an alternative state of affairs that benefits at least one person while leaving none worse off. Under either interpretation, cost-benefit analysis operationalizes the intuitive notion that decisionmakers should, when possible, implement policies that resolve the competing claims of stakeholder groups to achieve mutual benefits.

These standard arguments in support of cost-benefit analysis depend critically on decisionmakers' willingness (or capability) to mandate compensatory payments between winners and losers. The practical challenges of implementing this approach over intergenerational time scales point to a key limitation of cost-benefit analysis in the evaluation of climate-stabilization policies. Greenhouse gas emissions, left unmitigated, provide present benefits but impose costs on future generations in the form of reduced environmental quality and economic welfare. In a similar vein, greenhouse gas emissions abatement generates present costs and future benefits. While decisionmakers might generally support policies that strike an efficient balance between the private benefits and social costs of environmental degradation, they might reasonably question whether the distribution of burdens and benefits between generations was ethically defensible.

One way to circumvent this dilemma might be to design financial mechanisms that transferred monetary assets between present and future generations. Such institutions might either: *(a)* compensate future generations for the costs imposed by current greenhouse gas emissions; or *(b)* compensate present generations for the costs of climate stabilization. The logic behind such compensation schemes is theoretically elegant and conceptually appealing. But as Lind (1995) points out, the notion that intergenerational compensation might actually be implemented by real-world governments seems palpably unrealistic. Changes in governments would likely disrupt such policies before they achieved their intended outcomes, while cash-strapped decisionmakers would face strong incentives to raid compensation funds to finance short-run spending. In Lind's view, the moral dilemmas of intergenerational choice cannot be avoided, nor can they be reduced to the calculus of cost-benefit analysis.

A second objection to grounding climate change response strategies on cost-benefit criteria focuses on the ethical paradoxes that surround conventional discounting procedures. In cost-benefit analysis, the operational objective is to maximize the discounted net benefits of greenhouse gas emissions abatement. The social discount rate is appropriately set equal to the market rate of interest or after-tax return on capital investment, which reveals individuals' preferences concerning marginal changes in their consumption streams over time (Lind 1982; Howarth and Norgaard 1995). Suppose that C_t and B_t represent the monetary costs and benefits of climate-stabilization policies at a sequence of dates $t = 0, 1, 2,\ldots$ If r_t is the interest rate at time t, the problem of cost-benefit analysis is to maximize the expression where the relative weight is attached to costs and benefits realized t periods from the present. Under this decision rule, the marginal costs and discounted marginal benefits of greenhouse gas emissions abatement are brought into agreement.

According to critics, conventional discounting techniques are unfair to future generations because they imply that essentially no weight is attached to costs and benefits that are realized a generation or more into the future (Cline 1992). The force of this criticism is outlined in table 1, which describes the implications of choosing climate change policies using cost-benefit criteria for the simulation model described above. Under these conditions, the model converges to a long-run steady state after the passage of some five hundred years. Along the equilibrium path, interest rates fall gradually from 4.3 percent per year in the year 2000 to 2.8 percent per year in the long-run future. Although these interests rates are not particularly large, they imply that one dollar of benefits obtained one hundred years from today has a present value of only two cents.

Under cost-benefit analysis, carbon dioxide emissions taxes rise from $16 per ton-carbon in the present to $76 per ton-carbon in the long-run future. Emissions-control rates are relatively modest, rising from 16 percent to 25 percent over the period of the analysis. In the absence of aggressive policy interventions, carbon dioxide emissions rise from 8.6 to 24.2 billion tons-carbon per year, while mean global temperatures experience a net increase of 7.4%C relative to the preindustrial norm. These results are generally comparable to those obtained by Nordhaus's (1994) optimal growth model of climate-economy interactions.

TABLE 1: **COST-BENEFIT ANALYSIS**

Year	2000	2105	Long Run
Population (109 people)	5.9	9.7	10.5
Per capita consumption (1989 $/person/yr.)	4,058	10,542	15,268
Capital stock (1012 1989 $)	56	307	586
CO_2 emissions (109 tons-carbon/yr.)	8.6	19.6	24.2
% emissions abatement	16	24	25
Mean temperature change (%C)	1.7	4.6	7.4
Interest rate (%/yr.)	4.3	3.4	2.8
Wage income (1989 $/person/yr.)	3,460	8,629	12,481
CO_2 emissions tax (1989 $/ton-carbon)	16	56	76

Needless to say, the ecological impacts that such changes would entail are very substantial. A temperature increase of this magnitude has not been realized for several million years. Advocates of cost-benefit analysis, however, would point out that this policy outcome need not entail the unfair treatment of future generations. Under this scenario, per capita consumption—a broad-based if somewhat crude indicator of economic welfare—rises by a full 276 percent over the period of analysis. In this setting, the negative aspects of environmental degradation are apparently offset by capital investment and technological progress. Future generations are able to achieve a high standard of living in a degraded physical environment.

This conclusion, however, rests on the assumption that climate change will impose marginal costs on economic activity to which future producers and consumers will successfully adapt. In the model, the long-run costs of increased global temperatures amount to only 8 percent of gross world output, and the potential for unexpected, and perhaps catastrophic environmental impacts, is effectively ignored. This assumption is examined and relaxed in section 5 of the paper, where the rationale for precautionary measures to avert climatic risks is explicitly developed.

IV. CLASSICAL UTILITARIANISM

As was noted above, cost-benefit analysis is criticized on the grounds that discounting the impacts that policy decisions impose on future generations is morally inappropriate. This point of view is eloquently elaborated by Parfit (1983, 31), who argues that "the moral importance of future events does not decline at *n* percent per year. A mere difference in timing is in itself morally neutral." Based on this line of reasoning, Parfit calls for the principled rejection of discounting procedures in social decisionmaking.

Notions of impartiality and moral neutrality are a defining characteristic of philosophical ethics, and decision rules that confer privilege to some groups over others are difficult to defend on moral grounds. Consequentialist theories proceed from the principal that each individual's *interests* deserve equal weight in social decisionmaking. Deontological frameworks, in contrast, hold that individuals are entitled to equivalent political and economic *rights.* While Parfit's arguments against discounting might be neutralized if the net benefits generated by efficiency-enhancing policies were equitably shared between generations, this possibility is cast into doubt by Lind's (1995) claim that intergenerational compensation schemes are institutionally infeasible. The question of equity therefore arises as an irreducible aspect of climate change policy choices.

Classical utilitarianism rests on a simple and readily interpreted criterion of social choice. In evaluating the relative merits of policy alternatives, decisionmakers should assess the impacts of each prospect on the utility or welfare of every member of society. Policies should then be formulated to maximize total social welfare, calculated as the summed utility of all individuals. The foundations of this approach lie in the seminal contributions of Bentham (1823) and Mill (1863), whose work initiated voluminous literature in philosophy, political theory, and welfare economics. Cline (1992) and Broome (1992) have argued for the use of utilitarian concepts in the evaluation of climate-stabilization policies.

The moral arguments supporting classical utilitarianism are conceptually well defined. Some commentators, for example, maintain the view that classical utilitarianism would flow naturally from the choices made by an "impartial spectator" (Smith 1759) who sought to promote the interests of disparate individuals in a fair-minded way. More formally, Harsanyi (1977) argues that a commitment to utilitarianism would emerge from a social contract in which the consenting parties aimed to maximize their expected well-being but were uncertain about their particular positions in society. In a static world where individuals have identical preferences and where commodities may be transferred without cost from one person to another, utilitarianism gives rise to an egalitarian distribution of income and welfare.

The philosophical arguments against classical utilitarianism, however, are also well developed (Sen and Williams 1982). First, the notion that public policies should aim to maximize "the greatest good for the greatest number" requires that utility or well-being can be meaningfully quantified and compared between individuals. This claim is rejected by many philosophers and social scientists, who view utility as a psychic magnitude that is not amenable to empirical measurement. Overcoming this objection requires utilitarians to make strong assumptions that cannot be verified on scientific grounds. In essence, analysts and/or decisionmakers must appeal to their own subjective assessment of other people's welfare.

Second, classical utilitarianism is difficult to reconcile with the observation that ordinary moral concepts are fundamentally concerned with individuals' *rights* and correlated *duties* (Kant 1930). The right to personal freedom, for example, is widely understood as a basic principal of Western societies. Utilitarianism, however, might sanction the imposition of totalitarian over democratic institutions (or the persecution of despised minorities) if such actions would, on balance, promote the general welfare. Utilitarians answer this objection by placing bounds on the range of preferences that are deemed morally considerable and by arguing that conventional moral rules in fact serve to promote human well-being. Such arguments, however, are rejected by anti-utilitarians such as Rawls (1971) and Nozick (1974), who claim that the basic institutions that define liberal democracy depend critically on deontological (or rights-based) moral principles.

A final objection to classical utilitarianism concerns the perceived implausibility of certain consequences that stem from utilitarian social-choice rules. In the context of economic development, for example, utilitarianism would seem to require a major redistribution of income and capital assets from industrialized to developing nations. This follows from the conventional assumption that the marginal utility of income is diminishing so that transfers of wealth from the rich to the poor generate net increases in total utility. And as Manne (1995) points out, utilitarian concepts suggest that prevailing rates of capital investment may be far below optimal levels, with a substantial need for policies to reallocate income from present to future generations.

Since the evidence suggests that real-world governments are profoundly reluctant to undertake substantial North-South transfers or crash investment programs, one might conclude that utilitarianism offers a poor account of prevailing concepts of economic justice.

The foregoing analysis establishes that classical utilitarianism is both strongly supported and forcefully contested by competing schools of political economy. Given this observation, it is interesting to explore the consequences of the utilitarian approach for climate stabilization policies. Using the model outlined in section 2 above, it is possible to calculate the impacts of alternative policy decisions on the utility or welfare of each successive generation. To arrive at an optimal policy scenario, carbon dioxide emissions taxes are chosen to maximize the summed utility of all present and future persons.[2] As is the case under cost-benefit analysis, the optimal path converges to a long-run steady state after the passage of about five hundred years (table 2).

TABLE 2: **CLASSICAL UTILITARIANISM**

Year	2000	2105	Long Run
Population (109 people)	5.9	9.7	10.5
Per capita consumption (1989 $/person/yr.)	4,024	10,430	15,811
Capital stock (1012 1989 $)	56	301	603
CO_2 emissions (109 tons-carbon/yr.)	5.0	8.1	8.1
% emissions abatement	51	68	76
Mean temperature change (%C)	1.7	3.3	4.3
Interest rate (%/yr.)	4.2	3.4	2.8
Wage income (1989 $/person/yr.)	3,354	8,376	12,682
CO_2 emissions tax (1989 $/ton-carbon)	146	419	649

The results of this modeling experiment differ dramatically from those that arise when policy decisions are based on conventional cost-benefit criteria. In this scenario, optimal rates of carbon dioxide emissions abatement rise from 51 percent in the year 2000 to 76 percent in the long-run future, supported by emissions tax rates that increase from $146 per ton-carbon to $649 per ton-carbon. Under these

[2] This problem is well defined only in the case of a finite planning horizon. Given an infinite horizon, the sum of utility would become infinite in the long run. Prevailing scientific opinion, however, holds that the world will eventually come to an end given a large asteroid collision or the eventual extinction of the sun. The results given here hold for the case where the planning horizon is very large but finite (see Howarth 1998).

circumstances, carbon dioxide emissions rise from 5.0 to 8.1 billion tons-carbon per year, limiting the long-run increase in mean global temperature to 4.3%C relative to the preindustrial norm. This increase, although substantial, is a full 3.1%C below the total change that arises under cost-benefit analysis.

Cost-benefit analysis and classical utilitarianism support broadly similar wages, interest rates, and rates of capital accumulation. Utilitarianism, however, imposes a 0.8 percent reduction in short-run consumption that generates a 3.6 percent increase in the long-run future. The intuition behind this result is that a utilitarian decisionmaker would willingly tolerate the short-run costs of aggressive greenhouse gas emissions abatement in exchange for the long-run benefits of improved environmental quality. The requisite trade-offs are made through appeals to an explicit theory of intergenerational social choice that ensures the equal treatment of successive age cohorts.

The results described here assume that policymakers are able to impose carbon dioxide emissions taxes but lack other instruments to affect the future course of economic activity. As Manne (1995) observes, a utilitarian social planner would prefer to render substantial transfers of capital assets from present to future generations, but is unable to achieve such transfers in a competitive economy through climate change policies alone. Interestingly, however, the emissions-abatement policies summarized in table 2 are closely similar to those that a utilitarian planner would choose in the absence of institutional constraints (Howarth 1998). It is therefore a commitment to utilitarianism, not the specific constraints imposed on decisionmakers, that drives the results of this simulation. Similar conclusions are derived by Chapman et al. (1995), who analyze climate change policy choices in an optimal growth model with a zero rate of pure time preference.

V. THE PRECAUTIONARY PRINCIPLE

The foregoing analysis proceeds on the assumption that the costs and benefits of greenhouse gas emissions abatement, measured in terms of monetary units or utility, can be characterized with reasonable precision. The problem is then to balance these costs and benefits in a manner that strikes an appropriate balance between present and future interests. As indicated in the introduction, this approach runs into important conceptual barriers in the context of climate change. Although climate modeling and impact assessment have progressed substantially over time, uncertainty concerning both physical processes and prospective consequences is a central aspect of the climate change dilemma. Modeling approaches that abstract away from uncertainty are thus an incomplete guide to decisionmaking.

It is reasonable to suppose that small perturbations in climate relative to current conditions would induce moderate impacts to which future societies might favorably adapt. Large changes in climatic systems, however, entail the prospect of irreversible and catastrophic change through the disruption of ocean circulation patterns, the release of methane and other greenhouse gases from biogeochemical storage, and the possible collapse of the West Antarctic Ice Sheet (IPCC 1996b). Seen in this way, climate change policy choices pit the marginal economic benefits of greenhouse gas emissions—especially the low cost and convenience of today's energy technologies—against potential threats to the lives and livelihoods of members of future generations. Although the possibility of such impacts—which include famines, floods, disease epidemics, and a diminished ecological world—is generally recognized by scientists, their probability and potential severity is known in only speculative terms that are not amenable to empirical generalization.

The nature of this problem is well illustrated by the historical example of stratospheric ozone depletion caused by anthropogenic emissions of chlorofluorocarbons (CFCs; see French 1997). When introduced to the mass market following World War II, CFCs were seen as miracle compounds with low toxicity, low production costs, and physical properties that rendered them ideal for use as refrigerants, aerosol propellants, and industrial solvents. In the 1970s, laboratory experiments identified chemical reactions through which CFCs might, in principle, induce ozone depletion. The early models, however, suggested that the atmospheric accumulation of CFCs and related compounds would lead to a relatively modest thinning of the ozone layer. In 1985, satellite data pinpointed a 40 percent reduction in ozone concentrations over Antarctica during certain periods of the year—an effect that was so large that it was initially rejected as scientifically impossible. Subsequent analysis, however, established that CFCs, in conjunction with ice crystals found in the Antarctic atmosphere during the austral spring, lead to greatly accelerated rates of ozone depletion. Similar effects, if realized over populated regions, might have caused massive increases in skin cancer, crop failures, and ecological despoliation. By happenstance, the ozone hole was limited to the polar latitudes, and the problem was identified in time to curtail the production and utilization of CFCs under the Montreal Protocol before the onset of catastrophic global impacts.

In the context of climate change, DeCanio compares a laissez faire approach to greenhouse gas emissions abatement to gambling with the lives and welfare of one's children:

> [C]limate change is . . . like a game of Russian roulette, with negligible short-run benefits (of unconstrained fossil fuel consumption) weighed against the chance of huge losses (from climate-related disasters). . . . The image of a game of Russian roulette being played for some trivial payoff but with the pistol pointed at the head of one's *child* is almost too gruesome to contemplate. Yet modifying the global climate without knowing the ultimate consequences is akin to just this sort of imposition of dire risk on future generations for our own transitory or illusory advantage. (1997, 6–7)

The rejection of this gambit is implied by language of the Framework Convention on Climate Change (see above), which calls for precautionary action to maintain the integrity of climatic systems to support sustainable development. Exploring the foundations and implications of this statement has posed a fundamental challenge for economic analysis.

The standard approach employed in the economics of decisionmaking under uncertainty begins with the assumption that the potential consequences of alternative actions are fully characterized in quantitative terms. In this view, decisionmakers might be uncertain about the exact consequences (benign or catastrophic) that climate change will entail, but they know with precision the detailed physical processes and economic impacts that would hold under each scenario. Given a well-defined probability distribution over the set of prospective outcomes, analysts may account for decisionmakers' risk aversion or willingness to forego potential benefits to avoid the prospect of uncompensated costs.

Applications of this approach to climate-stabilization policy have yielded highly suggestive findings. Cline (1992), for example, constructs a hypothetical scenario in which greenhouse gas emissions-abatement rates of 40 percent relative to 1990 levels are economically justified if one believes that there is a significant probability that climate change would induce catastrophic losses. The heuristic nature of Cline's modeling experiment, however, highlights the logical difficulties of grounding actual policy choices on conventional models of decisionmaking under uncertainty. Although the scientific literature suggests that catastrophic outcomes might *possibly* arise if climatic systems are pushed beyond the limits of present understanding, the causal processes generating such outcomes, and indeed the nature of the consequences themselves, remain substantially unknown. Under such circumstances, decision problems shift from what Faber et al. (1992) term "uncertainty" to "ignorance." When neither probabilities nor payoffs are empirically defined, the conditions required to operationalize standard risk analysis simply do not apply.

How, then, might economic analysis inform rational decisions regarding greenhouse gas emissions-abatement strategies? One approach to this problem is to make use of the so-called *precautionary principle* as it arises in ecological economics. As was seen in the introduction, the precautionary principle entails "the commitment of resources now to safeguard against the potentially adverse future outcomes of some decision" (Perrings 1991). As Perrings notes, this definition is conceptually vague in the absence of further elaboration. To say that decisionmakers should willingly forego present benefits in exchange for reduced future risks does not in itself answer the question of just how far precautionary action should extend.

On the surface, this problem would seem to be particularly intractable in cases when the adverse impacts of policy decisions were shrouded in ignorance. A range of authors, however, have emphasized that this interpretation rests on an apparent misconception. Although knowledge of outcomes is required to implement *consequentialist* decision rules such as cost-benefit analysis and classical utilitarianism, one may build a case for precautionary action that is grounded on the perceived *right* of future generations to enjoy the sustained benefits of a stable climate (Bromley 1989). Under this view, current decisionmakers hold a moral duty to ensure that their actions do not impose uncompensated risks on members of future generations. Where costs and benefits are ill-defined, the benefit of the doubt falls on the side of climate stabilization, and the rights of future generations are enforced through an *inalienability rule.*

This approach invites at least two types of objections. First, one might question the notion that future generations are morally entitled to a stable climatic. Schwartz (1978), for example, rejects the proposition that future generations are entitled to anything at all beyond a barely tolerable quality of life since the very existence of future persons is contingent upon contemporary choices. Our moral intuitions, however, suggest that parents hold a duty to provide their children with a world of undiminished opportunities. More formally, Howarth (1997) argues that principles of fairness between generations are logically entailed by principles of equal opportunity between contemporaries. In a context of strong uncertainty regarding future technology and preferences, the life opportunities of future generations can be sustained only by maintaining the services provided by natural resources and environmental systems (Page 1983).

The second objection is premised on the view that climate stabilization would divert resources from capital investment and technological innovation, thereby reducing rates of economic growth and the expansion of opportunities. Future generations, in this view, might prefer a world of higher incomes and diminished environmental quality to the strict maintenance of natural systems (Solow 1993). This criticism, however, is already addressed in the version of the precautionary principle identified above, under which reductions in environmental quality are morally permissible *given compensating investments* in produced capital, new technologies, and other forms of wealth.

But in shifting the burden of proof toward climate stabilization, the precautionary principle acknowledges the general validity of compensatory strategies while limiting their application to the range of choices where the costs and benefits of climate change can be meaningfully assessed. Future generations would have scant right to complain if modest changes in climate were offset by substantial improvements in social and economic conditions. Beyond the limits of scientific understanding, however, appeals to the consequentialist logic of cost-benefit analysis amount to a blend of conjecture and speculation. Basing choices on the rights of future generations in such situations, in contrast, generates decisions that are procedurally rational and operational under circumstances of incomplete information.

In practical terms, the application of the precautionary principle to climate change policy analysis requires the identification of a safe upper limit on the accumulation of greenhouse gases in the atmosphere (Krause et al. 1989). While a full analysis of this problem is beyond the scope of this paper, the application of the approach may be illustrated as follows. First, it is well known that both general-circulation models and climate-impact assessments have focused mainly on the consequences of a doubling of greenhouse gas concentrations in the atmosphere relative to the preindustrial norm. Since few studies have substantively addressed the potential consequences of pushing beyond a doubling, there is no reliable basis for concluding that permitting higher greenhouse gas concentrations would be safe or fair to future generations.

Second, the existing literature suggests that a doubling of greenhouse gas concentrations might entail moderate costs on social and economic systems, with limited prospects for the onset of catastrophic impacts through identified feedback processes. To be sure, the safety of a doubling might be questioned on the grounds that a doubling itself would give rise to unacceptable ecological impacts. But for the purposes of illustration, it is useful to work with a doubling of greenhouse gas concentrations—in the model, a 2.91%C increase in mean global temperature—as a practically achievable safe upper limit. In real-world choice contexts, the determination of prospective warming limits would involve detailed deliberations concerning the scope and limitations of scientific knowledge.

TABLE 3: **THE PRECAUTIONARY PRINCIPLE**

Year	2000	2105	Long Run
Population (109 people)	5.9	9.7	10.5
Per capita consumption (1989 $/person/yr.)	4,056	10,188	15,766
Capital stock (1012 1989 $)	56	295	603
CO_2 emissions (109 tons-carbon/yr.)	7.0	3.7	3.8
% emissions abatement	31	85	88
Mean temperature change (%C)	1.7	2.9	2.9
Interest rate (%/yr.)	4.2	3.4	2.8
Wage income (1989 $/person/yr.)	3,419	8,253	12,777
CO_2 emissions tax (1989 $/ton-carbon)	59	662	895

To impose a constraint on long-run global warming does not in itself fully identify an optimal path for greenhouse gas emissions abatement. Decisionmakers might also desire to time abatement activities to minimize economic costs or maximize social utility subject to this limit, following what Norton and Toman (1997) term a “two-tier” approach to policy formulation. In the simulation run described in table 3, policy choices are made through a combination of cost-benefit analysis and the precautionary principle to maximize the present-value net benefits of carbon dioxide emissions abatement (see section 3 above) subject to the constraint that the increase in mean global temperature never exceeds 2.91%C in comparison with the preindustrial norm. As with the results generated under unconstrained cost-benefit analysis and classical utilitarianism, the model converges to a long-run steady state with the passage of about five hundred years.

The climate change mitigation policies that arise under the precautionary principle offer an interesting contrast to those derived under unconstrained cost-benefit analysis. Although cost-benefit analysis supports only modest steps to curtail the accumulation of carbon dioxide in the atmosphere, the precautionary principle entails optimal emissions-control rates that rise from 31 percent in the year 2000 to 88 percent in the long-run future. Under this scenario, carbon dioxide emissions fall from 7.0 to 3.8 billion tons-carbon per year over the period of analysis, while emissions tax rates rise from $59 per ton-carbon to $895 per ton-carbon.

Although critics allege that efforts to stabilize climatic systems would impose large economic costs on both present and future generations, this point of view is not entirely supported by the simulation results reported here. In comparison with the results obtained under cost-benefit analysis, the precautionary principle yields a reduction in per capita consumption of less than 0.1 percent in the year 2000, while *increasing* long-run consumption by a full 3.3 percent as future generations enjoy the sustained benefits of improved environmental quality. In this scenario, the costs of climate stabilization are borne mainly by intermediate generations, who also enjoy the unquantified benefits of reduced climatic risks. In the year 2100, for example, the precautionary principle gives rise to a 3.4 percent reduction in per capita consumption in comparison with the level that arises under cost-benefit analysis.

In comparison with classical utilitarianism, the precautionary principle implies reduced rates of carbon dioxide emissions abatement in the short run but somewhat more aggressive policies in the long-run future. Under the precautionary principle, emissions-abatement activities are timed to maximize discounted net benefits subject to the constraint that the stock of greenhouse gases in the atmosphere is limited to a doubling relative to the preindustrial norm. With positive discount rates, this approach attaches less weight to the future than to the present, shifting the burden of climate stabilization incrementally toward posterity. Classical utilitarianism, however, allows a long-run increase in mean global temperature in excess of the 2.91%C upper limit imposed by the precautionary principle.

Before turning to the conclusions, it is relevant to discuss one further methodological question concerning the application of the precautionary principle in climate change policy analysis. According to Kolstad (1994), scientific research will lead to successive reductions in the uncertainties that surround both the magnitude of climate change and the ensuing impacts on human and ecological systems. In this view, the prospect for learning offers a potential reason to delay costly steps toward greenhouse gas emissions abatement until the need for such policies is fully substantiated. Kolstad's reasoning applies to the case where the impacts of climate change are known to be of limited severity. In critiquing this argument, one might begin with the observations that:

1. A doubling of greenhouse gas concentrations relative to the preindustrial norm will occur by the mid-twenty-first century in the absence of aggressive policy measures.
2. The uncertainties that surround general-circulation models and climate change impact assessment might well persist past this date.
3. There is insufficient evidence to conclude that the environmental costs of exceeding a doubling would be tolerable to future generations.

In a variant of the approach taken in this paper, Woodward and Bishop (1997) explore the optimal climate-stabilization policies that arise under an axiomatic social-choice framework developed by Arrow and Hurwicz (1972). In a setting where excessive rates of climate change might generate intolerable impacts and where the resolution of uncertainty is delayed until the late twenty-first century, Woodward and Bishop find that it is optimal to plan for the worst, living within the limits imposed by the precautionary principle until such limits are rendered superfluous by advances in scientific understanding.

Using the procedures described by Howarth and Norgaard (1995) for implementing cost-benefit analysis under probabilistic uncertainty, the present analysis may be extended to allow for the prospect that long-run warming limits will be found unnecessary at some future date. If decisionmakers believe that the resolution of uncertainty may be delayed until the year 2070, then short-run policy choices are insensitive to the numerical probability that warming limits will eventually be removed and are aptly summarized by the simulation results given in table 3. In this sense, it is the *possibility* rather than the *probability* that climate change would give rise to unacceptable impacts that drives decisionmaking under the precautionary principle.

VI. CONCLUSIONS

This paper examines a stylized model of the interactions between climatic systems and the world economy. It finds that climate change policy choices are dramatically sensitive to the normative criteria employed to balance the interests of present and future generations in framing long-run social decisions. Economic efficiency, as operationalized through cost-benefit analysis, supports relatively modest steps to abate carbon dioxide emissions given central predictions of the rate of climate change and its environmental impacts. Classical utilitarianism, in contrast, defines optimal emissions-control rates that rise from 51 percent in the year 2000 to 76 percent in the long-run future. The paper reviews the substantive arguments for and against both cost-benefit analysis and classical utilitarianism, concluding that neither approach is fully effective in resolving the moral dilemmas implicit in long-run policy choices.

The paper also explores the conceptual foundations of the precautionary principle, linking this policy criterion to the problem of scientific uncertainty and concepts of procedural fairness as they arise in moral philosophy and institutional economics. Since existing studies have focused on the economic consequences of a doubling of atmospheric greenhouse gas concentrations relative to the preindustrial norm, it is reasonable to conclude that the implications of pushing climatic systems beyond this point cannot be reliably assessed. The paper argues that a doubling of greenhouse gas concentrations may be imposed as an upper limit that safeguards future generations against the unknown, but potentially catastrophic, consequences of global environmental change. Subject to this constraint, maximizing the present-value net benefits of carbon dioxide emissions abatement gives rise to optimal control rates that rise from 31 percent to 85 percent between the years 2000 and 2105.

Any modeling exercise is both shaped and constrained by its assumptions, and the analysis presented here is no exception. Perhaps the greatest shortcoming of the model described in this paper is its high degree of regional aggregation. This approach streamlines the problems of model building and interpretation, but calls attention away from a critical aspect of the climate change policy debate: the unequal distribution of burdens and benefits between industrialized and developing nations, and especially the prospect that the lifestyles and technologies of today's high-income societies may endanger the lives and livelihoods of future peasant farmers whose day-to-day activities are strongly constrained by the vicissitudes of nature.

Finally, it is important to note that certain elements of the model, which is based on the influential work of Nordhaus (1994), have been called into question by the recent literature. Nordhaus, for example, assumes that greenhouse gas emissions abatement is an inherently costly enterprise. The IPCC (1996a), in contrast, finds that net emissions-abatement rates of 10 percent to 30 percent might be achieved at negative or zero cost. Similarly, Schultz and Kasting (1996) argue that Nordhaus's analysis substantially overstates the long-term ability of the earth's oceans to remove carbon dioxide from the atmosphere. Altering the model to address either of these perceived weaknesses would result in increased rates of greenhouse gas emissions abatement. Finally, Nordhaus assumes that carbon dioxide emissions are proportional to gross world output and are not constrained by the geological availability of carboniferous fuels. This approach, while it simplifies the construction and description of the model, reduces the model's realism in the analysis of long-run policy choices.

While each of these issues calls for the need for further research, none diminishes the essential findings of this analysis: (1) Climate change policy decisions are strongly contingent on the normative criteria used to mediate the conflicting preferences of present and future generations; and (2) standard models can generate high rates of greenhouse gas emissions abatement under suitably defined policy criteria. Because Nordhaus's study is perhaps the most widely cited and influential work on the economics of climate change, it is useful to employ the study's empirical generalizations when comparing alternative frameworks for social choice.

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