

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY

WASHINGTON, D.C. 20502

September 16, 1997

MEMORANDUM FOR

TODD STERN
KATIE McGINTY
GENE SPERLING
DAN TARULLO

FROM: ROSINA M. BIERBAUM

RE: FYI

cc: TJ Glauthier
Peter Orszag
David Sandalow
Janet Yellen

Attached, please find a memo I received from the Staff
Director of the joint NAS/NAE/IOM report, "Policy Implications of
Greenhouse Warming..."

Note: potential for a 25% reduction of US greenhouse gases at
less than \$10/T.

Call me at 6-6077, if you have any questions.

- ① Rosina in oversight
mtg.
- ② Get Cecil → call (Lobov)
- ③ DSTP booklet
- ④ IGA - Daniel Locke

Research

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8 October, 1996

MEMORANDUM

Via Fax: 202-456-6025
Two Pages Total

To: Rosina Bierbaum, OSTP
From: Rob Coppock, Deputy Director **RL**
Subject: Greenhouse gas emissions reduction potential

The NAS report "Policy Implications of Greenhouse Warming: Mitigation, Adaptation and the Science Base" states on p. 493:

"[A review of Figures 29.2 to 29.5 indicates that] it would not be unreasonable to expect that a roughly 25 percent reduction in U.S. greenhouse gas emissions (i.e., 2 Gt CO₂ equivalent) might be achieved at a cost of less than \$10/t CO₂ equivalent. This is, in more commonly used terms, roughly an additional \$22 per short ton of coal, \$4.75 per barrel of oil, \$0.60 per million cubic feet of natural gas, \$0.11 per gallon of gasoline, or 0.7 cents /kWh for the current U.S. electricity mix.."

These costs were estimated using available technologies in a variety of sectors (residential and commercial energy management, industrial energy management, transportation, electricity and fuel supply, and nonenergy emissions reductions).

The Nation

May 1, 1995

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LENGTH: 2590 words

HEADLINE: The True State of the Planet.book reviews

BYLINE: Athanasiou, Tom

BODY:

Edited by Ronald Bailey. Free Press. 4 72 pp. Paper \$ 15.

The green movement leads a double life. On the surface, romantic idylls and semi-scientific reductionism decorate a history that runs far back into the traditions of liberal optimism. Beneath there flows a second and more somber tradition in which radicalism, sought in appeals to biology and nature, too often substitutes for clear-eyed political explorations.

Greens know this well enough, though they generally take it as a family secret, one that is rarely discussed in public. Here, then, is a wake-up call in the guise of a literary trend. Attacks on environmental romanticism and on social-ecological pessimism in general have become weapons of anti-environmental backlash, as liberal and libertarian pundits--and some of the more aggressive corporate P.R. departments--attack environmentalism by pretending that in its most fundamentalist corners they have found its truest secrets.

The founder of this genre was, I think, Anna Bramwell, whose 1989 *Ecology in the Twentieth Century* is an irritating but not unhelpful dark-side history of green romanticism. More recently came Martin Lewis, with his 1992 *Green Delusions: An Environmentalist Critique of Radical Environmentalism*. Lewis made much of the rather wacko claim that radical green ideas have "devastating implications for the global ecosystem" because they lead to "self-defeating political strategies," thus "preventing society from making the reforms it so desperately needs." This was not the standard anti-green position, for it did not altogether deny ecological problems, but its main focus was on ridiculing the "radicals."

Today distinct brands of anti-environmentalism line the shelves, and the more insidious come costumed as attempts by reasonable men and women to reject the "extremes" and "pessimism" of the past and search for a new and "better" environmentalism. The answer, typically, is "science" and "realism." This is

particularly clear in economic debates, in which the "science" most loved by anti-greens is often not the same science most widely accepted by the scientific community. This raises no end of fine questions about method and meaning, but it does not disturb the believers. Money cannot, perhaps, buy love, but it certainly buys confidence.

Here, as Exhibit A, is *The True State of the Planet*, a compendium of anti-environmental antiscience just published by the Free Press in partnership with the Competitive Enterprise Institute, a right-libertarian think tank whose specialty is attacking greens. To that end, **editor Ron Bailey, former writer at Forbes, contributing editor of Reason and proud author of *Eco-Scam: The False Prophets of Ecological Apocalypse*, has collected the strongest anti-environmental narratives he could find.** Some, like Bruce Ames's argument that the vast bulk of all chemical carcinogens are either natural pesticides (like spices) or (like high-fat foods) taken electively, will be all too familiar to connoisseurs of greenwashing. Some, like Robert Balling's claims that global warming is only a doomster myth, are well known and dismissed as ideology by the majority of climatological scientists. Others, like Dennis Avery's "Saving the Planet with Pesticides," are 1990s rehashes of old technology-uber-alles fairy tales, in this case the tale of the Green Revolution's boundless capacity to increase grain supplies. Taken together, packaged with Cato Institute optimism and padded out with a bit of vague, seemingly liberal filler, they form a sort of attack syllabus for the long-suffering friends of "progress."

The True State opens with "Population, Food, and Income," by Nicholas Eberstadt. It's a strong lead, for it plays upon the oldest stupidity of green reductionism--the confusion of the biologic notion of "overpopulation" with the political problems of poverty and sustainable food production. If ever there was a measure of the green movement's confusion, it is that so many environmentalists honestly believe that by soberly intoning that there are just "too many people" they somehow cut across all the moral and political agonies of globalization, of rising human migrations, mass extinctions, atmospheric instability and all the rest of it. In fact, "overpopulation" explains none of these things, and as long as we cling to it we remain the confused citizens of an incomprehensible world. This is where Eberstadt comes in, for with rigorous disregard for the realities of global poverty, he sounds the collection's theme: Even for the world's poorest people life is rapidly improving, and if only markets are left alone to work their magic it will inevitably continue to do so. Such optimism is, of course, anything but new. The core of neoliberal dogma is that growth will bring prosperity to all; Julian Simon, an economist of limitless faith (see *The Ultimate Resource*), long ago found fame by wielding it against Paul Ehrlich.

Simon is the spiritual godfather of *The True State*, and his voice echoes in

its relentless technological confidence. The forests are in no real danger--in fact, ecosystems are incredibly resilient and even monocultural tree plantations, far from endangering biodiversity, actually protect wilderness by satisfying the demand for wood. High-tech, high-yield agriculture will feed us all, and produce enough meat to provide even the world's poor with the "better" protein they deserve, and at the same time it will actually reduce the amount of land that must be granted to agriculture. In fact, by a marvelous irony of the invisible hand, it is just now, with ecological pessimism high, that we are approaching the "age of abundance." There is no "population" crisis, and even the oceans, which really are in trouble, can be saved. We need only privatize them!

Lies are not always simple things. The True Staters insist that "overpopulation" is not an essential problem, and though the conclusions they then draw are unjustified, the claim itself is quite correct. Around the world, human fertility is dropping rapidly, and today's projections of the likely peak human population are far lower than those made even ten years ago. That's the good news. The bad is that the fertility decline in poor lands has been caused by what one team of demographers called "the sharp economic contraction of the late 1970s and early 1980s," and by the widespread realization by people throughout the Third World that with more children, "their standard of living fell." This is not how it was supposed to be. The most widely accepted theory of demographic transition had it that "development" would bring security and even affluence, and thus, painlessly, smaller families. Instead, insecurity, urbanization, birth control and the cosmopolitanism of a small world in which people have a clear sense of their bad prospects have stepped in to do the job.

Right-wing optimism about declining human fertility cannot last. Too bad, then, that greens, well-schooled in reducing explosive political issues to biological abstraction, only continue to mumble Malthusian pieties, and too bad that the right has become so adept in manipulating the resulting confusion and in constructing a strategic caricature that seeks to tar the environmental movement as a whole with its fundamentalist excesses. Too bad greens are so rarely able to refute the Big Lie that tells us that, given only time and free markets, the poor will follow the rich into the kingdom of development.

A Moment on the Earth weighs in at 745 pages and claims the last word on everything from global warming (no problem) to petrochemicals (no problem) to nuclear power (no problem) to deforestation (no problem) to biotechnology (no problem) to extinction (no problem) to God (see page 138).

Moment is the creation of Gregg Easterbrook, a clever journalist with an ax to grind and a finger to the winds. Easterbrook's approach is essentially the same as that of The True State--to paint environmentalism as a quasi-religious

movement full of "transrational" souls who cannot tolerate good news. But unlike Bailey and company, Easterbrook would be a liberal, an "ecorealist," an avatar of the "coming age of environmental optimism." He claims the center by blithely dismissing the Wise Use movement--that bastard child of right-wing populism and corporate public relations--as a "minor fad" (which it is not) and pointing out that the right has done more exaggerating--"communists running the State Department, fluoride in the water, nuclear weakness"--than the left. His strategy, in a nutshell, is to speak for "logic" and "rationalism," to demolish easy targets (he finds plenty and makes up more), to overlook the (copious and often excellent) objections to his arguments and, of course, to position himself against green romanticism as the voice of the "new" environmentalism. His very marketable conclusion is that heavy-metal development-as-usual, with some minor green model changes, is the true path of progress and justice.

Easterbrook has long patrolled the environmental perimeter for Newsweek and The Atlantic, but it is a piece that appeared in The New York Times Magazine on September 11 of last year that perhaps best illustrates his strategy. "Forget PCB's. Radon. Alar. The world's greatest environmental dangers are dung smoke and dirty water" could almost take the Oscar in green-tinted casuistry. The foreground here is the environmental problems that plague the world's poorest people, and thus we are primed--all we good people--for sympathy. But observe where Easterbrook steers us. First comes the introduction, and then the setup: A large faction within the environmental movement "focuses on the real but comparatively minor problems of developed nations in part to support a worldview that Western material production is the root of ecological malevolence." After that we are given a quote from water scientist Deborah Moore ("Issues like African sewage are not sexy, so they always fall to the bottom of the agenda") and a twisted retrospective on the 1992 Earth Summit--"the prospect of global warming . . . was put above the palpable, urgent loss of lives from Third World water and smoke pollution"--as if Rio's failure to address poverty could be chalked up to "Western guilt-tripping and America-bashing." From there, the knockout is easy: "What developing-world nations need to free their populations from extreme air pollution is . . . hydroelectric dams, modern petroleum refining, advanced high-efficiency power plants."

Deborah Moore, for one, was not convinced. An activist in the global campaign to redefine development and stop large dams, she told me that Easterbrook had deliberately "manipulated" concern for poverty and wretched Third World conditions into support for a development model that routinely devastates the lives of the poorest and most vulnerable people--just the opposite of what he claimed to be doing. Indeed, a few months later, Hydro Review, a trade journal that carries the burden of making big dams appear modern and humanistic (in fact they are as socially and ecologically destructive as nuclear power, and as uneconomic and corruption-friendly), ran a paean to

Easterbrook that commended his lucidity, eagerly quoted his attacks on solar power ("How come if small solar is too expensive for the Sierra Club set, it's a great idea for peasants in Malawi?") and recommended mass purchases of *Moment*, "not just to read, but for friends as well."

In his book, Easterbrook is more careful. Solar power would be welcome, if the price was right, and unlikely though it is, global warming could be a threat. It doesn't matter. Carbon emissions will be brought under control, since liberal ecorealists will find ways to transfer clean technologies to the Third World and, in fact, will soon be boasting of "having saved capitalism from itself by curbing environmentally destructive aspects of the market system and compelling corporations to become resource-efficient." If, in the meantime, utility industry front groups are running ads in magazines as liberal as *Harper's* (see the April issue) counseling us to oppose the "radical environmental agenda" and "Repeal Rio" (the greenhouse treaty), and if these ads make exactly the same argument as does *Moment*, what can this be but an odd coincidence?

Readers who slog through *The True State* and *Moment* should try to find time as well for the real thing--the 1995 edition of the Worldwatch Institute's *State of the World*. This is an annual that serious students of environmental politics not only buy but actually read. Worldwatch is one of the most cited research organizations in the world, and *State of the World*, its flagship publication, is each year translated into twenty-seven languages. The 1995 edition, as always, is a judicious mixture of the grim and the upbeat. This year, on the grim side, we have the crisis in world fisheries, pressures on mountain peoples and environments, human migration, rising ecological strains in China and that most vexed of subjects, "nature's limits." On the upbeat side, there are the ongoing revolutions in solar and wind technology that will, any year now, become impossible to ignore, the prospect for a "sustainable materials economy" and, on an overtly political line, "Budgeting for Disarmament" and "Forging a New Global Partnership."

State of the World is not Malthusian or Pollyanna-ish, but somehow, peculiarly, both and neither. When Lester Brown, Worldwatch's president, offers a dark analysis of trends in global rice production and consumption, he does not omit the new bioengineered varieties now being developed at the International Rice Research Institute in the Philippines. He just gives the numbers, which don't look particularly good, and reiterates the pressures--from aquifer depletion to the boom in Chinese demand for pork and beer--that make predictions of grain-market strain so plausible. A far cry from *The True State's* wild optimism about yield increases which altogether ignores the many and serious problems that come with new hybrids. These range from herbicide dependence and soil compaction to what UNICEF once called the "paradox of

plenty"--increases in food productivity, when won by methods of industrial agriculture that promote land monopoly (and they commonly do), often increase hunger as well.

As will be obvious to any fair reader, *State of the World: 1995* is a careful text, full of considered detail. Far from an organ of doomster culture, it is a model of discretion and scientific balance. *Worldwatch* has its pragmatists and its Big Thinkers, its hard-nosed researchers and its closet apocalyptics. Its politics do not altogether suit my temper, but I gladly admit that its culture allows a rigorous, descriptive pessimism to coexist with conventional technical and political optimism. Indeed, it seems that it is just this balance that most infuriates the right. If even mainstream outfits like *Worldwatch* are finding positions in which (1) scientific details are taken seriously and (2) there is nevertheless room to legitimately and publicly doubt if small changes will finally be sufficient, then the green movement may, after all, be incubating a new and radical form of realism. And without such a realism, clearly, there can be no hope of emancipation.

Tom Athanasiou lives in San Francisco. His book *Divided Planet: The Ecology of Rich and Poor* is forthcoming from Little, Brown.

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HEADLINE: Green Hell

BYLINE: by Dan Cordtz

HIGHLIGHT:

Foes of environmental rules are starting to fight back, and they're winning a few skirmishes.

BODY:

AFTER YEARS OF CAVING IN TO the seemingly irresistible power of the environmental movement, a growing number of U.S. firms, workers, local governments and ordinary citizens are starting to strike back. They're attacking rules they say cost far too much (the government admits \$ 130 billion a year in direct costs, and private estimates go 50% higher), infringe on their rights, are inequitable, often aren't even needed, and usually don't work.

Stung by this unexpected challenge, environmental activists are sounding the alarm. Greenpeace, the Washington, D.C.-based group best known for its highly publicized efforts to halt whaling and nuclear tests in the South Pacific, recently published *The Greenpeace Guide to Anti-Environmental Organizations*, a 110-page book warning that "anti-environmental groups have declared war on every issue environmentalists support." The book includes capsule descriptions of 54 groups that it considers "anti-environmentalist" -- from think tanks and public relations firms to what it labels "corporate-front groups." Declares author Carl Deal: "Most anti-environmentalists are heavily financed by industry."

Greenpeace may be protesting too much. Tim Brown, environmental policy analyst for the libertarian Cato Institute (which is on the list), surveyed the budgets of the organizations singled out and found that "in 1992, Greenpeace alone outspent all 54 groups listed in its guide combined, \$ 65 million to roughly \$ 62 million." The top 12 environmental organizations, he adds, spent more than \$ 636 million -- 10 times the amount available to their critics. So much for "heavy financing" from industry, he says.

While a handful of names on the Greenpeace enemies list are reasonably well

known (Cato, the Heritage Foundation, Accuracy in Media, Keep America Beautiful), the rest are much smaller, less well-known groups like the National Inholders Association, the Center for the Defense of Free Enterprise, the Global Climate Coalition and the Science and Environmental Policy Project.

The Greenpeace Guide, simply by putting all those names together in a list, gives a misleading impression that the backlash is a coordinated movement with universally shared goals. In fact, it consists of a variety of groups whose interests don't necessarily overlap.

The most vocal are defenders of property rights, including leases and permits to mine, cut timber or graze cattle on federal land. They constitute what most of them refer to as the "wise use [of land] movement" and are concentrated in Alaska and the western states. "Our concerns are not much related to those of business," says Myron Ebell, Washington, D.C., representative of the National Inholders Association (an inholder is an owner of property located inside or adjacent to a national park or other protected area, although such owners now constitute only 20% of the association's membership). "We're not involved with most of the issues that business is worried about -- toxic emissions, hazardous waste, water pollution and the like. What we're very much concerned with are things like wetlands, endangered species and grazing rights." On the other hand, observes David Howard, who founded the Alliance for America, "We do have one important thing in common with business: We're all being crushed by regulations that simply don't make sense."

Because their own direct personal interests are so clearly at stake, the individual participants in the "wise use" movement are passionately committed to their cause. "It's the Sagebrush Rebellion, round two," Ebell declares, "and it's going to make the original Sagebrush Rebellion look tame." Predicts Howard: "The hinterlands will rise up -- not in real violence but in a political revolt."

These groups and their allies can already take credit for the backlash forces' victory in two recent skirmishes. A Senate filibuster prevented passage of legislation to boost grazing fees on federal land controlled by the Interior Department. In the House, amendments to the National Biological Survey bill would require written permission from landowners before government officials can enter their property to count wildlife and would also forbid the use of volunteer enumerators, most of whom would come from environmental groups. Faced with the amendments, the Administration withdrew the bill.

Notwithstanding such gains, nobody in the backlash ranks is predicting a quick victory. Fred L. Smith Jr., president of the Competitive Enterprise Institute, a Washington, D.C., think tank that supports many of the backlash groups, says with a chuckle, "We're a bit like the French underground in 1941."

Our efforts are good, but the other side has the tanks." Not only the tanks, but the planes, ships and nuclear weapons. Robert Hahn, resident scholar at the American Enterprise Institute and a former official at the U.S. Environmental Protection Agency, says that environmental activists have captured the Clinton White House. "This Administration will be the greenest ever," he declares gloomily.

Vice President Al Gore, who has been a leading environmental activist for years, will spearhead efforts to break new ground in a number of regulatory areas. Other committed environmentalists have been appointed to jobs throughout the Administration. The most recent example: Jack Ward Thomas, the Oregon biologist who advised President Clinton to limit logging in the Northwest to protect the spotted owl, will be head of the Forest Service.

Adds Hahn: "The reason little has been done on the environment so far is that they've had so many other things to do. Clinton will take a tough line eventually on a whole series of laws coming up for renewal: clean water, endangered species, the Superfund, global warming. The outlook for this Administration and Congress seriously balancing the needs of the environment with the cost-effectiveness of regulations is bleak."

To others on the backlash side, however, that may mean opportunity. The environmental movement has enjoyed so many years of success, the contend, that it is often inclined to overreach itself. And each tightening of the regulatory screws that pinches another group generates new opposition. With Congress scheduled to deal with a long list of environmental issues in the coming year, some big fights are shaping up. Jonathan Adler, an environmental policy analyst at the Competitive Enterprise Institute, asserts that "the environmentalists are more threatened than they've ever been. They know that if they're not careful they could put themselves in a position to lose some of those battles."

People like Smith who espouse what they call "free market environmentalism," insist that the current system is doomed to fail. "Everyone had great dreams for the Environmental Protection Agency," he says, "but the environmental movement is based on the notion that markets are incapable of dealing with environmental concerns, so you have to have political oversight. And since every economic area has some environmental impact, you're left with the EPA trying to run the whole world. Ecologically, central planning is no more likely to work than it did in the socialist economies."

Environmentalists frequently cite polls showing that three out of four Americans consider the environment very important and say that they are willing to pay to protect it -- whether through taxes or higher prices for goods. But skeptics doubt the depth of that support. "They'd feel different if someone actually presented a bill," one remarks. Certainly there is almost no popular

support for the extreme views of environmental radicals who want to limit technology and deliberately lower material living standards for the sake of conserving natural resources.

Confident that many ordinary citizens are simply uninformed, backlash participants are fighting on three main fronts. First, they seek to demonstrate that some of the risks and perils that environmentalists claim we face are exaggerated or even nonexistent. Second, where real problems are acknowledged, backlashers demand that the cost of solving those problems be balanced against the benefits. Finally, many argue that whatever needs to be done, the government is not the only, or even the best, institution to deal with environmental threats.

To make their case, these critics are trying to use one of the environmental movement's own most successful tactics: using publicity to alter the climate of popular opinion. For example, several skeptical writers have begun casting doubt on much of the evidence that environmentalists cite to make the case for regulation. Such an approach is entirely appropriate, since it was Rachel Carson's *Silent Spring* that spawned the environmental movement three decades ago. Since then, a flood of similar volumes have been published (Vice President Gore's *Save the Earth* made the best-seller lists in 1992).

Until this year, almost nothing was published to challenge these predictions of impending disaster. **But recently, several authors have weighed in with such books as *Eco-Scam: The False Prophets of Ecological Apocalypse*, *Science Under Siege* and *Apocalypse Not: Science, Economics and Environmentalism*.** The writers examine, in exhaustive detail, claims that Americans were endangered by dioxin or other pesticides, by computer screen emissions, by acid rain, or ozone depletion, or global warming. In each case, they cite later findings by qualified scientists that the threats were unproven -- and that the public and politicians were panicked into taking unnecessary action. Another recent volume, *Environmental Politics: Public Costs, Private Rewards*, recounts the way in which farm organizations, waste treatment firms and other private interest groups teamed up with environmentalists to push through rules that earned big profits for a number of companies.

Books like these are not widely read, of course, but a few journalists have also begun to examine scary statistics more carefully and to seek the views of scientists rather than simply reporting the claims of activists. The New York Times, for example, recently ran a lengthy story by environmental reporter Keith Schneider that cast doubt on the dangers of contracting cancer from the chemical dioxin. It was dioxin that caused the panics at Love Canal in Niagara, N.Y., and Times Beach, Mo., and led to passage of the multi-billion-dollar Superfund program to clean up hazardous waste dumps across the country. And Boyce

Rensberger of the Washington Post has written skeptically about global warming and holes in the ozone layer. Not surprisingly, both men have been fiercely attacked by environmentalists as biased and inaccurate.

But what gives the backlash forces the most hope for the future is the way environmental regulations are starting to have a palpable impact on Americans' everyday lives. For example, over the next few years, employees of large companies in regions with heavy air pollution will come under severe pressure to give up driving their cars to work. In fact, employers will have to compel at least 20% of their workers to take public transportation or join car pools. In the Philadelphia area, 300,000 people will be affected, and local officials insist it's unnecessary. The air quality reading which put Philadelphia over the limit, they say, was a fluke. But the EPA ruled otherwise.

An even more striking example of regulatory overkill is the New York City school asbestos scandal. After an audit last summer showed that many inspections of asbestos in schools had been inaccurate, local officials launched a huge inspection and repair program to eliminate this supposed threat to the city's school children. Standards were so stringent that much of the repair work had to be redone.

By the time school was scheduled to start, it was 11 days before any classes were held, infuriating thousands of parents. The cost of the cleanup, originally estimated at \$ 34 million, is a staggering \$ 120 million and rising. That's a catastrophe in a system whose annual maintenance budget is \$ 70 million. As a result of the skyrocketing repair bill, New York City will have to forego a number of badly needed renovation and construction projects.

Worst of all, the evidence is overwhelming that such a crash program was an ill-advised, perhaps counterproductive overreaction. Two years ago, after an exhaustive review of existing research on asbestos hazards, an independent panel of 19 scientists concluded (with only two dissents) that undamaged asbestos in buildings poses no more health risk to occupants than if they were outdoors. A report by a panel of doctors convened by the American Medical Association came to similar conclusions. Even William Reilly, when he was administrator of the Environmental Protection Agency, said that removing asbestos from buildings can well be more dangerous than "managing it in place."

There is no question that some forms of asbestos are extremely dangerous carcinogens, and the tragic toll of illness and death among World War II shipyard workers is beyond dispute. But the form of asbestos fiber used in 95% of building construction materials (chrysotile) has not been linked conclusively to mesothelioma or lung cancer. Still, that fact has not prevented panics like the one over asbestos in the New York City school system -- and it

has not kept tens of thousands of plaintiffs from creating what one observer calls "the mother of all messes in our legal system."

Because of cases like these, says Hahn of the AEI, "people are now speaking out more strongly on the fact that we have passed the point of diminishing returns on regulations to improve air and water quality, protect species and clean up toxic waste sites -- all these rules that are crazy from the point of view of social costs and benefits." Adds the CEI's Smith: "The public is beginning to perceive connections. When homes burn down in California because their owners couldn't clear out the chaparral where the kangaroo rat lives, people see that's senseless. It's the kind of thing that's generating the backlash."

Clearly these people remain a minority, and most have not false optimism about how long it will take to make an impact on the public. Ron Bailey, author of Eco-Scam, observes, "The environmentalists have had more than 20 years to sell their views. And clearly some regulations have been useful, which adds to their credibility. It's going to take a while to counter them."

But the movement to do so has definitely gotten under way.

GRAPHIC: Photo 1, no caption, E. Schuh/Contrast/Gamma-Liaison; Photo 2, no caption, Michael Schumann/Saba; Photo 3, no caption, Eugene Richards/Magnum; Photo 4, no caption, Sygma

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BYLINE: Jo Kwong

BODY:

American attitudes toward the environment have matured. Gone are the days when industries felt free to treat rivers and streams as a common dumping ground. Gone are the days of pouring used motor oil on suburban lawns to kill unwanted weeds. Gone are the days when households discarded recyclables without a thought.

This heightened awareness has produced many benefits: The air, water and land are in noticeably better shape than they were 20 years ago. But perhaps the time has come to take environmental awareness to yet a new level and recognize that things have improved and our environmental outlook is really quite good.

That's the theme of "The True State of the Planet," a collection of essays edited by Ron Bailey. After two decades of hearing how we teeter on the brink of environmental disaster, the book's message may seem counterintuitive. Yet its common sense and wealth of scientific evidence make for a compelling argument.

Take global warming. We have all heard that global temperatures have been rising and will continue to rise another 2 to 8 degrees centigrade over the next 50 years. But what do climatologists and atmospheric scientists say? According to contributing author Robert Balling, director of the office of climatology at Arizona State University, the scientific evidence argues against the existence of a greenhouse crisis. Highly accurate satellite-based atmospheric temperature measurements reveal that the earth's atmosphere has actually cooled by 0.13 degrees centigrade since 1979.

Mr. Balling examines the climate models that have formed the basis for catastrophic predictions and refutes them on several counts. He notes, for example, their failure to accurately simulate observed climate changes during the past century and their failure to factor in the role of sea ice, snow caps, localized storms and clouds. His conclusion is that the models are simply not advanced enough to use as the basis for public policy. Ignoring arguments like Mr. Balling's can lead us down a path of reckless spending for very little benefit.

Here Mr. Balling touches upon one of several themes Mr. Bailey outlines in his prologue: the necessity of trade-offs in sound environmental policy. As he writes, "Modern smart environmentalism must avoid the 'crisis of the month' media mentality. ... It must focus on setting priorities and dealing with the biggest problems first. ... Trade-offs have to be made."

The essays in this collection argue that wealth, technology and the human being are not all bad for the environment. The idea that economic growth is a major contributor to environmental problems actually inhibits our ability to improve the environment and the human condition at the same time.

As societies become wealthier, spending increases for environmental improvement. Increasing wealth allows the luxury of caring about potential environmental threats. Poorer countries are too concerned with such pressing concerns as starvation and exposure to worry about mysterious and invisible threats like global warming or other environmental concerns. And often ignored is the fact that technological innovation and adaptation are precisely the vehicles that fuel much of the world's wealth gains.

In forging a "new, smarter environmentalism," "The True State of the Planet" offers several hundred pages of scientific findings, data and hard evidence.

Beyond global warming, the essays stand the culture of environmentalism on end. Nicholas Eberstadt describes how the world's population has tripled this century, yet the average person eats better and produces more. As for areas of the world where population pressures have led to environmental disasters and famine, Mr. Eberstadt shows how governmental policies, such as collectivization, are to blame for the century's great famines, rather than "overpopulation."

Other essays devoted to analyses of food, forest and ocean resources, biodiversity, pesticide use, air quality and environmental cancer all consider the trade-offs that sensible policy choices entail.

Beyond trade-offs, each contributor shows how innovation and technology have

helped alleviate pressure on resources. Wealth and technology, rather than being the culprit in environmental degradation, can help improve our physical world. The only thing that stands in our way are erroneous perceptions about finite resources and statist "solutions." "The True State of the Planet" is a great start for a smarter, more aware, environmental reasoning.

Jo Kwong is an environmental research associate with the Atlas Economic Research Foundation in Fairfax.

***** THE TRUE STATE OF THE PLANET

Edited by Ronald Bailey

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20 October 1997

MEMORANDUM FOR GENE SPERLING
 KATIE MCGINTY
 JANET YELLEN
 TODD STERN
 DAVID SANDALOW
 PETER ORSZAG
 JEFF FRANKEL

FROM: ROSINA M. BIERBAUM

RE: HEADS UP ON CO2 EMISSIONS STUDIES

Attached, please find 2 studies that will be released sometime this week.

- 1) The Battelle study (see p. 10) says costs of stabilizing US emissions at 1990 level by 2010 range from \$26/ton carbon to \$108/ton carbon -- depending on trading.
- 2) The WWF study puts emissions at 20% below 1990 levels by 2010 "with net economic benefits."

**Return to 1990:
The Cost of Mitigating United States
Carbon Emissions in the Post-2000 Period**

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CN MacCracken
RD Sands
MA Wise

October 1997

Prepared for
U.S. Department of Energy
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Pacific Northwest National Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

 **Battelle**

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Return to 1990
The Cost of Mitigating United States Carbon Emissions in the Post-2000 Period

James A. Edmonds
Son H. Kim
Christopher N. MacCracken
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More than 160 nations have signed the Framework Convention on Climate Change (FCCC). That agreement required Annex I nations, the developed nations of the world plus economies of the Former Soviet Union and Eastern Europe,¹ to undertake measures to return emissions to 1990 levels or below in the year 2000. The parties to the FCCC met in Berlin in the Spring of 1995 and determined that additional measures were required to implement the ultimate objective of the FCCC, *"to stabilize the concentration of greenhouse gases in the atmosphere at a level which would prevent dangerous anthropogenic interference with the climate system."*

Subsequent to the Berlin discussions, nations of the world have begun to consider measures that would set quantifiable emissions limitation requirements in the post-2000 period for Annex I nations.² A variety of measures have been considered. The purpose of this paper is to explore the economic consequences of efficient policy instruments—carbon taxes or tradable emissions permits—which might be employed to achieve a variety of targets in the post-2000 time frame.

We begin by describing our general approach and the variety of policy runs to be considered. We then review some of the necessary assumptions for this exercise, as well as the structure and calibration of the Second Generation Model (SGM). Finally, we discuss the results of our analysis, including time paths of emissions and measures of cost.

¹ Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Czechoslovakia, Denmark, European Economic Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, and the United States.

² In the United States, efforts were undertaken by the Interagency Analytical Team, and results were summarized in United States Government (1997). The Second Generation Modeling team was one of three modeling teams which participated in the evaluation of potential emission mitigation measures under discussion.

EMISSIONS MITIGATION SCENARIOS

Four scenarios were constructed that reduce carbon emissions in Annex I countries by 2010. The SGM was used to simulate the impact of these scenarios on the United States economy. In each scenario, emissions are reduced linearly from 2000 to the emissions target in 2010. Since the SGM operates with five-year time steps, emissions in the year 2000 are at reference case levels, and emissions targets in 2005 are half-way between year 2000 emissions and the target emissions level required in year 2010. Figure 1 shows United States emissions paths for the four scenarios as well as reference emissions.

- | | |
|-----------|---|
| M1990 | Emissions from Annex I regions must be no greater than 1990 emissions levels beginning in the year 2010. |
| M1990+10% | Emissions from Annex I regions must be no greater than 10% above 1990 emissions levels, beginning in the year 2010. |
| M1990-10% | Emissions from Annex I regions must be no greater than 10% below 1990 emissions levels, beginning in the year 2010. |
| M1995 | Emissions from Annex I regions must be no greater than 1995 emissions levels beginning in the year 2010. |

[Figure 1. Carbon Emissions Scenarios for the United States]

These mitigation policies were run under three emissions trading regimes: independent emissions mitigation, Annex I joint mitigation, and Annex I mitigation with global permit trading. In the independent emissions mitigation case, each Annex I region must individually reach the stated emissions target without any trading of permits across regions. The Annex I joint mitigation case allows Annex I regions to trade permits amongst themselves so long as the total constraint is met in each time period. The global permit trading case allows permit trading across all regions, including those not in Annex I. The Annex I joint mitigation and global permit trading regimes result in a single Annex I or global permit price common to all regions in the market for carbon permits.

In none of the above scenarios and trading combinations are non-Annex I regions forced to constrain their emissions. No mitigation targets or emissions trajectories are imposed on those regions. Under the global permit trading regime, non-Annex I regions participate in the market for carbon permits only when it is to their economic benefit to do so. These regions are allocated permits equal to their projected baseline emissions, so they are only required to reduce their emissions by an amount equal to the number of permits they wish to sell.

Eastern Europe and Former Soviet Union Permit Allocations

Eastern Europe and the Former Soviet Union (EEFSU) present a special case because carbon emissions are currently below the benchmark year of 1990. Two approaches to permit allocations for EEFSU regions have been discussed in recent months. The first allocates permits based on the stated policy scenario (e.g., M1990 allocates permits based on 1990 emissions level) so that permits are allocated to EEFSU in the same way as they are to other Annex I regions. Because of

the decline in emissions in those regions from 1990 to 1995, however, this approach results in 'paper credits' equal to the difference between the lower post-1990 emissions and the policy-level (i.e., 1990) emissions being granted to EEFSU. For example, the FSU's baseline emissions level in 2010 is 836 TgC, significantly lower than its 1990 emissions of 1050 TgC. If granted permits equal to its 1990 emissions, the FSU would have 214 TgC worth of permits more in 2010 than its projected emissions, giving the region 214 TgC worth of permits to sell without incurring any emissions reductions of its own.

The second approach to allocating permits to EEFSU is to grant permits equal to reference emissions in each period until the projected path is constrained by the policy. For example, in the M1990-10% case, the FSU would be granted permits equal to its projected baseline emissions because emissions in the policy years never recover to 1990 levels.

For the purpose of this exercise, we chose to use the latter approach in allocating emissions to Eastern Europe and the Former Soviet Union. This baseline allocation scheme ensures that the stated Annex I emissions targets are achieved in both the independent mitigation and permit trading scenarios.

APPROACH

The SGM is a computable general equilibrium economic model that projects economic activity, energy consumption, and carbon emissions for twelve world regions, including the United States. The twelve SGM regions listed in Table 1 provide the necessary global coverage to simulate a system of global carbon permit trading. We also simulate a carbon permit trading system among the Annex I countries only, which are represented by seven of the twelve SGM regions. Our strategy has been to continually expand the number of regions by breaking them out of the Rest of World region. The Rest of World includes Latin America, Africa, and other Asian countries.

Table 1. Regions in the SGM

Annex I	Non-Annex I
United States	China
Canada	India
Western Europe	Mexico
Japan	South Korea
Australia	Rest of World
Former Soviet Union	
Eastern Europe	

While carbon emissions in most regions are anticipated to increase over time, this is not true for the Eastern Europe and Former Soviet Union Regions. Emissions in these regions have declined since 1990.

Each of the four emissions mitigation scenarios defines a set of emissions rights for the Annex I regions. Carbon taxes are used to constrain emissions for the cases of independent emissions mitigation, Annex I joint mitigation, and Annex I mitigation with global trading of emissions rights.

In the independent case, each Annex I region meets its own emissions targets independently. A time series of carbon taxes is determined for each region to reduce emissions to be equal to its emissions rights.

With Annex I joint mitigation, a common carbon tax is applied to all Annex I regions to meet the overall Annex I emissions target. However, regions that emit more carbon than their emissions rights must pay the other Annex I regions an amount equal to the difference in emissions valued at the common carbon tax.

In the global trading case, emissions are reduced from the global reference case by the same amount as the difference between Annex I reference emissions and Annex I emissions rights. The SGM is used to determine a global carbon tax just large enough to meet the global emissions target. This global carbon tax turns out to be lower than the carbon taxes required for independent mitigation by Annex I countries. Therefore, Annex I countries emit more carbon than in the independent case, but still less than in the reference case. Annex I countries must purchase rights to emit carbon from the non-Annex I countries. The non-Annex I regions must reduce their own emissions levels to sell those permits to the Annex I regions.

In this paper, we summarize the following results for the United States for each scenario: time series of carbon emissions; carbon taxes required for emissions mitigation; and measures of the cost of mitigation.

MODEL OVERVIEW

The SGM is designed specifically to address issues associated with global change. The model is designed to perform the following types of analysis:

1. Provide estimates of future time paths of environmentally important emissions associated with economic activity.
2. Provide estimates of the economic cost of actions to reduce greenhouse gas emissions.

Sectors

The SGM has nine producing sectors and twelve inputs to production. The inputs are labor, land, capital, and the nine produced goods. Economic detail is maintained in the energy supply and transformation sectors, but collapsed elsewhere into one large "everything else" sector. Price stability is maintained by keeping the price for goods produced by the "everything else" sector equal to 1.0 during all time periods.

Five different fuels are used for producing electricity, resulting in five subsectors for the electric generating sector. A separate economic production function, of the constant elasticity of substitution (CES) functional form, is used for each sector or subsector. Capital investment decisions depend on an assumed lifetime of capital for each sector or subsector. Capital lifetimes range from 15 years in the oil, gas, and coal production sectors to 70 years for hydroelectric power. The relative size of each production sector and subsector is shown in Table 2.

Table 2. Producing Sectors in the SGM

	Producing Sector	Gross Output in 1985 (millions of 1985 \$)
1	Agriculture	468,618
2	Everything Else	5,086,486
3	Oil Production	64,171
4	Gas Production	45,804
5	Coal Production	20,006
6	Uranium Processing	2,195
7	Electricity Generation	165,800
	a. oil	10,959
	b. gas	34,152
	c. coal	85,930
	d. nuclear	21,370
	e. hydro	13,389
8	Petroleum Refining	145,015
9	Gas Transmission and Distribution	105,330

Market Clearing

In the SGM, markets are said to *clear*. In other words, the SGM solves for the set of prices for all markets (or sectors) in the modeled economy so that demands and supplies of each market are in equilibrium. The set of prices in which the equilibrium holds is called the *market-clearing* price set. In an equilibrium model like the SGM, markets are linked to other markets through the market-clearing process. For example, a change in the demand for coal will have an effect on not just the price of coal, but also the prices of oil, gas, and, at least indirectly, the prices of all markets in the economy.

Carbon permit prices and taxes are also solved by the SGM as part of the market equilibrium. Specifically, the SGM finds the carbon price such that, given that market-clearing equilibrium prices hold in the rest of the markets, the amount of carbon emitted is just equal to the carbon constraint of the region or group of regions under a carbon emissions limitation constraint.

Carbon Taxes and Revenue Recycling

The SGM uses a carbon tax within each region to provide an economic incentive for the economy to substitute away from carbon. Revenues obtained from the carbon tax can be very large and it makes a difference, in terms of final economic cost, how the revenues are recycled. For this exercise, we assume that all carbon tax revenues are recycled back to consumers through a lump-sum government transfer.

For the cases where emissions rights are traded between countries, each SGM region is allocated an initial amount of carbon emissions permits. Carbon permits can then be traded between countries at a price that clears the global market in these permits.

Modes of Operation

All of the SGM regions were initially developed as single-region models with a base year of 1985. Each regional model operates in five-year time steps through either 2030, 2050, or 2100. Often, the models were developed in collaboration with experts from that country. It is possible to run all of the regions simultaneously in a global model with international trade. The three modes of operation for the SGM are:

1. Single Region
2. Global with Partial Market Clearing
3. Global with Full Market Clearing

Single-region operation. For each SGM region, all produced goods are classified as being tradable, nontradable, or traded at a fixed quantity. When SGM regions are operated independently, a fixed world price is assumed for each tradable good; regions may import or export as much of that good as desired at that fixed world price, subject to an overall balance of payments constraint. For all nontradable goods, the quantity of trade is fixed in advance. The following assignments are used when the United States model is operated independently:

Numeraire Sector:	everything else (price always equals 1)
Fixed World Price:	crude oil
Fixed Trade Quantities:	agriculture, coal, nuclear fuel, refined petroleum, electricity
Nontradables:	distributed gas, land, labor

Since only relative prices matter, we are allowed to fix the price of either one produced good or one primary factor of production. For each region, the large 'everything else' sector is the numeraire, with its price fixed at 1 for all time periods. This 'everything else' good is a tradable good for all regions. An exogenous balance of payments constraint is specified in advance for each region. Most regions are assumed to move linearly from a historical trade balance in 1985 to balanced trade by 2005.

Given a trial set of prices, the SGM computes supply and demand for all producing sectors and primary factors of production. Markets for the nontradables and goods traded at fixed quantities are brought into equilibrium by searching for a set of prices that equate supply and demand. Prices are adjusted until supply and demand are within 0.01% of each other.

Global model with partial market clearing. The global version of the SGM is used when there is at least one market that must clear globally. For the scenarios described in this paper, that market is tradable carbon emission permits. The model searches for a global carbon tax, which can be interpreted as a world carbon permit price, that clears the market for permits.

Each region is initially allocated a number of carbon permits and may trade those permits at the world permit price. Some regions will be sellers of permits and some will be buyers. After trading permits, all regions must hold permits equal to the domestic level of carbon emissions.

All regions are still subject to a period by period balance of payments constraint. The model does not allow borrowing to pay for carbon emissions permits. Imports of permits must be paid for with exports of some other good.

Global model with full market clearing. There are no longer any markets with a fixed world price. A set of world prices is found that clears all world markets. Also, world markets can be created for goods that were traded in fixed quantities in the single-region mode¹.

All of the scenarios described in this paper were run in the second mode, global with partial market clearing. This mode was chosen for two reasons. The first is that we were asked to assume a fixed time path of world oil prices for SGM model runs that were completed for the United States Government during the spring of 1997. This meant that the world oil market would not be allowed to clear in the model. The second reason is that model results are often easier to interpret when some variables in the model remain fixed over time. Although we are missing any feedback from reduced world oil consumption to lower world oil prices, the magnitude of this feedback is highly uncertain and difficult to model.

Data Requirements

Three types of data are used to construct and calibrate each region of the SGM.

1. Economic and Demographic Data
2. Energy Balances
3. Technology Descriptions

Economic data include input-output tables and supplemental information from the national income accounts. Population projections were obtained from the World Bank. Energy balance tables were obtained either from the International Energy Agency or from government agencies within a region.

Input-output tables describe, in value terms, the flow of goods between industries and consumers in an economy. However, a model concerned with quantities of carbon emissions must also be concerned with quantities of energy. An input-output table, by itself, is not sufficient to determine the quantities of oil, gas, coal, electricity, and refined petroleum that are produced and consumed. Supplemental information on energy quantities is required to map currency units from an input-output table to energy units needed to calculate levels of carbon emissions. We combine economic input-output tables with energy balance tables to create a hybrid input-output table with units of joules for energy products and real dollars for all other products. Miller and Blair (1985) provide a general description of, and the motivation for using, hybrid input-output tables.

Individual energy technologies are characterized by the annualized cost of providing an energy service. Data needed to determine the annualized cost include capital cost, equipment lifetime, annual fuel requirements, the interest rate, and other annual maintenance and operating costs.

REFERENCE CASE AND CALIBRATION

The cost of reducing greenhouse gas emissions is very dependent on the reference case. The greater the level of reference case emissions, the higher the cost of returning to 1990 emissions. Therefore, much effort is expended on creating an acceptable reference case before running any of the mitigation scenarios.

The SGM operates in five-year time steps from 1985 through 2050; results for this study are reported for 1990 through 2020. The United States reference case was closely calibrated to the Annual Energy Outlook 1997 (AEO97). Since AEO97 projects only up to the year 2015, projections beyond 2015 are SGM model results and are not calibrated to any other established projections. Projections of carbon emissions, population, GDP, primary energy consumption, and electricity generation for the United States are described below.

For the other global regions, economic and primary energy consumption growth rates were roughly calibrated to regional projections from the World Energy Outlook 1996 (WEO96). For the Former Soviet Union region, projected primary energy consumption levels were adjusted down from the WEO96 projection. Population projections for these regions were based on the World Population Projections 1994-1995, published by the World Bank. In addition to the exogenously set population levels, the international crude oil price trajectory from the AEO97 was used as an exogenously set price. Prices for all other fuels and goods in the model were determined endogenously.

The general calibration procedure is to first match GDP growth by adjusting parameters that control total factor productivity in the 'everything else' sector. Then energy consumption by primary fuel is calibrated by adjusting input-specific technical change parameters. Carbon emissions are derived directly from primary energy consumption by applying fuel-specific emission factors.

Carbon Emissions

In 1990, total carbon dioxide emissions from the combustion of fossil fuels in the United States were 1,350 million metric tons of carbon. Model results show that total carbon dioxide emissions continue to rise as fossil fuel consumption increases and emissions reach 1,871 million metric ton by 2020. This amounts to a 39 percent increase in total emission and an emissions growth rate of 1 percent per year. Reference case carbon emissions were shown earlier in Figure 1.

Gross Domestic Product

The two most important determinants of GDP are population growth and rates of change in productivity. Total population levels for the United States were taken directly from AEO97. United States population grows from 250 million in 1990 to 323 million in 2020. This represents an annual population growth rate of 0.85 percent per year.

GDP for the United States was matched to AEO97 projections by changing the total factor productivity parameter for the 'everything else' sector. Beginning with the 1990 GDP of 6.1 trillion dollars, the economy grows at 2 percent annually to reach 10.6 trillion dollars by 2020.

Primary Energy Consumption

Total primary energy consumption from 1990 to 2015 was calibrated to be within 2 percent of projections from AEO97. Primary energy consumption by fuel is shown for the United States in Figure 2. Energy consumption rises from 86 EJ in 1990 to 116 EJ in 2015. This increase represents an annual growth rate of 1 percent. The energy consumption growth rate decreases with time and in 2020, the total consumption is 119 EJ and the annual growth rate is 0.5 percent.

Crude oil is the major source of primary energy in the early years; however, natural gas competes with crude oil as the leading source of fossil fuel by 2020. Coal is the third largest source of primary energy and its consumption grows steadily at slightly less than 1 percent per year. Nuclear energy's contribution to primary energy consumption declines, while energy from renewable sources increases with time.

[Figure 2. Primary Energy Consumption – United States Reference Case]

Primary energy consumption does not grow as fast as GDP, which implies that the energy-GDP ratio is falling over time. Figure 3 shows the energy-GDP ratio generated by the SGM for the United States.

[Figure 3. Energy-GDP Ratio – United States Reference Case]]

Electricity Generation

Projections of electricity generation are similar to that of the AEO97. SGM total electricity generation results are higher than the AEO97 projections by approximately 10 percent. Electricity generation from natural gas is the reason for the higher result. Total electricity generated in 1990 is nearly 11 EJ, which grows at 1.5 percent per year and expands to 17 EJ by 2020. The major source of electricity is from the combustion of coal; however, electricity generation from natural gas plays a significantly larger role with time. In 1990, electricity generation from coal contributed to 53 percent share of the total generation, while that from natural gas combustion contributed to 17 percent of the total. By 2020, the shares of electricity generation from coal and natural gas are closer. Electricity generation from coal and natural gas comprise 44 and 34 percent share of the total respectively. Highly efficient and low cost natural gas combined cycle power plants incorporated into the SGM contribute to the growth of natural gas as the fuel for electricity generation. Nuclear power's contribution to the overall demand for electricity decline with time as existing power plants are retired and no new additional plants are constructed. Renewable energy sources for electricity generation include hydroelectricity, solar photovoltaics and others. Generation of electricity from renewable sources increases slightly from 1990 to 2020; however, renewable energy's share of total electricity remains below 10 percent of the total.

COST OF EMISSIONS MITIGATION

Although this exercise did employ the 12-region version of the SGM, discussion of results in this paper will focus on the United States. The SGM provides output on regional GDP and its components and a detailed description of the composition of energy supply. In this analysis, we will focus on the broad economic impacts on the economy. Specifically, we will discuss the permit prices required to meet the various mitigation requirements and the costs to the United States economy of undertaking such policies. We will also discuss the impacts of the domestic carbon taxes on primary energy consumption.

Permit Prices

Table 3 shows the permit prices by trading regime required for the United States to meet its emissions targets under the four mitigation scenarios. Permit prices in the United States must reach \$108 per metric ton of carbon to reduce United States emissions to 1990 levels in 2010. This price increases significantly with the tighter constraint imposed under the M1990-10% case. Permit prices in the M1995 and M1990+10% scenarios are very similar as only 5 TgC separate the constraints in the two cases.

**Table 3. United States Carbon Taxes Required to Meet Policy Goal
Eastern Europe & FSU Allocated Reference Case Permits
(1992 US\$ per Metric Ton of Carbon)**

	Independent Mitigation		Annex I Joint Mitigation		Annex I Mitigation with Global Trade	
	2010	2020	2010	2020	2010	2020
M1990	108	170	72	87	26	27
M1990+10%	60	110	42	58	16	18
M1990-10%	173	260	109	122	38	36
M1995	61	112	70	106	26	32

Permit prices fall as more regions are included in the market for carbon permits. In the independent emissions mitigation case, carbon emitters in the United States may undertake emissions mitigation options available only within the United States. In the Annex I joint and global permit cases, however, regions are included that have mitigation options with significantly lower costs, thereby lowering the marginal cost to the carbon permit market of meeting the desired emissions targets. As we will discuss, this 'where' flexibility in meeting emissions targets has a significant impact on costs as well as permit prices.

Permit prices tend to increase over time as it becomes more expensive to reduce emissions to the desired goal. Increasing population in the United States, and the economic growth that accompanies it, put upward pressure on emissions that, in turn, forces larger shifts away from inexpensive coal toward more expensive natural gas and renewable energy sources. The availability of relatively inexpensive abatement options in the developing world allows the permit price to remain relatively constant over time in those cases.

As the permit prices decrease across trading regimes, the United States purchases more and more permits from abroad, thereby enabling it to emit more than its allocated permits alone would allow. Figure 4 shows United States emissions for the M1990 case across the three trading regimes. Under the independent emissions mitigation regime, the United States is limited to emitting only what it is allocated under the scenario, its 1990 emissions level. With Annex I trading, however, the United States purchases 209 TgC worth of permits in 2010 and 244 TgC in 2020. The purchases increase to 316 TgC and 436 TgC in 2010 and 2020, respectively, under the global trading regime. This 'where' flexibility reduces the amount by which a permit-buying region must reduce its emissions and, therefore, reduces the cost to the region.

[Figure 4. United States Carbon Emissions – M1990 Cases]

Primary Energy Consumption

Emissions mitigation is achieved through reduction in total primary energy consumption and fuel substitution in the electricity sector. The domestic carbon tax of \$108 in 2010 in the M1990 case results in a reduction of total primary energy consumption by 16 percent relative to the reference case. Primary energy consumption of coal drops by 57 percent while consumption of crude oil drops by 12 percent. Consumption of natural gas increases by 1 percent due to fuel switching. For reductions in primary energy consumption by fuel, refer to Figure 5.

[Figure 5. United States Primary Energy Consumption in 2010]

Fuel substitution in the electricity sector results in the share of electricity generated from coal dropping from 45 in the reference case to 20 percent in the M1990 case. The reduction in electricity generation from coal is compensated for by increased generation from natural gas. The share of electricity generation from natural gas increases from 29 percent in the reference case to 51 percent M1990 case.

Cost Calculations

A very convenient way to characterize the response of any SGM region to a carbon tax is by constructing a marginal cost of carbon curve. Figure 6 is a scatter plot of various carbon taxes applied to the United States economy, and the corresponding reduction in carbon emissions. Data points plotted in Figure 6 are from the four independent mitigation scenarios for the United States. Note that a positive tax is required to achieve any reductions in carbon emissions.

[Figure 6. Marginal Cost of Carbon]

The marginal cost curve is used to calculate one measure of cost that we will call the *direct cost*. For any level of carbon emissions mitigation, the direct cost is defined as the area under the marginal cost curve up to that amount of mitigation. The first units of emissions reductions are very inexpensive, successive units become more and more expensive. Figure 7 shows the size of these direct costs for the United States for the four independent mitigation scenarios. Direct costs are shown at five-year intervals through 2020 as a percentage of GDP. These costs are plotted as negative numbers in Figure 7. As expected, the M1990-10% scenario shows the greatest costs.

[Figure 7. Cost of Emissions Mitigation – No Trading]

Figure 8 focuses on the M1990 case and shows how costs to the United States are reduced with trade in emissions permits between countries. The 'independent' cost line shown in Figure 8 is the same as the M1990 cost line in Figure 7. In 2010, costs are reduced somewhat with Annex I

trading and reduced by about one-half with global trading. In later years, the flexibility in where emissions reductions are undertaken impacts mitigation costs even more significantly.

[Figure 8. Illustration of 'Where' Flexibility - Costs for M1990 Cases]

Cost calculations for the emissions trading cases are different than in the independent case. Costs for the trading case take into account the value of permits traded. For a seller of permits, such as the United States, net cost includes the direct cost plus expenditures on carbon permits. A breakdown of these two cost components is shown for the M1990 Annex I trading case in Figure 9. Direct cost is roughly half of the net cost. The remaining cost, the difference between the 'direct cost' and 'net cost' lines in Figure 9, is the value of emissions permits that would be purchased from other Annex I countries.

[Figure 9. Cost Breakdown - M1990 Annex I Trading Case]

DISCUSSION

Several important issues have arisen during the development and operation of the SGM. In this section, we summarize some of the insights gained from our modeling activities. First, economic costs depend a great deal on our assumptions about future carbon emissions. Second, several measures of cost are available from the SGM. Third, the distribution of costs among countries in a system of global permit trading is sensitive to assumptions on exchange rates as well as the initial allocation of permits. Fourth, any system of global trade in carbon permits implies potentially large transfers of wealth from developed to developing nations. Finally, we discuss how some of our assumptions affect the results on costs.

Role of Reference Emissions in Shaping Marginal Mitigation Costs

All of the results in this study depend on assumptions used to create a reference emissions scenario from the present to 2020. The amount of mitigation required to return to 1990 levels depends directly on reference case emissions for each region. In the Annex I trading cases, carbon permit prices are particularly sensitive to reference scenarios for potential sellers of permits, especially Eastern Europe and the Former Soviet Union.

Among the Annex I countries, projecting future carbon emissions is especially uncertain for Eastern Europe and the Former Soviet Union. Of particular importance is when emissions in these regions will once again reach 1990 levels. If this point is reached before 2010, then we model EE and FSU just as any other Annex I country. If this point is reached after 2010, then emissions restrictions are not binding in EE and FSU until that point in time.

Measuring and Reporting Costs

At least two measures of cost are available from the SGM and from other models as well. The first measure, which we call the *direct cost*, can be thought of as either a deadweight loss or the integral under the marginal cost curve for carbon. Using either approach, direct cost is

approximately equal to one-half of the carbon tax (or permit price) times the reduction in carbon emissions. For the permit trading cases, direct costs are then adjusted by the value of transfer payments required to purchase or sell permits. This measure of net cost is simple to construct and is comparable across models.

Of ultimate interest, however, is the net impact on some broader measure of economic activity (such as GDP) or on economic welfare (such as real consumption). There are many reasons why the change in GDP (or real consumption) is different than direct cost net of transfer payments. These other components of cost include the effects of pre-existing distortionary taxes, changes in terms of trade, and how tax revenues are recycled. In addition, measurement of GDP (or real consumption) depends on the choice of index and base year used to construct that index. This reflects real world problems in constructing a quantity index for GDP when relative prices are changing.

Foreign Exchange Rates

Permit prices for the global permit trading cases are very sensitive to assumptions on exchange rates. This is particularly true for developing countries where market exchange rates, in local currency per U.S. dollar, are three to five times the corresponding exchange rate based on purchasing power parity. A global permit price of \$100 per metric ton translates, at market exchange rates, into a much higher relative price in the developing countries than in the United States.

Exchange rates based on purchasing power parity are usually used to compare income levels between countries, but market exchange rates must be used for goods actually traded between countries. This creates a potential problem for developing countries considering participation in a global permit trading program; carbon permits would be traded at market exchange rates, while GDP losses are better measured using purchasing power parity. For developing countries, losses in GDP could be greater than the value of carbon permits sold.

International Transfer Payments

Transfer payments required by some of the permit trading scenarios can become quite large. From the point of view of a buyer of permits, the amount spent on permits should be more than offset by the avoided cost of further emissions reductions.

Transfer payments of this size will affect the pattern of other goods traded internationally. Our model does not allow regions to borrow between time periods; trade must balance during each time period. Buyers of permits must export more of other goods to pay for the permits and adhere to a balance of payments constraint.

Sensitivity of Costs to Model Assumptions

Economic costs reported by the SGM for the United States are sensitive to many of the model inputs. These include the choice of exchange rate, the inclusion of paper permits, and the method of revenue recycling.

If purchasing power parity exchange rates were used instead of market exchange rates for the developing countries, then any given world permit price would translate into a lower carbon tax in that country's local currency. For global trading cases, this would increase the global permit price needed to meet a global emissions limit, and the SGM would report higher costs for the United States.

For regions with emissions below 1990 levels, carbon permits were allocated based on their reference case, and not on 1990 emissions. If we had allocated permits based on 1990 levels, these extra 'paper permits' would create a less-stringent Annex i target. The model would then report a lower permit price for the trading cases, and a lower cost to the United States.

In this study, we assumed that all revenues from a carbon tax would be recycled as a lump sum to consumers. Another option is to use the carbon tax revenues to offset other taxes. This has the potential to reduce overall costs, since carbon tax revenues would displace other distortionary taxes.

KEY OBSERVATIONS

Economic costs are reduced with a permit-trading program that equalizes the marginal cost of carbon between countries. The least expensive emissions reductions are taken first, regardless of where they occur. Costs shown in Figure 8 provide a good example of the importance of this 'where' flexibility.

For the four mitigation scenarios in this study, economic costs to the United States remain below 1% of GDP through at least the year 2020. This was the case even in the scenarios where the United States met its mitigation targets without international trading of carbon permits.

Each region in the SGM can be characterized by a marginal cost of carbon curve, as was shown in Figure 6. This shows the approximate carbon tax required for any given level of carbon emissions reduction. For the amount of emissions reductions needed in 2010 to return to 1990 levels, a carbon tax of \$108 per metric ton of carbon is required.

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Figure 1. Carbon Dioxide Emissions Scenarios for the United States

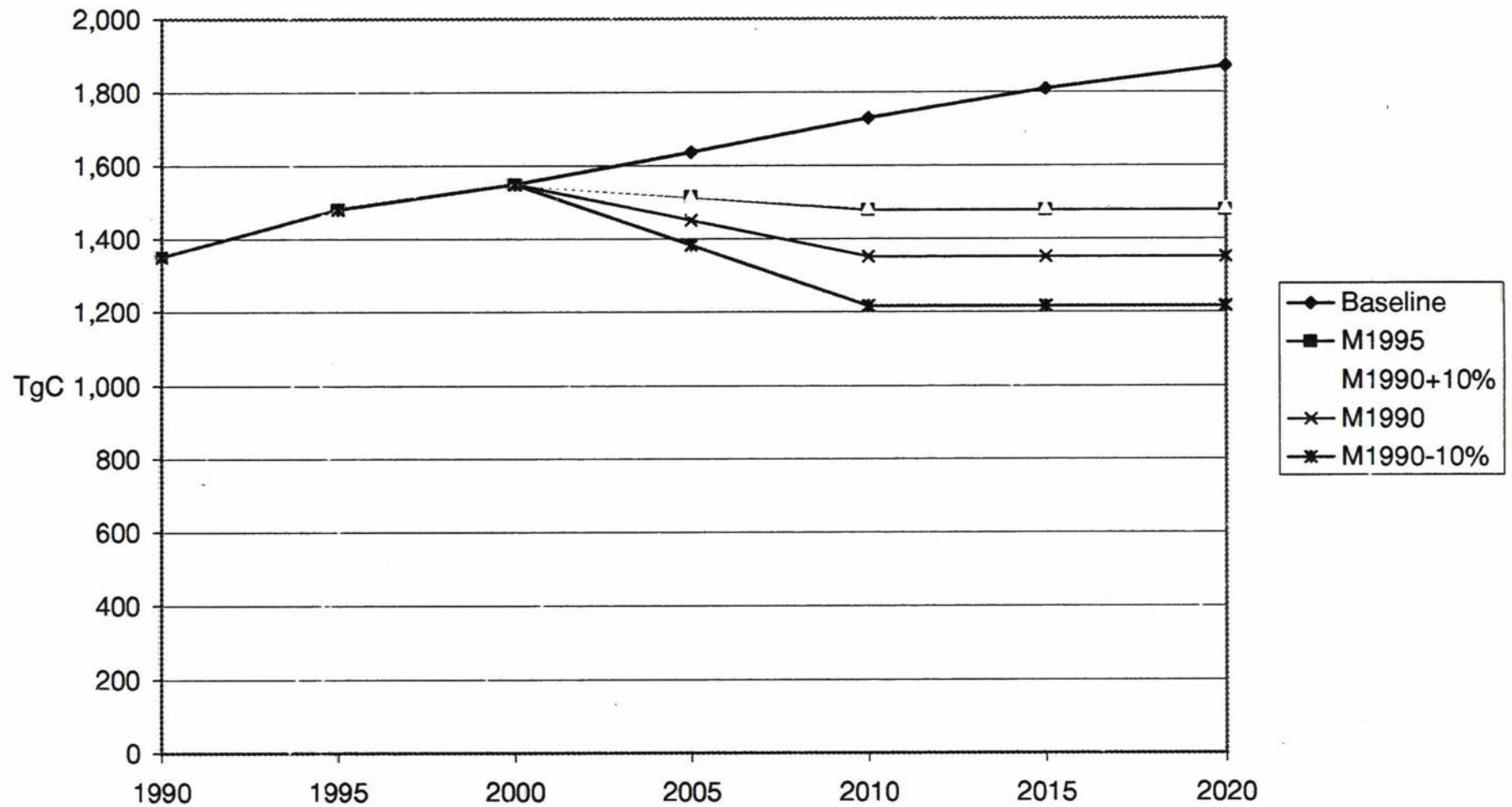


Figure 2. Primary Energy Consumption
United States Reference Case

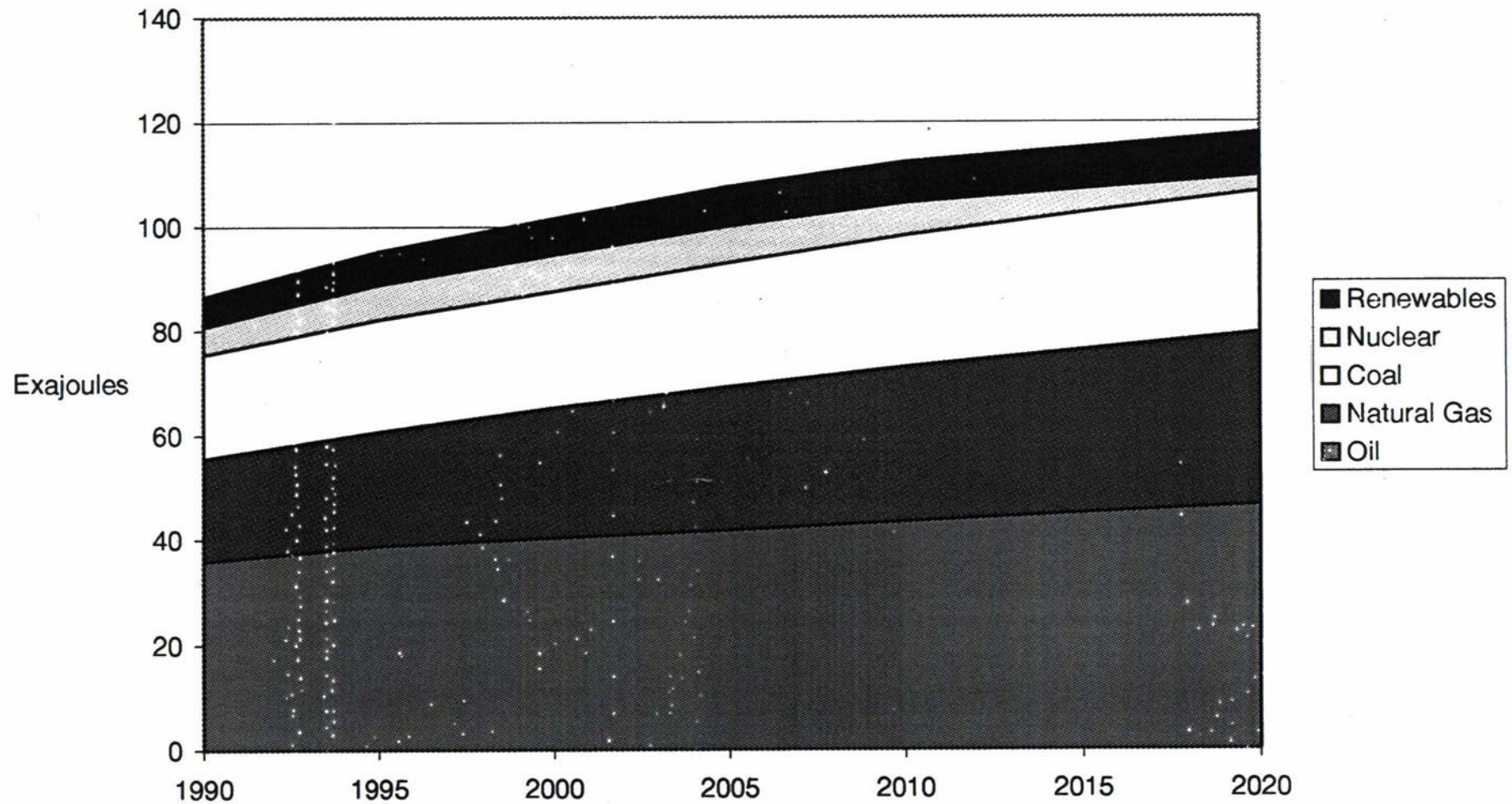


Figure 3. Energy-GDP Ratio
United States Reference Case

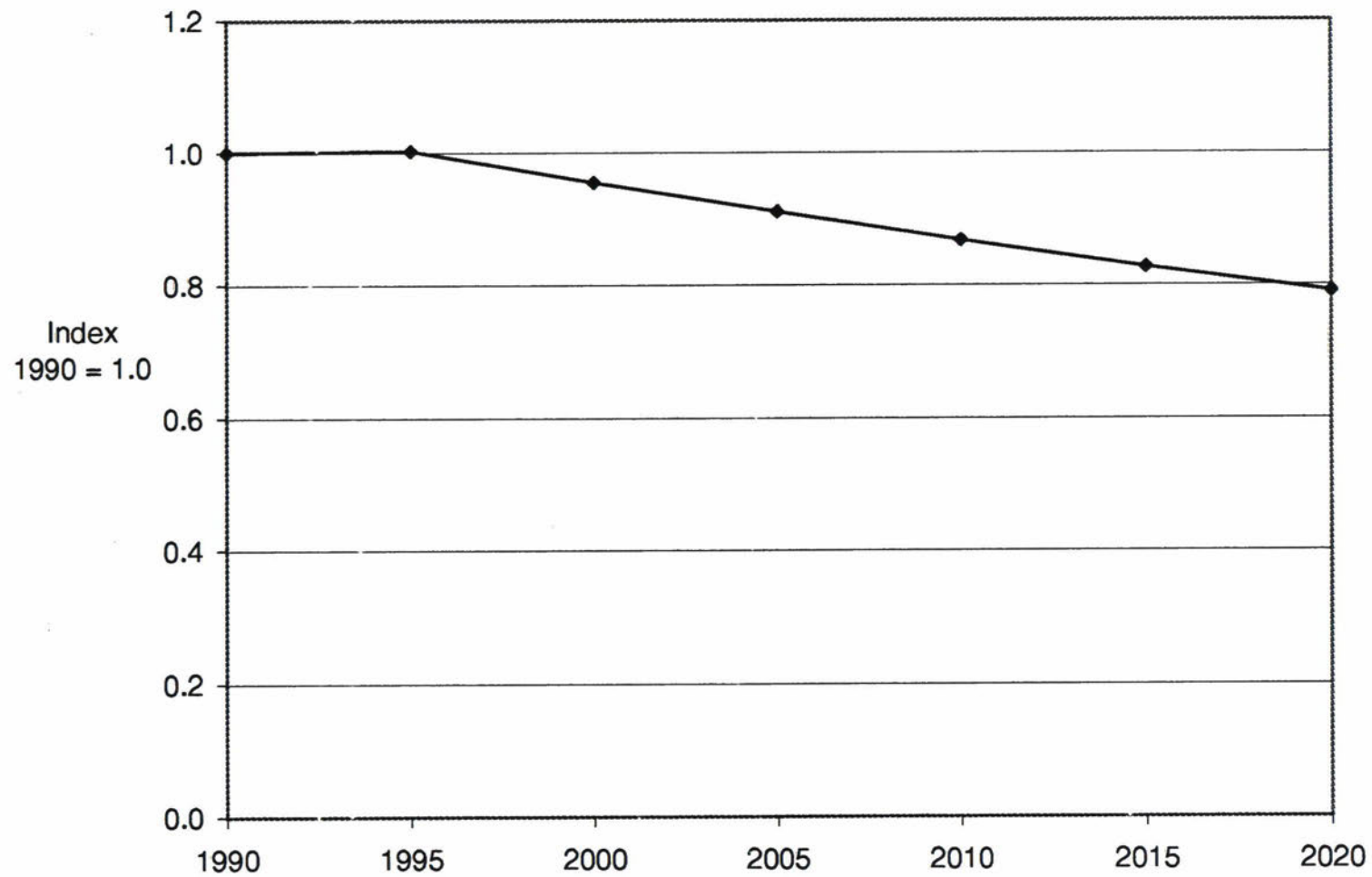


Figure 4. United States Carbon Emissions
M1990 Cases

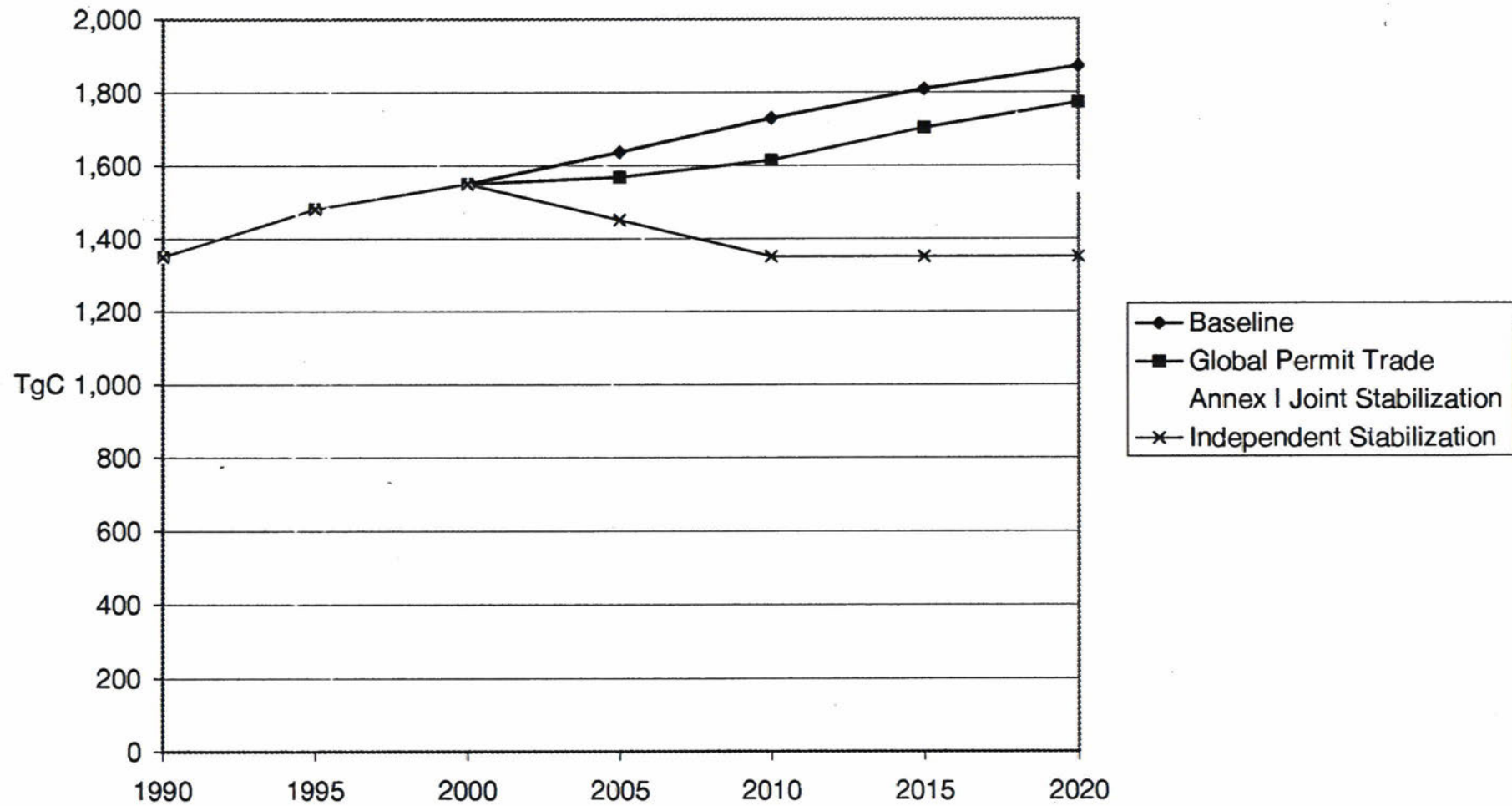


Figure 5. US Primary Energy Consumption in 2010

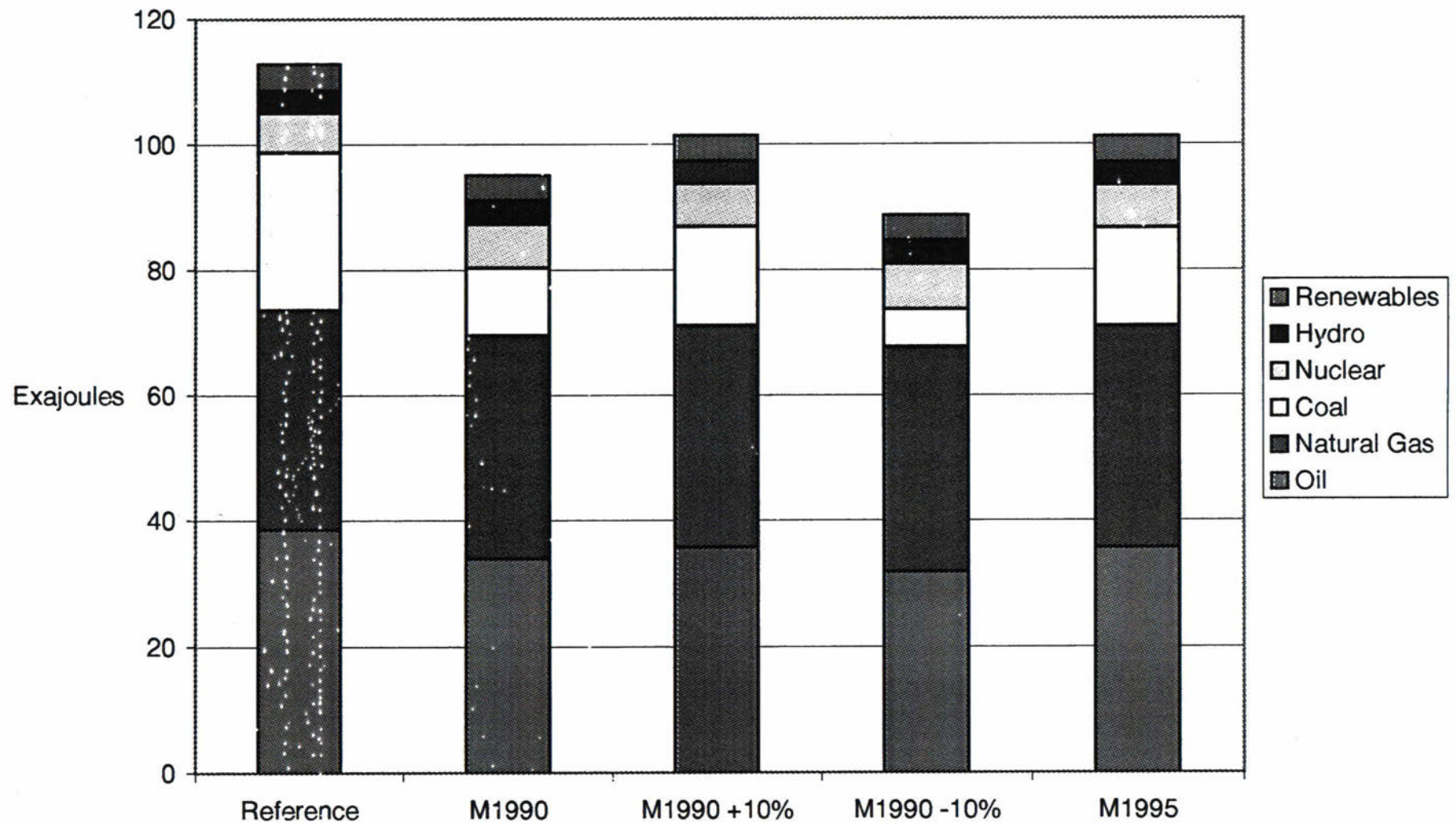


Figure 6. Marginal Cost of Carbon

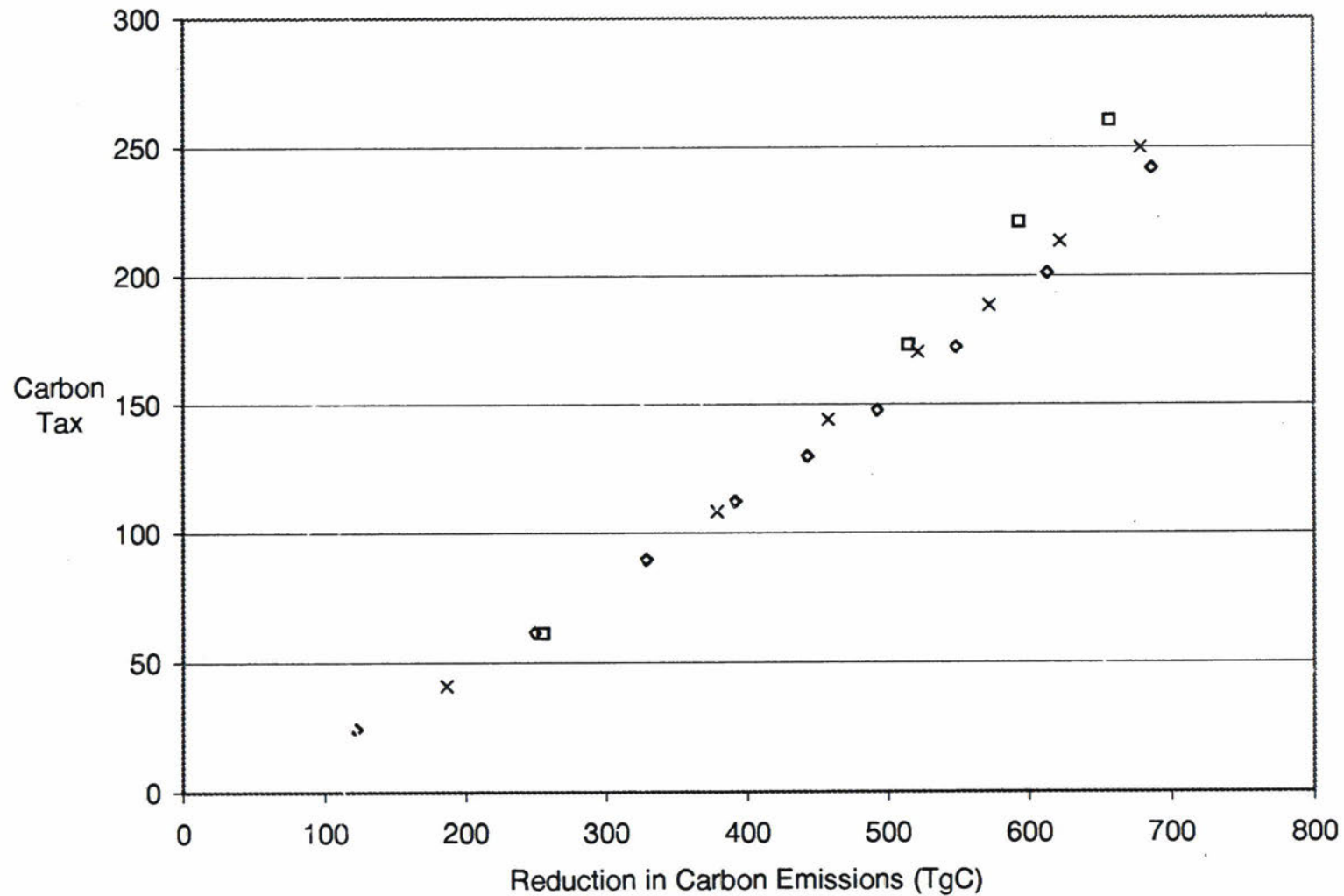


Figure 7. Cost of Emissions Mitigation
No Trading

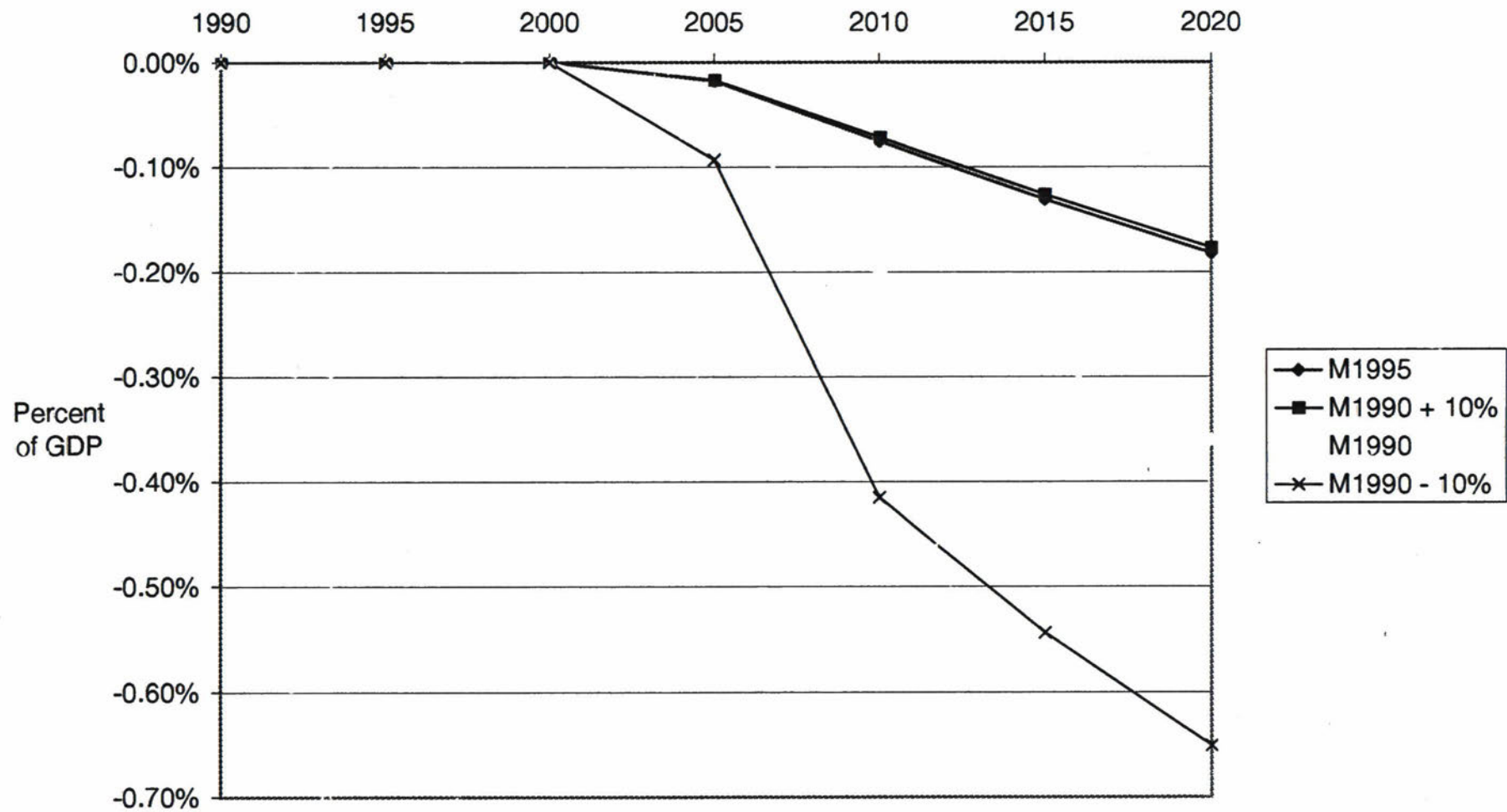


Figure 8. Illustration of 'Where' Flexibility
Costs for M1990 Cases

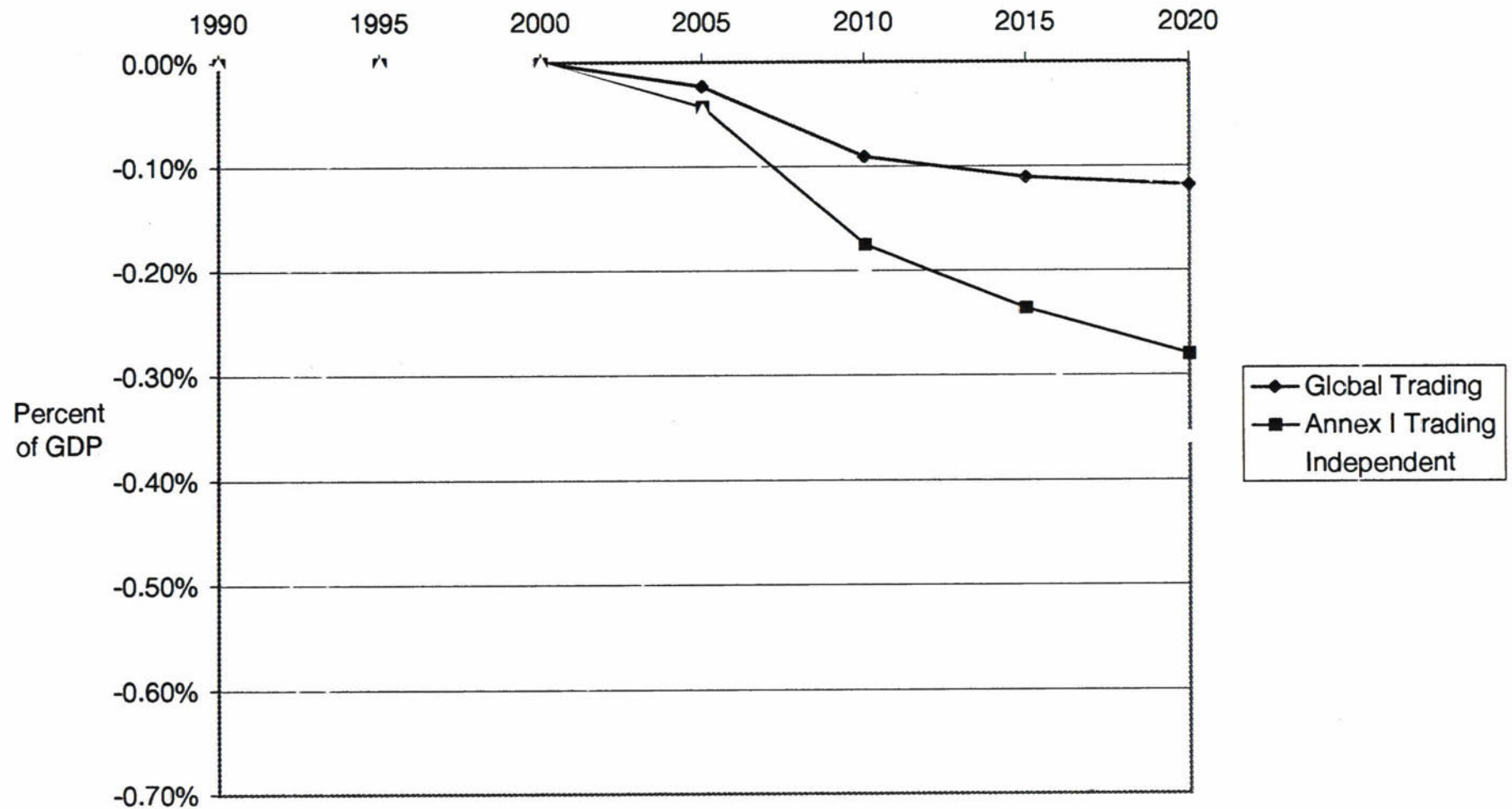
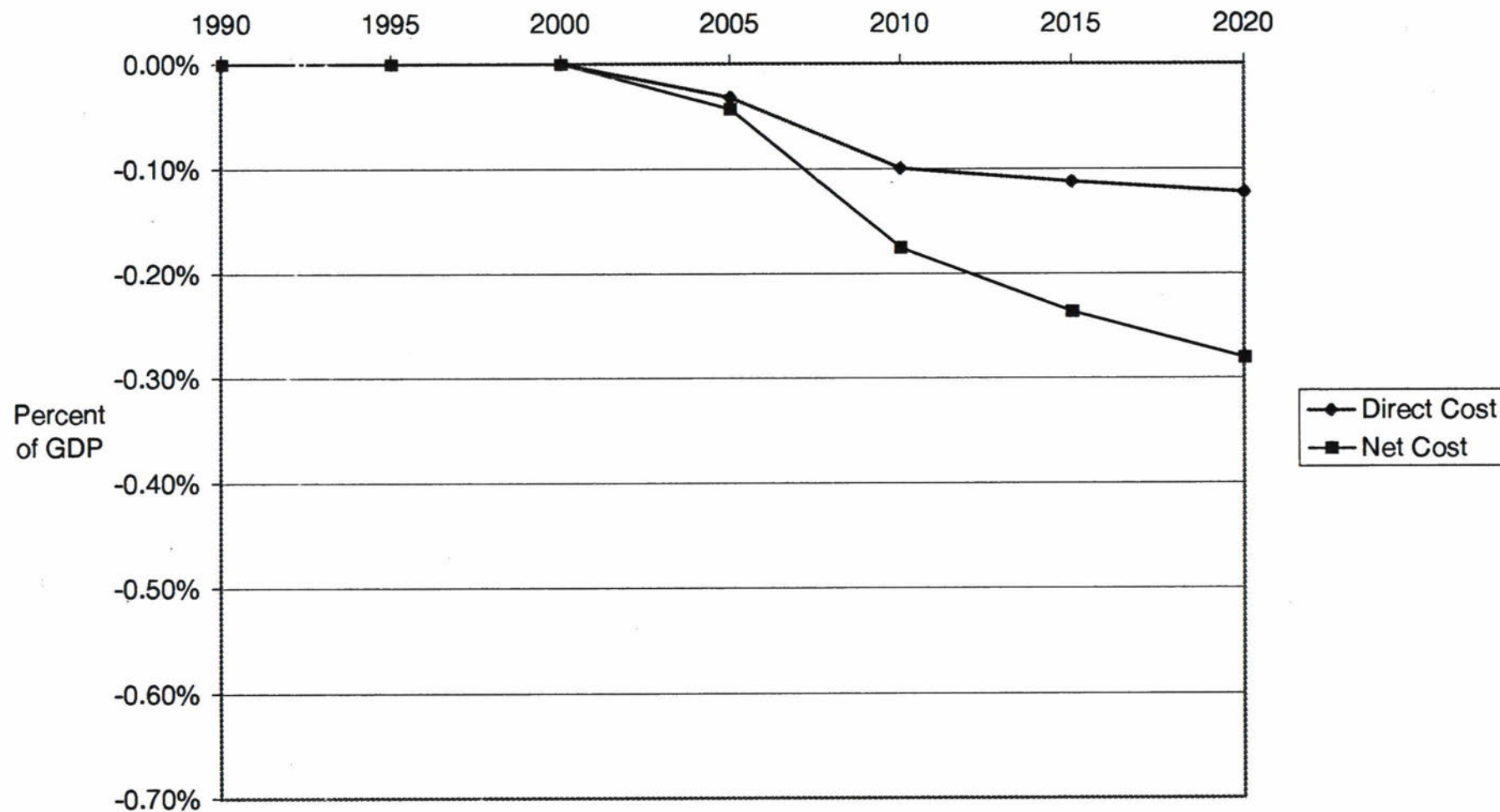


Figure 9. Cost Breakdown
M1990 Annex I Trading Case





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MEMORANDUM

To: Rosina Bierbaum
From: Adam Markham
Date: 17 October 1997
Subject: Policies and Measures to Reduce CO₂ Emissions in the United States

Rosina,

I'm attaching summaries of two new studies WWF has undertaken, and which will, I hope, be useful for you in developing a final position for Kyoto. Some additional polling carried out after we briefed you a couple of weeks ago, and a detailed new study on emissions reduction policy options, costs and benefits for the U.S.

New energy study shows potential for significant cuts below 1990 levels by 2010.

The "policies and measures" study is a peer-reviewed report prepared by Boston-based consultants, the Tellus Institute. The bottom line is that it provides a blueprint for an innovative and cost-effective set of measures which, if followed, could bring US carbon emissions 21% below 1990 levels by the year 2010. Cumulative net economic benefits are calculated at more than \$278 billion through 2010.

The Climate Protection scenario lays out a series of cost-effective measures including:

- Renewables content standards
- Pollutant emissions cap and trade schemes
- An advanced vehicle initiative
- Investment tax credits
- Regulatory reform
- Market transformation incentives
- Appliance and building standards
- Biomass cofiring expansion

Detailed parameters for these policies and measures were used as inputs to the Energy Information Administration's National Energy Modeling System (NEMS), and additional analysis carried out to compensate for some of the limitations of NEMS:

It is worth noting that to get the 10% reduction by 2005 requires the incremental costs to be \$60/ton of CO₂. If, for example, an 8% reduction is the goal, the marginal costs would be significantly lower. It should also be noted that it would be possible to achieve the same cumulative emission reductions by 2010 without going so deep in 2005, perhaps at lower overall costs and lower marginal costs.

This report is in its final pre-publication stage, and we expect to release it early next week. I wanted you to see at least the summary as soon as possible, and I will courier a full copy of the study over as soon as we have a final draft.

New polling results show strong support for unilateral action by US at Kyoto

The other attached memo, from the Mellman Group, is self-explanatory. It details polling carried out in the first week of October, in which we tried to clarify whether Americans feel that developing countries should be required to commit to emission targets before the US takes action. The answer is clearly no. 71% support action by the developed world alone, and 57% would support unilateral US action. It seems there is a strong feeling in the country that a significant commitment by the US in Kyoto would be a good thing.

I'm also sending these results to Beth Viola, Tim Wirth, Todd Stern and TJ Glauthier.

Policies and Measures to Reduce CO₂ Emissions in the United States

An Analysis of Options for 2005 and 2010

Tellus Institute and SEI-Boston

October 17, 1997

Abstract

The Intergovernmental Panel on Climate Change has unequivocally reported that in order to prevent global climate disruption and its attendant ecological, economic, geo-physical, demographic and political consequences, it is necessary to stabilize atmospheric concentrations of greenhouse gases well below the levels that would result if greenhouse gases continued to accumulate along current trends. Thus, to protect global climate, annual greenhouse gas emissions must be reduced by at least 60 percent below present emission rates. As the principal greenhouse gas is carbon dioxide, which is released in the energy production and use at the heart of industrial economies, this daunting objective will require two complementary sustained initiatives. First, the advanced industrial societies must dramatically reduce their carbon emissions from current levels. Second, industrializing nations must economically develop along a path of low carbon-intensity. Arguably, the United States, whose current per capita carbon emissions are roughly five times the present global average, must radically decrease emissions as its contribution to climate protection.

This study finds that the US can reduce its annual carbon emissions to 10 percent below 1990 levels by 2005 and to 21 percent below 1990 levels by 2010, at net savings to its economy relative to the present energy-intensive and fossil-based path. The US can achieve this by implementing an ambitious set of targeted policies, beginning in 1998, which would overcome market and institutional barriers and stimulate more rapid introduction of advanced technologies and fuels that are cleaner and more efficient. These near-term carbon reductions, and the technologies and policies that underlay them, establish a trajectory and a basis for the much deeper long-term cuts that are needed for climate protection.

This study was commissioned by the World Wildlife Fund (WWF) as a companion to parallel studies of the European Union (Blok *et al* 1996) and Japan (Morita *et al* 1997), which together with the US are responsible for roughly 40 percent of the world's annual carbon emissions. The study builds and expands upon another study -- *Energy Innovations: A Prosperous Path to a Clean Environment* (EI 1997), which was recently released by five non-profit energy and environmental policy research organizations. This study strengthens, accelerates and adds to the policies identified and analyzed in *Energy Innovations*, to build an augmented policy package that more aggressively captures near-term carbon emissions reductions, in the time frame proposed by the Alliance of Small Island States (AOSIS).

I. Introduction and Summary

Background

At the 1992 Earth Summit in Rio de Janeiro, signatories to the Framework Convention on Climate Change committed themselves to achieving ...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system. Since that time, however, emissions of greenhouse gases have continued to rise, even as the community of climate scientists has moved toward the consensus that already human activities are having a discernible impact on global climate (IPCC 1996).

Annual carbon dioxide emissions of the industrialized countries are about 4 billion metric tons (a bit more than 3 tons per capita) including US emissions of about 1.5 billion tons (at 6 tons per capita), while the developing world releases about 2 billion tons (at about 0.5 ton per capita). Adequate response to the threat of global climate change will require stabilizing annual global carbon emissions at least 60 percent below current levels. However, under a business-as-usual future, in which no special attention is paid to the threat of climate change, overall annual emissions would likely *increase* from the current 6 billion tons to about 14 billion tons by 2050, driven by conventional economic development and a near doubling of population. Avoiding this path will require that two trajectories be established and sustained to reach the required global emissions of less than 2.5 billion tons; the industrialized world must reduce its annual carbon dioxide emissions from about 3 tons per capita (for the US, 6 tons per capita) to about one quarter ton per capita, and the industrializing world must be helped to achieve economic growth along a path of low carbon intensity.

Equity considerations aside (such as the current carbon accumulations owing to historic industrial development, which have nearly saturated the atmosphere's capacity to absorb additional carbon without inducing large-scale climate change; and the current imbalance in per capita emissions among nations), it is essential for climate protection that the industrialized countries take vigorous action to drive down their emissions towards the levels identified above, *no matter what action developing countries take*; the chief consideration affected by developing country action is how rapidly this must occur. Indeed, recognition of these facts is implied in the commitment to action by the industrialized world, prior to that of the developing world, in the Berlin Mandate.

The upcoming December, 1997 Conference of Parties to the FCCC in Kyoto offers a pivotal opportunity to make concerted progress toward this goal. Signatory states are obligated to formulate a greenhouse gas reduction regime in Kyoto, including quantified reduction targets and explicit timetables that will be legally binding on industrialized nations. The signatories will be considering the proposal offered by the Alliance of Small Island States (AOSIS), which targets a reduction in greenhouse gas emissions to 20 percent below 1990 emissions by 2005, a reduction target already adopted by some nations as their individual targets but argued by others to be unrealistic (Blok *et al* 1996).

The present study, along with parallel studies for the European Union and Japan, has been commissioned by the World Wildlife Fund (WWF) to develop a set of concrete policies and measures for emissions reductions that could realistically approach the AOSIS' proposed 20 percent reduction target by 2005. Although very little time remains to achieve this, especially as current levels of emissions exceed considerably the 1990 benchmark, it is also

clear that tremendous potential exists for emissions reductions below projected business as usual levels.

This study has sought to identify policies and measures that (1) achieve significant carbon emissions reductions quickly, (2) are economical in the aggregate, owing to the energy-cost savings that are induced, even without considering greenhouse gas, pollution and ancillary benefits, and, perhaps most importantly, (3) serve as an effective transitional strategy that establishes a foundation and builds momentum toward the much deeper long-term emissions reductions required for climate protection.

Methodology

The analysis reported here builds and expands upon *Energy Innovations: A Prosperous Path to a Clean Environment* (EI 1997), a collaborative effort recently released by the Alliance to Save Energy, American Council for an Energy-efficient Economy, Natural Resources Defense Council, Tellus Institute, and Union of Concerned Scientists. The aim of EI was to formulate and model a set of targeted and complementary policies that would guide the US economy towards lower cost, less polluting, more secure, and more sustainable ways of producing and using energy. The EI methodology, which we have adopted and extended for the present study, consisted of translating the selected policies into technical and economic parameters that were then used as inputs to the Energy Information Administration's National Energy Modeling System (NEMS) as the primary analytical tool (EIA 1995). Supplemental analysis was done to compensate for limitations of NEMS, as mentioned in the sections below. Experts on the technologies for the residential, commercial, industrial, transportation and electricity generation sectors reviewed the detailed specifications used in NEMS and refined them as appropriate. This report borrows heavily from the original EI study, which was peer-reviewed by many leading US energy analysts.

This analytical approach is based on an integrated model that simultaneously considers the entire set of policies and models the direct impact of each policy along with the interactions among them. As this analytical approach yields results that are comprehensive and integrated, it is necessarily difficult to unambiguously attribute carbon reductions to specific policies or technology measures. Owing to the integrated nature of the analysis, individual measures have impacts that interact with one another, and have non-additive and sequence-dependent effects. In the sectoral descriptions below, we briefly describe the individual policies, give the modeling assumptions into which they translate, and report the resulting carbon reductions as aggregate figures for each sector. To the degree feasible, we also report the separate impacts of individual policies or groups of policies.

The baseline scenario considered in this study is essentially a "business as usual" projection, which was derived from the baseline scenario in EI by using updated fuel price projections (EIA, 1997). This projection assumes that there are continued modest improvements in the fuel economy of new vehicles, continued decline in industrial energy intensity, and continued penetration of more efficient equipment in buildings at historical rates. However, the steady increase in demand for energy services more than compensates for these improvements, and by 2005 energy consumption increases 20 percent and carbon emissions 17 percent above 1990 levels, rising further in 2010 to 24 percent and 22 percent,

respectively. (For further details regarding the baseline scenario see the respective sections below and *EI*.)

The policy-driven scenario developed in *EI* (dubbed the *Innovation Path* in that report) projects carbon emissions to fall below the 1990 benchmark by 6 percent in 2005 and 10 percent in 2010, both substantially short of the 20 percent reduction target proposed by AOSIS for 2005. However, owing to the policies of the *Innovation Path*, carbon emissions were projected to continue their decline, reaching the 20 percent reduction level by about 2015, and 45 percent by the 2030 horizon of the study.

It is interesting to note that the policies and measures modeled in the *Innovation Path* are roughly as effective as those developed for the European Union (EU) study commissioned by WWF (Blok 1996) -- each achieving a 19 percent reduction in emissions relative to its own baseline scenario projections for 2005. The lower reductions relative to 1990 found in *EI* reflect a quicker growth of baseline emissions in the US than in the EU, due in part to shifts from coal to gas made feasible by the comparable prices of these fuels in the EU.

The present study strengthens, accelerates and adds to the policies identified and analyzed in *Energy Innovations*, to build an augmented policy package that more aggressively captures near-term carbon emissions reductions. The key changes are acceleration of combined-heat-and-power (CHP) in the industrial sector, more rapid penetration of ethanol in blends with gasoline for transportation, and co-firing of biomass in coal-fired electric generation. The enhanced policy package achieves carbon emissions reductions to 10% below 1990 levels by 2005 and 21% below 1990 levels in 2010.

Policies

The *Climate Protection* scenario developed in this study is an integrated and balanced set of policies that can put the US on a path of technological diffusion and innovation towards an economically and environmentally sustainable future. The sector-specific policies and programs would guide the economy toward more efficient, lower cost, less polluting, more secure, and more sustainable production and consumption of energy. Some of the key policies are:

- *renewables content standards*, which would require increasing proportions of renewable resources for electricity and motor fuels, through credit-trading market mechanisms.
- *pollutant emissions caps*, which would limit SO₂, NO_x, particulates and CO₂ emissions in the electric power sector through allowance trading systems
- *biomass cofiring expansion*, which would quickly establish a significant amount of renewable energy in the electricity supply sector without requiring substantial investment in new power plants
- *an advanced vehicles initiative*, which would introduce stronger fuel economy and emissions standards along with pricing reform, incentives and demand management,

with the objective of encouraging the commercialization of clean and efficient vehicles and more environmentally benign travel patterns

- *investment tax credits*, which would speed the adoption of modern and energy-efficient technologies for new manufacturing equipment, through an incentive that is paid for by fees on energy purchases
- *research, development and technical support*, to ensure that innovation proceeds at a pace that makes improved energy-efficient and low-carbon technologies available more rapidly
- *regulatory reform*, to refine protocols and ensure market access, to fairly represent the economic and environmental benefits of industrial combined-heat-and-power (cogeneration) and, thereby, to speed its adoption by industrial firms
- *market transformation incentives*, including technology demonstrations, manufacture incentives, and consumer education, which would reduce transaction costs, help move products from prototype to commercial production, and lower the key hurdles between potential and realized energy savings
- *appliance and building standards*, which would establish norms for equipment, design and performance that, through purchases and practices, would reduce energy used in providing services in homes and offices

Details on these and additional policies in the *Climate Protection* scenario are provided in the relevant sections below.

Results

Carbon Reductions

The *Climate Protection* scenario developed here builds on the original *Innovation Path* (EI 1997) by implementing additional and strengthened policies in each sector to achieve deeper carbon reductions in the time-frame proposed by AOSIS. The policies and modeling results for each sector are described in the following sections. The combined effect of the more aggressive set of policies calculated in the integrated analyses is a 10 percent carbon reduction in 2005, which still falls short of the AOSIS target. However, reductions reach 21 percent by 2010, with excellent momentum towards deeper long-term reductions.

The carbon emissions of the baseline and *Climate Protection* scenarios are given in Figure 1. This figure reflects the separate and combined impacts of the sectoral policies -- in buildings, industry, transportation and electricity supply -- which induce decreases in energy-intensity through more efficient technologies, processes and practices, in addition to decreases in carbon-intensity through shifts to lower carbon energy sources and associated energy conversion facilities. The upper and lower curves give total carbon emissions for the two scenarios, while the shaded regions show the reductions from policies in each sector in succession. For this presentation, we adopt a convention for allocating electric sector emissions reductions that consists of first obtaining the reductions owing to electric supply

policies, which decrease the carbon-intensity of electric power generation, and then obtaining the further reductions from demand sector policies, which decrease the amount of power required. The latter reductions are allocated to the demand sectors in proportion to their demand reductions.

PRELIMINARY: Figure 1 shows baseline scenario carbon emissions reaching 1567 million metric tons (MTc) by 2005 and 1634 MTc by 2010, increases of 17 percent and 22 percent, respectively over the 1990 carbon emissions of 1338 MTc. The *Climate Protection* scenario projects carbon emissions that decrease to 1203 MTc in 2005 and 1061 MTc in 2010, reductions of 10 percent and 21 percent, respectively below 1990 emissions.

{Figure 1}

PRELIMINARY: Economic Costs and Benefits

On balance, the set of policies of the *Climate Protection* are estimated to be cost-effective by a significant margin, as shown in Figure 2, which provides cumulative discounted (present value) of costs, savings and net benefits through 2005 and 2010. Cumulative present value net benefits are almost \$70 billion through 2005 and almost \$200 billion through 2010. This magnitude of net economic benefits could be taken as leeway for yet more aggressive carbon reduction measures that have net incremental costs. However, the rather aggressive set of measures already embodied in the policy scenario of this study have costs per saved carbon-dioxide at the margin of about \$60/ton; identifying realistic additional measures at a reasonable cost in the time-frame of this study is difficult; further improvements in efficiency and greater reliance on alternative energy sources before 2005 are constrained by the slow capital stock turnover in the four sectors. Rather than implementing more aggressive measures that might incur substantial cost, an effective longer-term strategy would involve implementing and sustaining the policies discussed here (or variations upon them) while committing substantial resources to R&D for broad classes of promising technologies that can provide the basis for the deeper long-term carbon emissions reductions needed to prevent global warming.

{Figure 2}

Carbon Reductions in All Sectors in the Climate Protection Scenario

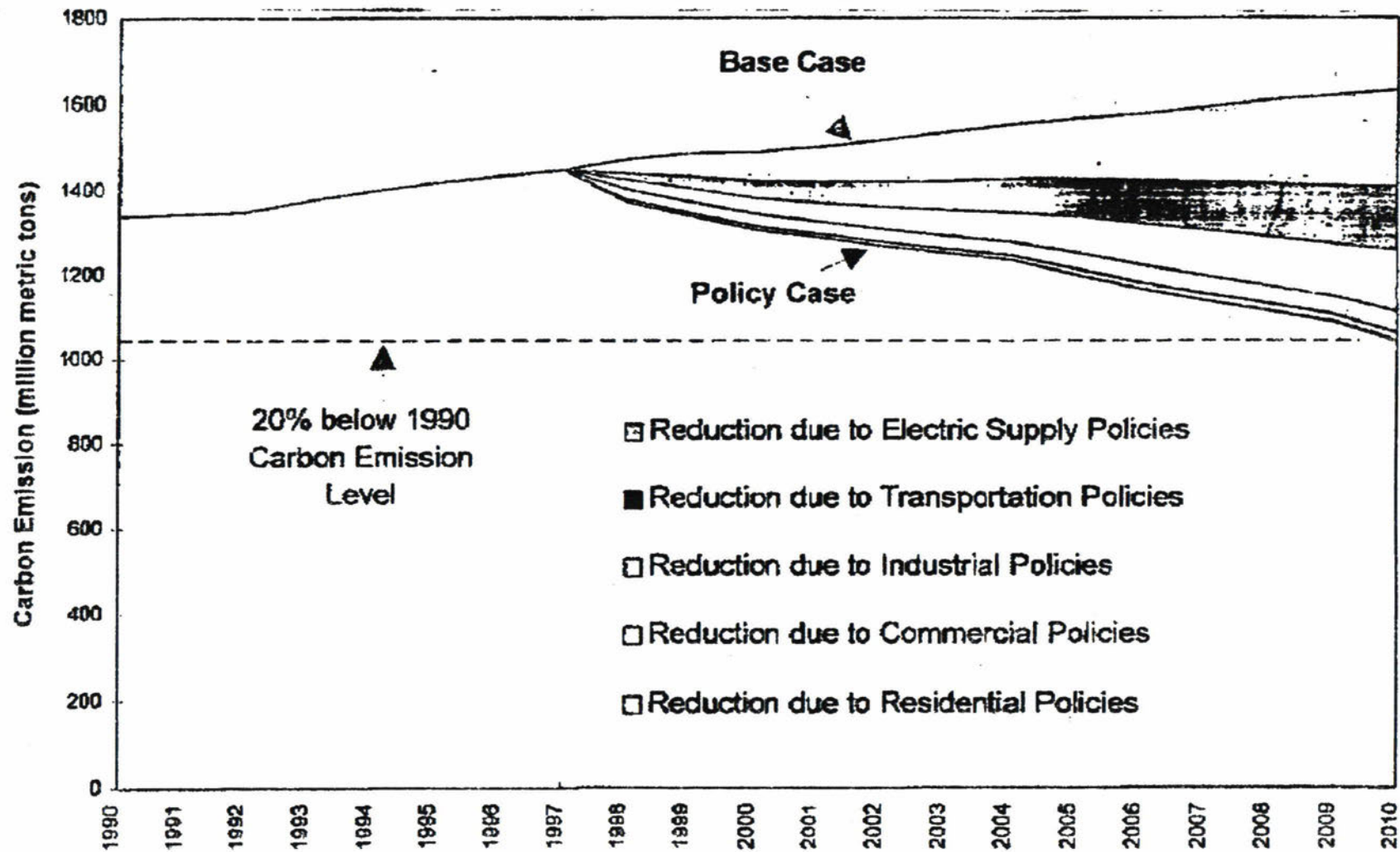


Fig 1

The Cumulative Present Value of Economy-Wide Costs, Savings and Net Benefits of the Climate Protection Scenario

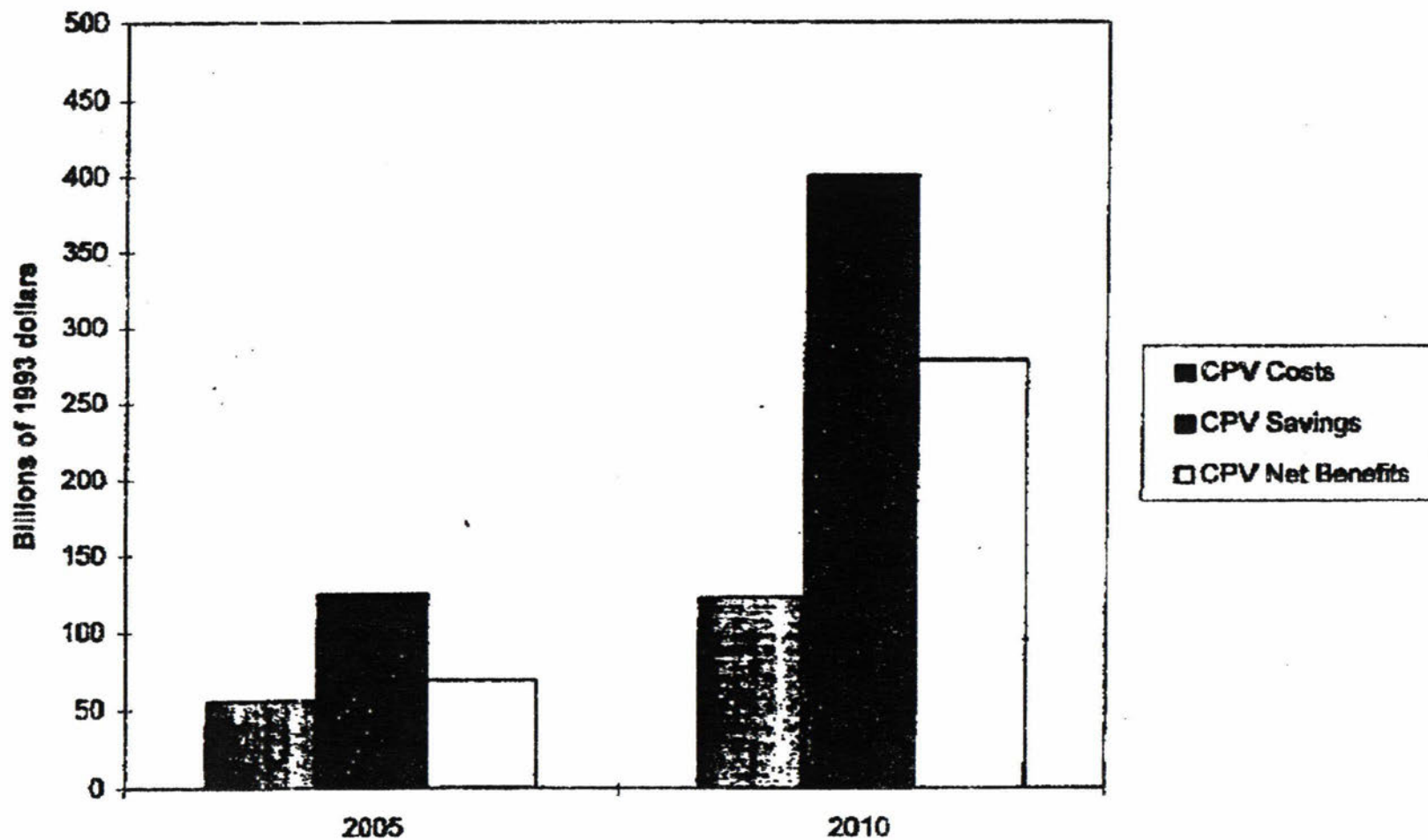


Fig 2



TO: World Wildlife Fund

FROM: The Mellman Group

RE: Support For Unilateral American Action To Curb Global Warming

DATE: October 9, 1997

This analysis reports the findings from a national survey of 1,012 adults who were interviewed by telephone October 3-7, 1997. The study is based on a random-digit dialing (RDD) probability sample of all telephone households in the continental United States which ensures that every telephone household had an equal chance of participating in the survey. The margin of error for the sample as a whole is +/- 3.1 percentage points at the 95% confidence level. The margin of error for subgroups varies and is larger.

Our previous survey provided the first comprehensive examination of public attitudes toward global warming. We found that while the issue may not be at the top of the public agenda, Americans nonetheless believe global warming is real and presents a serious threat. Also evident in that survey was a clear demand for action on the part of elected officials to curb carbon dioxide emissions. One piece of evidence for that public demand was the overwhelming support for an international treaty to reduce carbon emissions by 20% by the year 2005. Since then an intensive industry campaign has argued that the United States should not sign the treaty because it excludes the developing countries. Our latest survey was designed in part to test that argument.

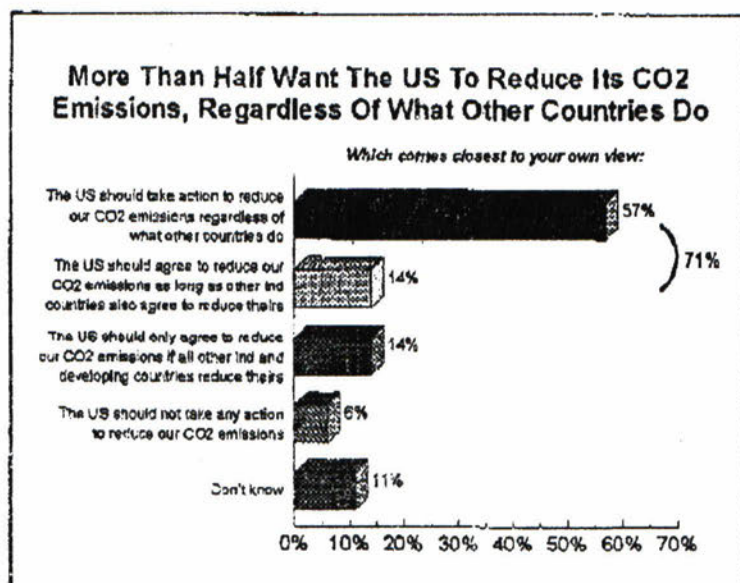
The results are clear. A majority of Americans support unilateral action on the part of the United States to reduce its carbon dioxide emissions to help stop global warming. There is strong support for an international agreement among the industrialized countries to reduce carbon dioxide emissions by the year 2005. Support for such an agreement is even stronger when respondents are told how much of the world's carbon dioxide emissions are produced by the United States, other industrialized countries and the developing world.

Another goal of this briefer study was to re-examine support for proposals to achieve carbon dioxide reductions through emissions credit trading schemes. Our earlier survey described these proposals in ways some regarded as negative, and we found majorities opposed. In this survey we offered a positive phrasing of these proposals and find support to be mixed at best. More Americans support a proposal to reduce emissions by establishing a worldwide limit and allowing countries to cut their own emissions or contribute to other countries' efforts to do so,

than support a similar plan for emissions reductions within the United States. However, neither proposal receives even majority support, let alone the overwhelming support found in our previous poll for regulatory action such as requiring cleaner burning engines in cars or requiring utilities to provide clean energy. Support for economic incentives, such as providing incentives to households to increase energy efficiency or to utility companies to sell clean energy, was also substantially greater than the support for trading proposals.

Americans Support Unilateral Action By The United States To Reduce Carbon Dioxide Emissions

Fully 71% of Americans believe that the United States and the other industrialized



countries of the world should agree to reduce carbon dioxide emissions **irrespective of what the developing countries do**. Indeed, more than half of Americans (57%) say that the United States should take action to reduce emissions **regardless of what any other countries do**. Despite an aggressive industry advertising campaign, only 14% believe that the United States should not agree to carbon dioxide emission reductions unless all the industrialized and all the developing countries agree to reduce their emissions. A mere 6% say the U.S. should do nothing to

curb its carbon emissions. The view that the United States should take action in this regard cuts across demographic and geographic groups, with those living in the West (65%) supporting unilateral action most strongly.

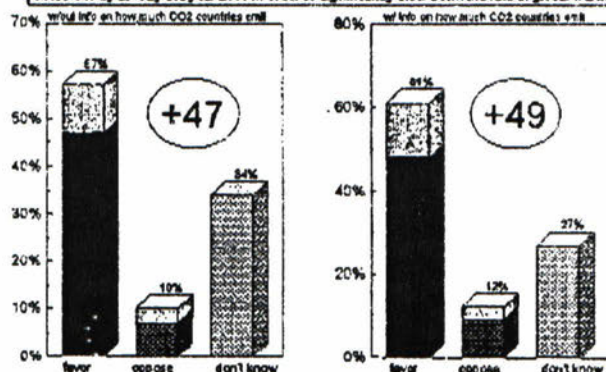
Americans Support A Treaty Among The Industrialized Nations

A majority of Americans (57%) support an international treaty to reduce carbon dioxide emissions by just the industrialized nations (47% strong support). A mere ten percent oppose such a treaty, while 34% are undecided. Another half of the respondents were also told that the United States has 4% of the world's population and produces 22% of the world's carbon dioxide emissions, the rest of the industrialized world produces 38%, and the developing countries produce 40% of the world's carbon dioxide emissions. Among this group, support for an agreement among the industrialized countries is 61%, while only 12% are opposed and 27% are undecided.

A Majority Support An International Treaty To Reduce CO2 Emissions Among Industrialized Nations

Support Remains Consistent When Respondents Learn How Much The US Produces Compared To Other Countries

It has been proposed that the industrialized countries of the world agree to reduce their CO2 emissions by 20% by the year 2005 in order to significantly slow down the rate of global warming.



Support for a treaty among the industrialized countries to limit carbon dioxide emissions remains strong even after respondents hear arguments for and against such a treaty. Respondents were read two arguments. One argued against the treaty saying:

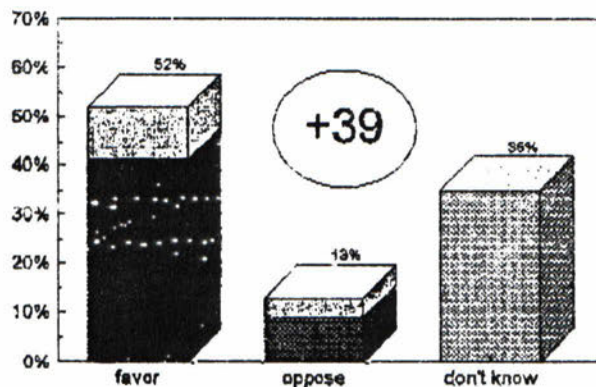
"making these reductions will mean much higher gas taxes, half a million lost jobs a year and will mean making major changes to our lifestyle. Opponents say that this treaty is not global because developing countries don't have to reduce their carbon dioxide emissions at all."

The other statement argued that:

"because the United States and the rest of the industrialized countries produced most of the carbon dioxide, we have a responsibility to limit carbon emissions no matter what other countries do. Supporters say these limits will help stop the effects of global warming which is causing increased respiratory problems, extreme weather and the destruction of animals and their habitats. They say the technology already exists to reduce carbon dioxide emissions without increasing taxes or costing jobs."

After hearing both arguments, still 52% support a treaty to limit emissions among industrialized nations, 13% oppose the treaty and just over a third (35%) are undecided.

After Hearing Arguments On Both Sides, A Majority Continue To Support A Treaty Among Industrialized Nations



Americans Are Mixed On Emissions Credit-Trading Proposals

Voters are evenly divided on a proposal to reduce carbon dioxide emissions in the United States by establishing a total limit on emissions and allowing businesses to bid for emission credits which they can then trade in order to choose between reducing their own emissions or paying other companies to reduce theirs in order to meet the overall limit more cheaply. One-third (33%) support such a proposal, while 34% oppose and 33% are undecided. There is slightly more support for a similarly structured global proposal which would give countries the right to discharge carbon dioxide up to a limit and trade their emissions credits with one another. Forty percent (40%) of Americans support such a plan, while 31% are opposed and 29% are undecided.

Our earlier poll asked similar questions; however, these particular proposals were framed as allowing companies and countries to bid for the "rights to pollute" -- what some regarded as a negative description of the proposals. In this survey these proposals were described more positively as "carbon emission credits." Support for the "carbon emission credits" proposals (within U.S. 34% oppose, 33% favor; worldwide 31% oppose, 40% favor) is greater than for "pollution rights" proposals (within U.S. 57% oppose, 29% favor; worldwide 56% oppose, 32% favor), though this support is still mixed at best. Thus, support for emissions credit proposals seems to be sensitive to how the proposals are described. While "pollution rights" are reviled, "carbon emission credits" generate a more even division. At the same time, even when framed very positively, these solutions are still far less popular than regulatory action or incentives. In substantial numbers Americans favor regulatory action to curb emissions such as requiring cleaner burning engines in cars (86% favor) or requiring utilities to offer clean energy (82% favor). They also strongly support incentives to help reduce emissions, such as incentives to households for energy efficient appliances (85% favor) and incentives to utility companies to encourage the sale of clean energy (81% favor).

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Gene / Dan / Kate / Todd -
PUI. Here's a
brand new paper
from RRR presenting
the "academic" rationale
for the hybrid approach.

-PUI

Prices vs. Quantities Revisited: The Case of Climate Change

William A. Pizer

Discussion Paper 98-02

October 1997



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Prices vs. Quantities Revisited: The Case of Climate Change

William A. Pizer

Abstract

Uncertainty about compliance costs causes otherwise equivalent price and quantity controls to behave differently. Price controls – in the form of taxes – fix the marginal cost of compliance and lead to uncertain levels of compliance. Meanwhile quantity controls – in the form of tradable permits or quotas – fix the level of compliance but result in uncertain marginal costs. This fundamental difference in the face of cost uncertainty leads to different welfare outcomes for the two policy instruments. Seminal work by Weitzman (1974) clarified this point and derived theoretical conditions under which one policy is preferred to the other.

This paper applies this principal to the issue of worldwide greenhouse gas (GHG) control, using a global integrated climate economy model to simulate the consequences of uncertainty and to compare the efficiency of taxes and permits empirically. The results indicate that an optimal tax policy generates gains which are five times higher than the optimal permit policy – a \$337 billion dollar gain versus \$69 billion at the global level. This result follows from Weitzman's original intuition that relatively flat marginal benefits/damages favor taxes, a feature that drops out of standard assumptions about the nature of climate damages.

A hybrid policy, suggested by Roberts and Spence (1976), is also explored. Such a policy uses an initial distribution of tradeable permits to set a target emission level, but then allows additional permits to be purchased at a fixed “trigger” price. The optimal hybrid policy leads to welfare benefits only slightly higher than the optimal tax policy. Relative to the tax policy, however, the hybrid preserves the ability to flexibly distribute the rents associated with the right to emit. Perhaps more importantly for policy discussions, a sub-optimal hybrid policy, based on a stringent target and high trigger price (e.g., 1990 emissions and a \$100/tC trigger), generates much better welfare outcomes than a straight permit system with the same target. Both of these features suggest that a hybrid policy is a more attractive alternative to either a straight tax or permit system.

Key words: Climate Change, Policy Under Uncertainty, Price and Quantity Controls, General Equilibrium Modeling

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Prices vs. Quantities Revisited: The Case of Climate Change

William A. Pizer¹

1 Introduction

Seminal work by Weitzman (1974) drew attention to the fact that, in regulated markets, uncertainty about costs leads to a potentially important efficiency distinction between otherwise equivalent price and quantity controls. Despite this well-known observation and its relevance for climate change policy, most of the debate concerning the use of taxes and emission permits to control greenhouse gases (GHGs) has centered on political, legal and revenue concerns. This paper responds to this important omission by examining the efficiency properties of permit and tax policies to reduce global warming.

The basic distinction among policy instruments arises because taxes fix the marginal cost of abatement at the specified tax level (assuming optimal firm behavior). With uncertainty about costs, this generates a range of possible abatement levels and emission outcomes. In contrast, a permit system precisely limits emissions but leads to a range of potential cost outcomes. When coupled with a model of the benefits associated with emission reduction, this divergence in emission and cost outcomes creates a distinction in the expected welfare associated with each policy.

In the case of climate change, part of the cost uncertainty arises due to uncertainty about the level of future baseline emissions. The Intergovernmental Panel on Climate Change (1992) gives a range of CO₂ emission levels in 2025 of between 8.8 and 15.1 GtC.² The cost of attaining a particular target, say the 1990 emission level of 7.4 GtC, will obviously fluctuate depending on the level of future uncontrolled emissions.

In addition to the baseline, however, there is considerable uncertainty about the cost of reducing emissions below the baseline. A study by Nordhaus (1993) reports that a \$30/tC tax might reduce

¹Fellow, Quality of the Environment Division, Resources for the Future. Financial support from the National Science Foundation is gratefully acknowledged (Grant SBR-9711607). Richard Morgenstern, Raymond Kopp and Richard Newell, along with seminar participants at the CEA and RFF, provided valuable comments on an earlier draft. The author alone is responsible for all remaining errors.

²Gigatons Carbon.

emissions anywhere from 10 to 40%. While some models predict that a \$300/tC would virtually eliminate emissions, other models require a tax in excess of \$400/tC. This wide range of reduction estimates only compounds the uncertainty about baselines to generate extreme uncertainty about the cost of a particular emission target fifteen or twenty years in the future.

Motivated by the policy implications of these large uncertainties, this paper uses a modified version of the Nordhaus (1994b) integrated climate-economy model in order to analyze alternative policies under uncertainty. In particular, the model incorporates uncertainty about a wide range of model parameters developed in both Nordhaus (1994b) and Pizer (1996). The simulations are then sped up using a technique presented in Pizer (1996) that greatly facilitates computation. Key elements of the model are discussed in the next section while specifics are covered in Appendix A.

Before presenting the multi-period policy results in Section 4, Section 3 presents a simpler one-period analysis. This analysis, following Weitzman, uses marginal cost and benefit estimates derived from the full multi-period dynamic model to examine optimal policy for the single year 2010, ignoring the policy choice in future years. This simpler analysis provides considerable intuition for the full multi-period policy analysis and, surprisingly, closely replicates the optimal multi-period policy results in 2010.

The simulations indicate that an optimal permit policy would begin with a 13 GtC target in 2010, rising gradually over time to accommodate some economic growth. This policy generates \$69 billion in expected net benefits versus a no policy, business-as-usual alternative. Importantly, this gain is very sensitive to correctly setting the target. Slightly more stringent targets lead to dramatic welfare losses. Meanwhile, the optimal tax policy starts at \$7/tC in 2010 and also rises gradually over time. In contrast, this policy generates \$337 billion in net benefits and the gain is much less sensitive to the exact choice of tax level.

As an alternative to both the pure tax and permit policies, a combined hybrid policy is proposed (Roberts and Spence 1976; Weitzman 1978; McKibbin and Wilcoxon 1997). Such a mechanism would involve an initial distribution of tradeable permits, with additional permits available from the government at a specified “trigger” price. This system turns out to be only slightly more efficient

than a pure tax system, but allows a flexible distribution of rents associated with emission rights due to its permit system component. Perhaps more importantly for current policy discussions, sub-optimal hybrid policies based on a stringent target and high trigger price have much better welfare outcomes than a sub-optimal permit policy with the same target. Both the improved flexibility and better welfare outcomes make the hybrid policy an attractive alternative to either permits or taxes alone.

2 Background

2.1 Weitzman's Result

The analysis presented in Weitzman (1974) concerns the choice of policy instrument used to regulate a market where either political considerations or market failure require government intervention. A price (tax) or quantity (permit) instrument is at the government's disposal and the question posed by Weitzman is which of the two leads to the best welfare outcome, measured as net social surplus.³ Importantly, the policy must be fixed *before* any uncertainty is resolved.

With complete certainty concerning costs, price and quantity controls can be used to achieve the same outcomes. For every price, there is a profit maximizing level of production where price equals marginal cost and for every level of production there is an associated marginal cost. Note that while uncertainty about *benefits* leads to uncertain welfare outcomes, it does not lead to uncertainty about the level or marginal cost of production – these are determined by the structure of costs. Therefore, the two instruments (which affect production) can be used to obtain exactly the same production outcome, generating the same set of welfare outcomes, as long as costs are known.

The interesting case arises when *costs* are not certain. Then, fixing the marginal cost through a price instrument leads to an uncertain level of production. Correspondingly, fixing the level of production with a quantity instrument leads to an uncertain marginal cost.

Weitzman's basic result was that price instruments would be favored when the marginal benefit

³Here and throughout it is assumed that the quantity instrument is an *efficient* quantity instrument; e.g. a tradeable permit system with negligible transaction costs.

schedule was relatively flat and quantity instruments would be favored when the marginal cost schedule was relatively flat. In particular, he derived an expression for the difference in expected welfare between the price and quantity instrument:

$$\Delta = \frac{\sigma^2}{2C''^2}(B'' + C'') \quad (1)$$

where σ^2 is the variance of the shocks to the marginal cost schedule, C'' is the slope of the (linear) marginal cost schedule and B'' is the slope of the (linear) marginal benefit schedule.⁴ Since the marginal benefit schedule is assumed to be downward sloping ($B'' < 0$), the price instrument is preferred when $|B''| < |C''|$ and the quantity instrument is preferred when $|B''| > |C''|$.

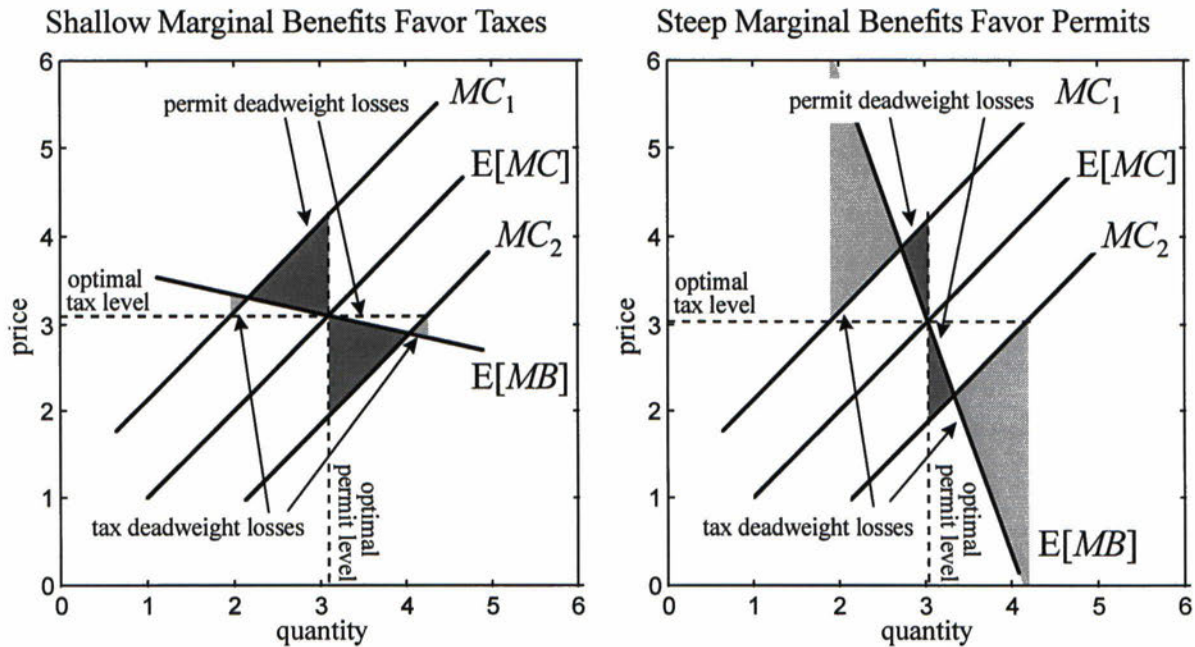
The intuition behind this result is that when marginal benefits are relatively flat ($|B''| < |C''|$), the optimal price *after* uncertainty is resolved remains relatively constant over the range of potential cost outcomes. Therefore, fixing the price before the outcome is known leads to levels of control that are “close” to what would be chosen after uncertainty is resolved. In contrast, when marginal benefits are relatively steep ($|B''| > |C''|$), the optimal quantity is relatively constant over the range of outcomes. In that case, fixing the quantity in advance leads to results close to what would be chosen after uncertainty is resolved. By choosing policies that provide levels of control close to what what would be chosen after uncertainty is resolved, the deadweight loss is minimized. This is shown visually in Figure 1.

2.2 Combining Taxes and Permits

Not long after Weitzman’s original article, several authors suggested using a hybrid permit policy (Weitzman 1978; Roberts and Spence 1976) to regulate a market. That is, producers are given the choice of either obtaining a permit in the marketplace or purchasing a permit from the government at a specified trigger price. Such a system works like a permit system by fixing emissions as long as the marginal cost (e.g., the price of the permit) lies below the trigger price and works like a tax system by fixing marginal cost when marginal cost hits the trigger price. When the trigger is set

⁴This result is derived for the case of linear marginal costs and benefits, where uncertainty enters as small shifts to each curve (therefore the slopes B'' and C'' are known with certainty). The uncertainty about costs is assumed to be independent of the uncertainty about benefits.

Figure 1: Deadweight Loss of Taxes Versus Permits^a



^a $E[MB]$ indicates expected marginal benefits, $E[MC]$ indicates expected marginal costs, and MC_1 and MC_2 indicate alternative cost outcomes.

high, such a combined mechanism functions like a pure permit system (since additional permits are never sold) and when the number of permits is set low, it functions like pure tax mechanism (since additional permits are always sold). By encompassing both tax and permit mechanisms as special cases, the hybrid policy should always perform at least as well as either one.

Recently, a paper by McKibbin and Wilcoxon (1997) proposed just such a hybrid policy to address the problem of global climate change, but not based on these efficiency arguments. Instead, they discuss the merits of a hybrid policy in comparison to a strict 1990 emission target in a certainty context. Based on a trigger price of \$10/tC (at which price additional permits would almost certainly be sold), McKibbin and Wilcoxon argue that the hybrid policy would lower costs, improve monitoring and enforcement, and avoid disruptive international capital flows. While the lower cost would come at the expense of a less stringent policy, they argue that a 1990 target is unrealistic. They also point out that a hybrid system would preserve the permit system's ability to flexibly distribute the rents associated with emission rights while, at the margin, providing a

revenue incentive for governments to enforce and monitor emissions.⁵ Finally, they point out that an efficient international permit system involving international permit trades would lead to potentially large trade distortions.

While their points concerning the benefits of a hybrid policy under complete certainty are important, they are tangential to the question addressed in this paper. That is, what are the expected welfare gains associated with alternative policies under *uncertainty*. More to the point, it turns out that these welfare gains are large enough to potentially dwarf almost all other concerns.

2.3 Model Description

This analysis uses a global integrated climate economy model containing a stylized representation of global economic activity and climate behavior. The stylized approach, based on Nordhaus (1994b), is appropriate given this paper's focus on uncertainty. While additional detail in both the climate and economy modules might improve the results for a particular set of assumptions or provide answers to other questions, it is unlikely that such embellishments would affect the range of predicted aggregate outcomes or the insight concerning optimal policy choice under uncertainty.

Economic behavior in this model involves a single sector of global economic activity. Global capital and labor are combined to produce a generic output each year which is either consumed or invested in additional capital. A representative agent chooses that amount of consumption each period which maximizes her expected utility across time.

Climate change enters the model through the emission of greenhouse gases arising from economic activity. These emissions accumulate in the atmosphere and lead to a higher global mean temperature. This higher temperature then causes damages by reducing output according to a quadratic damage function.

The opportunity to reduce the effect of climate change arises from the use of more expensive, GHG reducing, production technologies. In particular, there is a cost function describing the reduction in output required to reduce emissions by a given fraction. This cost function captures

⁵As pointed out by Goulder, Parry, and Burtraw (1996), losing the revenue from such rents could also have important welfare consequences.

substitution both among and away from fossil fuels. While the cost of reductions in any period are born entirely in that period, the consequences of reduced emissions persist far into the future due to the longevity of greenhouse gases in the atmosphere.

Appendix A describes the model in more detail.

2.4 Key Modeling Assumptions

Repetto and Austin (1997) point out that many of the prediction differences among climate change models can be linked to differences in a few key assumptions. For that reason, it is instructive to highlight how such issues are handled in this model. Two of the assumptions they identify – the use of a computable general equilibrium (CGE) framework and the provision of revenue recycling options – are impossible to explore in this model (due to the fact that it is already a CGE model without a government sector). However, the remaining assumptions considered by Repetto and Austin are related to alternative descriptions of costs and benefits.

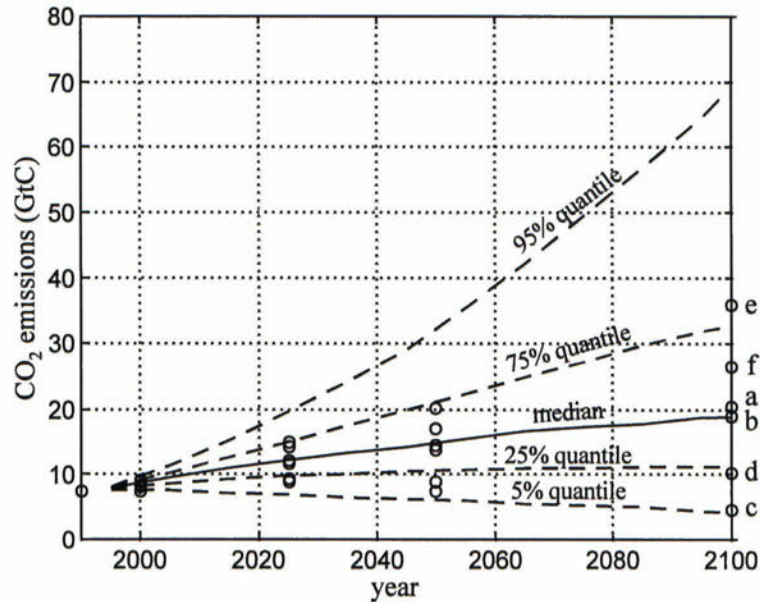
Costs and benefits vary widely in this model due to uncertainty. Still, realized costs and benefits can be traced to two distinct sets of assumptions: those addressing underlying trends and those addressing abatement costs and climate damages directly.

2.4.1 Trends

Trends are essential features in any model with long time horizons since they determine the course of exogenous change. Particularly in the climate change context, assumptions about (1) exogenous population growth, (2) productivity improvements and (3) energy efficiency/carbon content determine the baseline of future uncontrolled greenhouse gas emissions – and by extension the baseline for costs and benefits. This model combines the work of Nordhaus and Yohe (1983), Nordhaus (1994b), Pizer (1996), and Nordhaus and Popp (1997) to characterize each of these trends. Within each state of nature, these three trends are governed by an initial growth rate coupled with an associated slowdown.⁶

⁶The trend in productivity growth is further overlayed with a mean-zero random walk.

Figure 2: Simulated CO₂ Emission Distribution vs IPCC Scenarios



^aLines indicate the distribution of CO₂ emission paths generated by the model. These reflect controllable carbon equivalent GHG emissions, scaled by the fraction due to CO₂ (e.g., 86.6%; see p. 71, Nordhaus 1994b). Circles (o) indicate 1992 IPCC CO₂ emission scenarios (p. 12, IPCC 1992; pp. 101–112, Pepper et al. 1992); letters in right margin refer to individual scenarios.

Table 1: Summary of Baseline Trend Assumptions

	range	source
Global Output (\$ trillions, 1995)	24	Nordhaus (1994b) ^a
Emissions/Output Ratio (tC billions/\$ trillions, 1995)	0.385	Nordhaus (1994b) ^a
Population Growth (1995)	1.24%	Nordhaus (1994b) ^a
Productivity Growth (1995)	0.16 to 2.46%	Pizer (1996)
Emission/Output Ratio Growth	−0.11 to −2.31%	Nordhaus and Popp (1997)
Population Slowdown Rate	0.27 to 3.31%	Nordhaus (1994b)
Productivity Slowdown Rate (also used to slow the growth in the emissions/output ratio)	0.20 to 2.43%	Nordhaus (1994b)

^a Adjusted to 1995.

While Table 1 summarizes the range of underlying trend assumptions, the consequent distribution of CO₂ emission scenarios is shown in Figure 2 along with the 1992 IPCC projections. The IPCC forecasts tend to fall between the 25th and 75th percentile in 2025 and between the 5th and 75th by the years 2050 and 2100. The median of the IPCC forecasts remains quite close to the median (50th percentile) of the simulated emission levels throughout the forecast period. This suggests that, relative to the IPCC forecasts, the model in this paper predicts a similar central tendency but with a larger spread. In particular, this paper suggests that future uncontrolled emissions could be much higher than all six of the IPCC forecasts. For several reasons, this is arguably a realistic assessment.

First, it is important to recognize that the IPCC scenarios do not have a probabilistic interpretation. They are subjectively developed scenarios combining a large number of alternative assumptions in six particular combinations. Their two high emission scenarios, for example, alternatively combine high population growth with lower per capita productivity growth, and vice versa. Further, the underlying growth forecasts themselves have little if any probabilistic interpretation.⁷

Second, even analyses that are well-grounded in probability often underestimate the probability of extreme events. This phenomena has been documented in everything from the measurement of physical constants to the forecast of future energy demand (Shlyakhter and Kammen 1992). Such results suggest that forecasts with “thicker tails” (like the distribution in Figure 2) are a more realistic description of the likely outcome distribution.

Finally, the time horizon under consideration – over one hundred years – makes any forecast based on historical data somewhat dubious. Such forecasts implicitly assume that recent historical trends will continue far into the future without appreciable change. For example, based on recent experiences with growth slowdowns, global CO₂ emissions – which tripled over the last fifty years – are forecast to triple again only after one hundred years. It is quite plausible, however, that this assumed slowdown could fail to materialize. If emissions continued to triple every fifty years, this

⁷See Pepper et al. (1992) for further details. Note that early Census population forecasts using similar non-probabilistic techniques often grossly misforecast population. For example, the forecast range given in 1966 (#381, U.S. Department of Commerce, Bureau of the Census) lies completely above the actual population reported in 1989 (#1045).

would essentially agree with the 95% quantile of the predicted emission distribution.

All of these reasons indicate that while the assumptions in Table 1 and emission forecasts in Figure 2 are not above question, they provide a reasonable probabilistic picture of the likely emission outcomes.

2.4.2 Damages

Damages are perhaps the least understood aspect of climate change and at the same time one of the most important. In this model, damages are modeled as a quadratic function of temperature change, in turn determined by GHG concentrations. In particular,

$$\text{fractional reduction in GDP due to damages} = 1 - \frac{1}{1 + D_0/9 \cdot T^2}$$

where T is the change in temperature relative to a pre-industrialization (1860) baseline and D_0 is a parameter describing the GDP reduction associated with a 3° temperature increase.⁸

In addition to the parameter describing the GDP loss from increased temperatures, two other parameters affect the degree of climate damages. First, there is a parameter describing the fraction of emitted GHGs which actually accumulate (versus those which are absorbed in the oceans). Second, there is a parameter describing the change in temperature for a doubling of atmospheric GHG concentrations. Table 2 describes the range of assumed values for all three parameters.

There are also two implicit assumptions which influence the final results concerning taxes and permits. The first is that climate damage is presumed to be a gradually occurring phenomenon (represented by a quadratic function). The fact that damages from increased GHG concentrations rise smoothly and gradually contributes to the relatively flat marginal benefit schedule discussed in Section 3.1. In contrast, a damage function that involved sudden and/or critical phenomena – such as the breaching of a concentration threshold generating dramatically higher damages – would lead to a steeper or perhaps stepwise damage function (though uncertainty about the threshold level would tend to smooth the expected damage function).

⁸This function is almost identical to specifying fractional damages = $-D_0/9 \cdot T^2$ as long as the damages are less than 5% of GDP. The more complex specification simply prevents global GDP from becoming negative.

Table 2: Summary of Climate Damage and Abatement Cost Assumptions^a

description	probability parameter equals the given value				
	20%	20%	20%	20%	20%
Damage Assumptions:					
fraction of emitted CO ₂ which accumulates	0.50	0.59	0.64	0.69	0.78
change in temperature from CO ₂ doubling	1.5	2.2	2.9	3.7	4.4
GDP loss ^b for 3 degree rise in temperature	0.0	0.4	1.3	1.6	3.2
Cost Assumptions:					
GDP loss ^b for 100% reductions	2.7	3.4	6.9	8.0	13.3
GDP loss ^b to obtain 1990 emissions in 2010 ^c	0.08	0.11	0.21	0.25	0.41

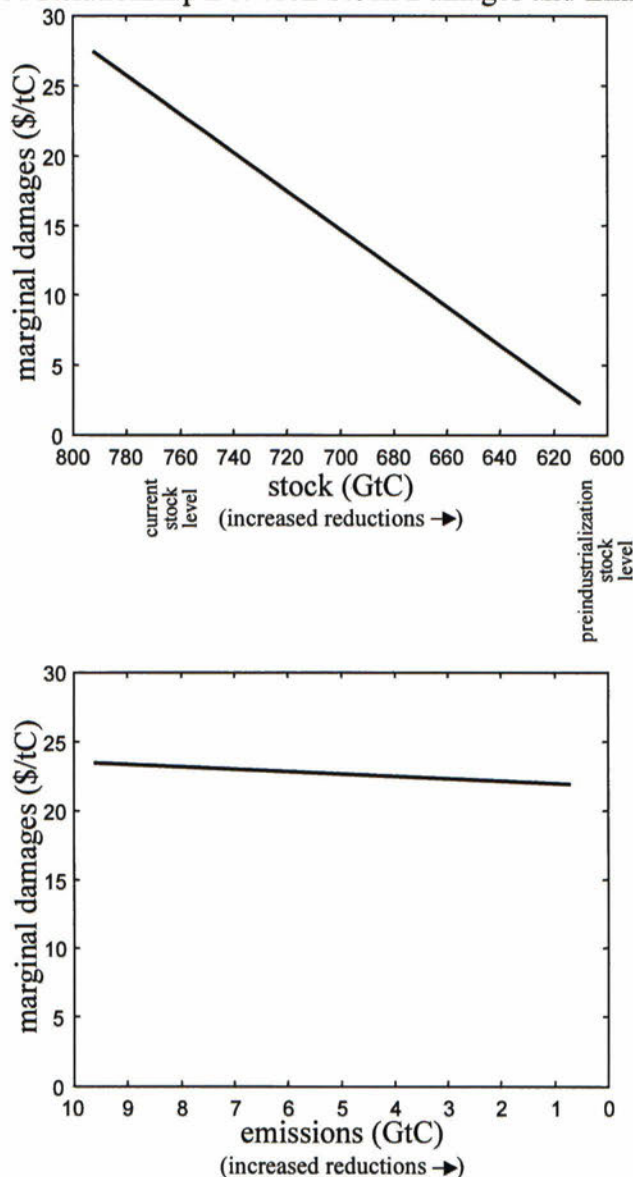
^aSource: Nordhaus and Popp (1997).^bAs a percent of global GDP.^cAssuming a 30% reduction from baseline.

The second, less controversial, assumption is that damages are related to the *stock* of GHGs in the atmosphere and not the annual *flow*. This contrasts with traditional pollutants, such as particulates, SO_x, NO_x, etc., whose damages are related to annual flows. Stock pollutants by their nature will have relatively flat benefit curves associated with emission reductions since the reductions in any period have a relatively small effect on the total stock. Even though emissions in one period persist far into the future, the volume of emissions in a single period always remains a tiny fraction of the existing stock. If the total stock changes by a small amount – even if that change persists – the marginal benefit schedule remains essentially constant.

To better understand this phenomenon, imagine a pollutant, like carbon dioxide, where it is assumed that damages depend on the stock of the pollutant. Presumably, the damages themselves are not linear (i.e., directly proportional to concentrations) but rise by an increasing amount as the stock rises. The damage from the first ton of CO₂ above the preindustrial baseline is small, while the incremental damage from an additional ton of CO₂ on top of current concentrations is much larger – as depicted in the top panel of Figure 3. In that panel, damages from the first ton of CO₂ above the preindustrial baseline are around \$1/tC but damages from an additional ton of CO₂ once emissions reach the current level of 760 GtC are over \$20/tC.

Now suppose that total annual emissions are currently 10 GtC and, for simplicity, a ton of emis-

Figure 3: Stylized Relationship Between Stock Damages and Emission Damages^a



^aThis figure highlights the fact that reductions in any one period are a relatively small fraction of the total stock of GHGs. Therefore, for any smooth damage function determined by the GHG stock (in turn implying somewhat linear marginal damages for the GHG stock), the marginal damage function for emissions in any one period is essentially flat. It simply expands a tiny segment of the stock marginal damage schedule over the range of possible policy choices. This ignores the possibility that emission reductions in one period may be associated with emission reductions in other periods, in turn leading to a steeper slope in the future.

sion reductions translates into exactly one ton of reduced stock.⁹ Even if emissions are reduced to zero, the stock – and by extension marginal damages – fall only slightly, as shown in the lower panel of Figure 3. This is because annual emissions are only a small fraction of the total stock.

There are three important caveats to this point. The first, noted above, is that damages are assumed to be relatively smooth. If, for example, the marginal damages rose dramatically at around 750 GtC, the graphical argument in Figure 3 would fail. The second is that there are likely to be ancillary benefits associated with GHG reductions. In particular, the reduced burning of fossil fuels promises to reduce concentrations of particulate matter, SO_x and NO_x, all of which have non-trivial morbidity and mortality benefits.¹⁰

Finally, it presumes that reductions in different periods are unrelated. If reductions in one period are accomplished only in conjunction with reductions in other periods, such a presumption is wrong. As an extreme example, suppose emission reductions in one period imply equal reductions in all future periods. In this scenario, emission reductions in one period would eventually lead to proportional reductions in the stock after enough periods elapsed. While Figure 3 would be an appropriate rendering of the immediate effect of emission reductions on the pollutant stock, the effect on the stock in future periods would be more dramatic as the associated reductions in future periods took effect.

There are several reasons to think that such a relation is plausible. First, certain decisions about emission reductions – namely investments in research, fixed plant and equipment – affect emissions in many periods. While it is unlikely that marginal adjustments in emissions would be completely restricted by such decisions, some linkages are inevitable. Second, some policies, such as taxes, will lead to increased or decreased controls in every period depending on whether costs turn out to be high or low in each state of nature. In both cases, however, it remains an empirical question whether these effects significantly affect the otherwise flat slope of the marginal benefit schedule.

⁹In reality it translates into something less than a ton of reduced stock in the atmosphere since between 25 and 50% of emissions are quickly absorbed in the oceans.

¹⁰See, for example, Burtraw and Toman (1997).

2.4.3 Costs

The cost of reducing GHG emissions below the uncontrolled baseline is based on a survey of studies summarized in Nordhaus (1993). These studies consider the cost of reducing GHG emissions through various means, including the use of specific technologies, econometric estimates of fuel substitution, and mathematical programming. The relationship and range of estimates is approximated in Nordhaus (1994b) by a power rule,

$$\text{fractional reduction in global GDP} = b_1 (\text{fractional reduction in GHG emissions})^{2.887}$$

where the parameter b_1 takes on the values shown in Table 2.

More important than the particular numbers entering the cost function, however, are the assumptions that (1) marginal costs rise more and more steeply as additional reductions are undertaken and (2) that the choice of emission level is an annual decision involving an annual cost function. Both of these points are crucial because they affect the relative slope of marginal costs. This, in turn, affects the difference in expected welfare between taxes and permits discussed in Section 2.1.

If, for example, we believe that substantial reductions of GHGs will involve the development of new carbon-free technologies, it seems reasonable that the marginal cost of reducing emissions will eventually flatten once those technologies are brought on-line. This will diminish the argument that marginal benefits are relatively flat compared to costs. Alternatively, many decisions to reduce emissions – such as investment in innovative research or in new capital – are made over horizons of decades rather than annually. This introduces a positive correlation of among costs and potentially reductions in different periods. As pointed out previously, such correlation makes the benefits associated with a reduction decision in one period more valuable than the actual reductions in that period alone. This effect tends to favor quantity controls.

3 Single-Period Policy Simulations

Given the long-term nature of climate change, a policy to reduce GHG emissions inevitably involves decisions over periods of years or decades. However, understanding the differences between GHG tax and permit mechanisms under uncertainty is complicated when policies are viewed as paths for tax and permit levels, rather than single-period, single-valued choices. With that in mind, this section presents welfare results for a single-period policy analysis – reductions in GHG emissions in the year 2010. Since a single dimension captures the range of policies in this context, graphs can be used to view policy consequences. It should be emphasized that while the policy is only implemented in a single period, the measurement of costs and benefits especially includes consequences over a 250 year horizon. Section 4 discusses the multi-period policy results.

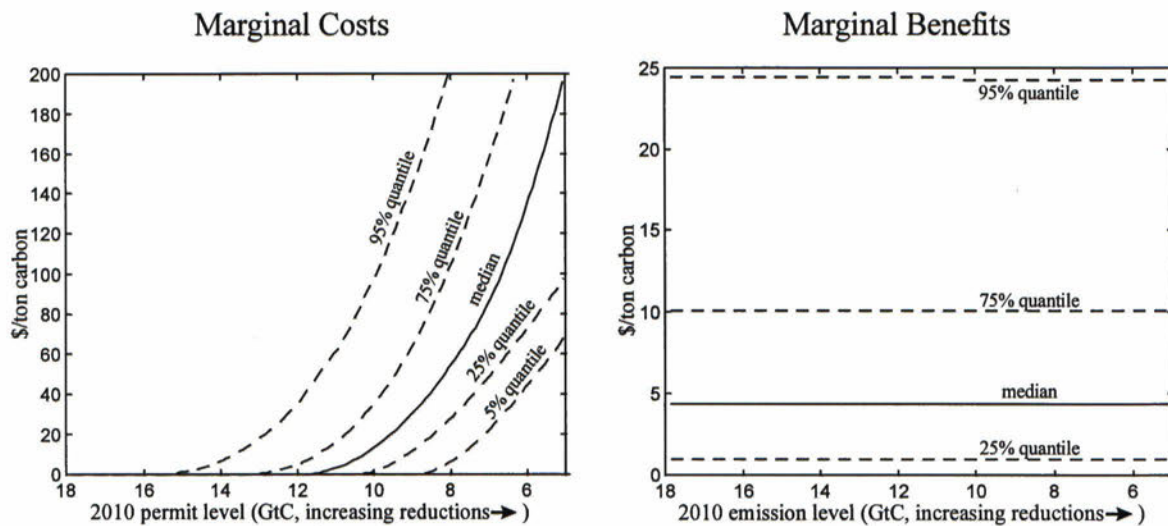
3.1 Marginal Costs and Benefits

While there are a number of strong assumptions in the Weitzman analysis which are inappropriate for examining climate change policy, it remains a sensible starting point. Based on that principle, the obvious question is how the marginal costs and benefits of GHG emission reductions in the year 2010 compare in terms of relative slopes. In order to answer this question, the integrated assessment model outlined in Section 2.3 and described in detail in Appendix A is used to compute costs and benefits.

First, the welfare associated with different levels of emissions in 2010 is computed in net present (2010) value terms for several thousand randomized trials. Marginal benefits are computed by numerically differentiating the derived schedule of benefits. Second, the cost associated with achieving different levels of emissions in 2010 is computed based on the model's cost function for the same set of randomized trials. This cost is similarly numerically differentiated to obtain marginal costs in the year 2010. In some trials and for some levels of emissions, the cost is zero since the given emission level may be higher than actual uncontrolled emissions. Achieving the specified emission level in such cases is costless.

These two calculations result in a distribution of marginal benefits and marginal costs at dif-

Figure 4: Distribution of Marginal Costs and Benefits in 2010^a

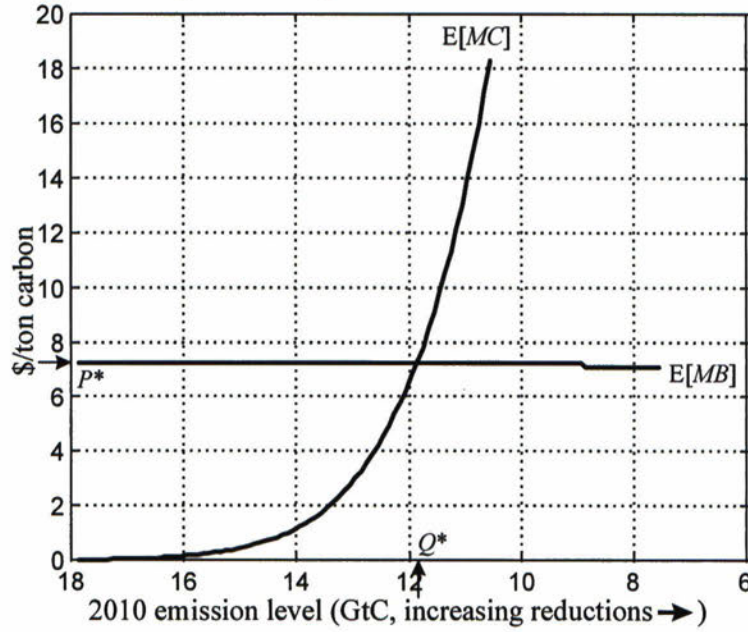


^aMarginal costs are based on dollar value (\$2010) of lost global GDP in order to reduce emissions at or below the indicated level. In those cases where uncontrolled emissions are below the indicated level, the marginal cost is zero. Marginal benefits are based on the dollar value (\$2010) of the net present value of forgone damages at the given emission levels. These foregone damages hold constant all future emissions at their baseline level. Values are expressed in \$2010 and, due to different discount rates across states of nature, will not be weighted equally when balancing costs and benefits.

ferent levels of emission. Figure 4 attempts to summarize these distributions by showing how the different quantiles of marginal costs and benefits vary over the range of emissions considered. Keeping in mind that 1990 GHG emissions were around 8.5 GtC, the left-hand panel indicates that achieving 1990 emission levels in 2010 would involve a marginal cost of between zero and \$180/ton – a very wide range. This large variation occurs for two reasons: (1) marginal costs are assumed to rise steeply given the specified cost function, and (2) the baseline emissions in 2010 are not known with certainty. This panel essentially depicts a distribution of fairly steep curves whose horizontal intercept is unknown.

The right panel, in contrast, indicates constant but still unknown marginal benefits. As suggested earlier, the fact that damages due to GHGs depend on their stock in the atmosphere rather than emissions in any one year, coupled with the fact that GHGs remain in the atmosphere for a very long time, makes marginal benefits insensitive to the level of annual emissions in a single year. For example, in 1995 the stock of GHGs in the atmosphere was 760 GtC (170 GtC above the pre-industrial baseline) and annual emissions were around 10 GtC. The difference in stock between

Figure 5: Expected Marginal Costs and Benefits in 2010^a



no reductions and 100% reductions in 1995 is only 6% of the stock,¹¹ making it unlikely that the marginal benefit of the first ton of reductions is much different than the marginal benefit of the last ton.

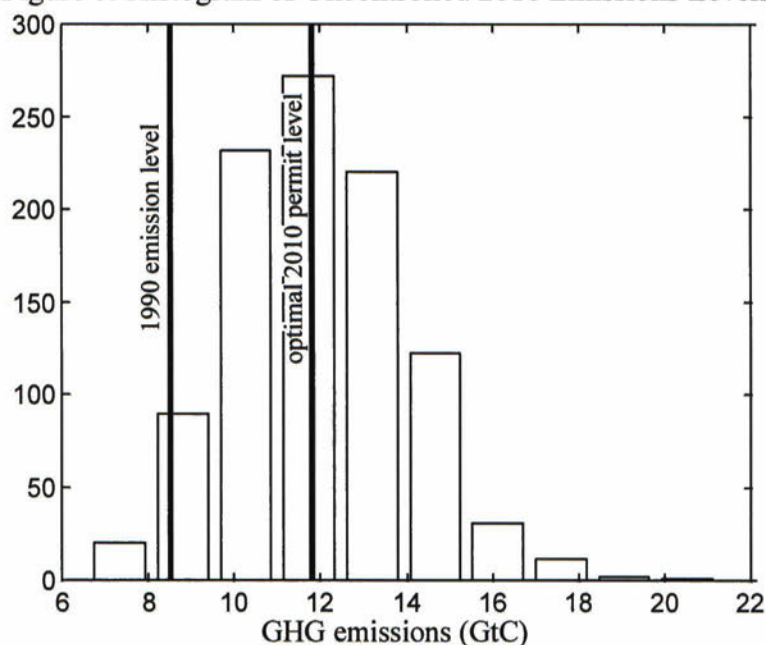
Taking expectations across these marginal costs and benefits yields the schedules shown in Figure 5. Under the assumptions made by Weitzman, the optimal permit level is simply emission level where expected marginal benefits equal expected marginal costs and the optimal tax level is similarly the expected marginal benefit at that intersection. Thus P^* and Q^* indicate the optimal tax and permit policies in 2010 for controlling GHG emissions.

Visually, it is apparent that expected marginal benefits are flatter than expected marginal costs. Calculating the slopes at the intersection, $B'' = -0.0012$ and $C'' = 5.4$. Further, setting $\sigma^2 = \text{var}(MC_{\text{emissions}=11.9\text{GtC}})$ yields $\sigma^2 = 270$. This allows a rough calculation of the welfare gain of taxes over permits using Equation (1): $\Delta = \frac{270}{2 \cdot 5.4^2} (-0.0012 + 5.4) \approx \25 billion. Discounting this to 1995 (the base year of the model) with a 6% discount rate generates an estimated gain of \$10 billion from using taxes instead of permits – just in the year 2010.

In addition to the welfare difference, it is interesting to compare the optimal quota in 2010 to

¹¹This ignores the fact that perhaps only 50% accumulates.

Figure 6: Histogram of Uncontrolled 2010 Emissions Levels

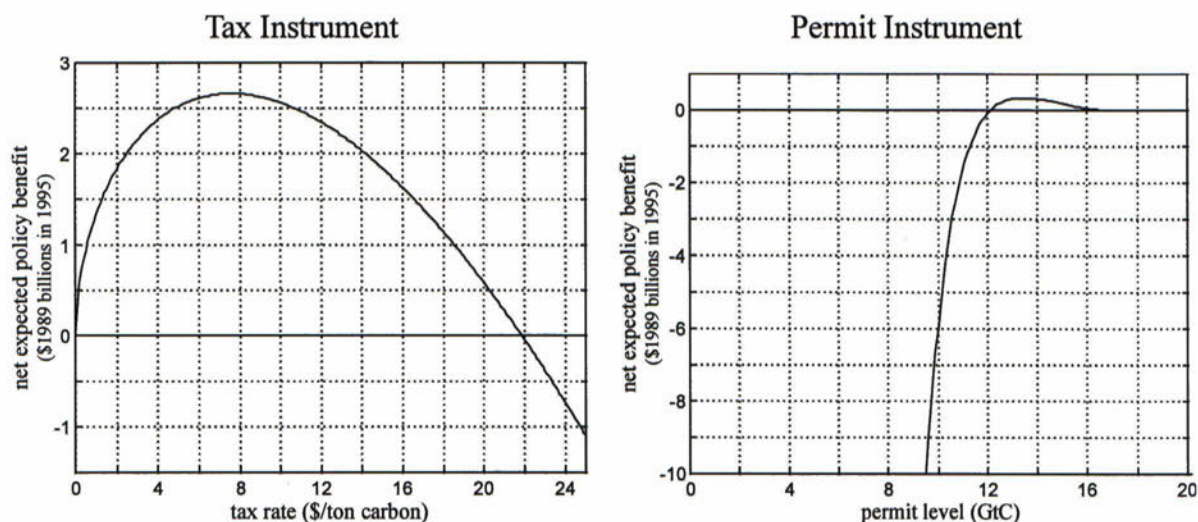


^aGHG emissions include CO₂ and CFCs. 1990 emissions are based on 7.4 GtC of CO₂ and 1.1 GtC of CFCs (p. 71, Nordhaus 1994b). The 1990 emissions also correspond to data from IPCC(1992), p. 12, using a factor of 1300 to convert tons of CFCs into tons of carbon equivalent global warming potential (GWP) (Lashof and Ahuja 1990). The optimal 2010 permit level is discussed in the text.

the range of actual emissions. Figure 6 shows 1990 emissions (a target under consideration), the optimal 2010 permit level, and the distribution of uncontrolled emissions in 2010. Roughly half of the emission scenarios involve uncontrolled emissions *below* the optimal permit level (versus around 3% below the 1990 level). That is, implementing the optimal permit policy would result in non-binding targets half the time.

Why is the optimal permit policy so loose? Intuitively, uncertainty about baseline emissions is large relative to reductions and a large amount of reductions is costly. Therefore committing to an emission target which is almost surely below all forecasts (such as 1990 emissions levels) will involve extremely high costs in the event of high growth and high baseline emissions. The risk of such high costs, even taking into account the highest estimated benefits, are unjustified in this model and lead one to prefer a less stringent (higher) target.

Figure 7: Welfare Consequences of Pure Tax and Permit Instruments in 2010



3.2 Welfare Consequences of Pure Tax and Permit Mechanisms

While the previous analysis based on Figure 5 provides important intuition and a rough approximation of the welfare consequences of taxes and permits, it fails to capture several important failures of the Weitzman assumptions. While the intuition behind these failures and their individual consequences is discussed in Appendix C, this section summarizes their net effect. In particular, the net welfare gains of alternative tax and permit policies are computed numerically and shown in Figure 7.

These results simply confirm the intuition in Figure 5. Namely the welfare gain from the optimal tax instrument, around \$2.5 billion, is much larger than the gain from the optimal permit instrument, around \$0.3 billion. Although the rough calculation using Weitzman's formula suggested a difference of \$10 billion, there are many reasons why Weitzman's result is not exactly right in this context as discussed in Appendix C.

Figure 7 also indicates the large risk associated with setting an emission target incorrectly – specifically setting a target too low. While the net benefits of a tax are positive for a wide range of values, from zero to \$20/ton C, the net benefits of a permit system rapidly become negative as the target falls below 11 GtC. At the proposed 1990 emission level, 8.5 GtC, the welfare loss is more than \$10 billion. This is a consequence of reductions becoming extremely expensive in the

high-emission states of the world. Thus, an important conclusion from Figure 7 is that low targets could turn out to be very costly. Importantly, were the world to confront such high costs, in all likelihood the parties to any global climate agreement would agree to relax their commitments. The fact that such a potential even exists could then lead to strategic behavior in the private sector in order to make costs appear high, a point returned to in Section 4.5.

3.3 The Hybrid Permit Policy

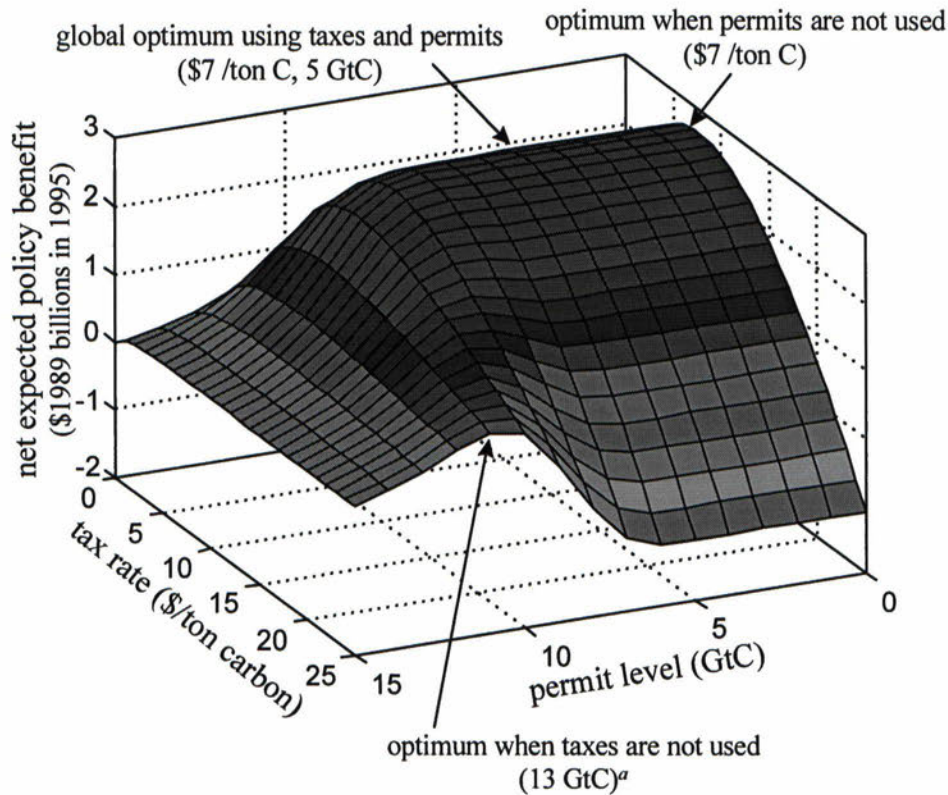
As pointed out by Roberts and Spence (1976), a hybrid permit policy which encompasses permits and taxes and special cases will perform at least as well as either alternative. It is natural to wonder whether it can do much better. Figure 8 shows that, in fact, it cannot; the optimal hybrid policy is only marginally better than the optimal pure tax policy. The global optimum across all permit levels and trigger prices, roughly a 5 GtC emission target and a \$7/ton C trigger, is remarkably close to the proposal suggested by McKibbin and Wilcoxon (1997).¹²

The proper way to read Figure 8 is to note that for low permit levels (< 5 GtC; back right edge of figure), the policy is essentially a tax and the shape of the surface is simply an extrusion of the tax curve shown in Figure 7. For extremely high trigger prices (not shown; $> \$50$ tC), the policy is essentially a permit system and follows the permit curve shown in Figure 7. The outline of this shape is just beginning to show along the front right edge of the figure. For higher permit levels and lower trigger prices (essentially the middle of the figure), some combination of permits and taxes is at work, indicated by the odd shape of the surface.

While the optimal hybrid policy appears to be no better than the optimal tax policy, it clearly performs better than the optimal permit policy. In fact, relative to a straight target of 1990 emissions, with its attendant \$10 billion loss from Figure 7, *any* of the policies shown in Figure 8 are an order of magnitude better (note the vertical scale only descends to a \$2 billion loss). As long as policy debate continues to focus on targets and timetables, rather than taxes, these two comparisons are most relevant.

¹²They advocated 1990 emission levels as the permit volume coupled with a \$10/ton C trigger. 1990 global controllable GHG emissions were 8.5 GtC.

Figure 8: Net Expected Policy Benefits of Alternative Hybrid Permit Policies in 2010



^aThe optimal permit level when additional permits are no longer purchased (13 GtC) does not become apparent until the trigger price is set roughly twice as high as shown in the figure (around \$50/ton carbon), otherwise the additional permits are purchased in a non-trivial number of states of nature. From the figure, it is evident that the optimal permit level as a function of the trigger price is increasing. At \$25/ton carbon, however, the optimal permit level is only 11 GtC. The net expected benefit when the trigger price is high enough to no longer matter and the permit level is 13 GtC is \$0.3 billion, roughly one-tenth of the benefit from a straight tax or hybrid permit policy.

4 Multi-period Policy Under Uncertainty

Up to this point the analysis has focused on the costs and benefits of different policies in a single year. The problem of climate change, however, is spread out over decades if not centuries. Policies to combat climate change are therefore likely to be in place for a long time. It is not immediately obvious whether the results comparing different instruments in a single year are immediately applicable to a multiperiod policy (since policies in future periods may change the optimal policy in 2010).

In this section optimal policy paths for taxes, permits and hybrid permit mechanism are explored. In addition to considering the net welfare consequences of optimal policies, results concerning the range of climate outcomes are presented and sub-optimal policies are explored.

4.1 Optimal Permit Policy

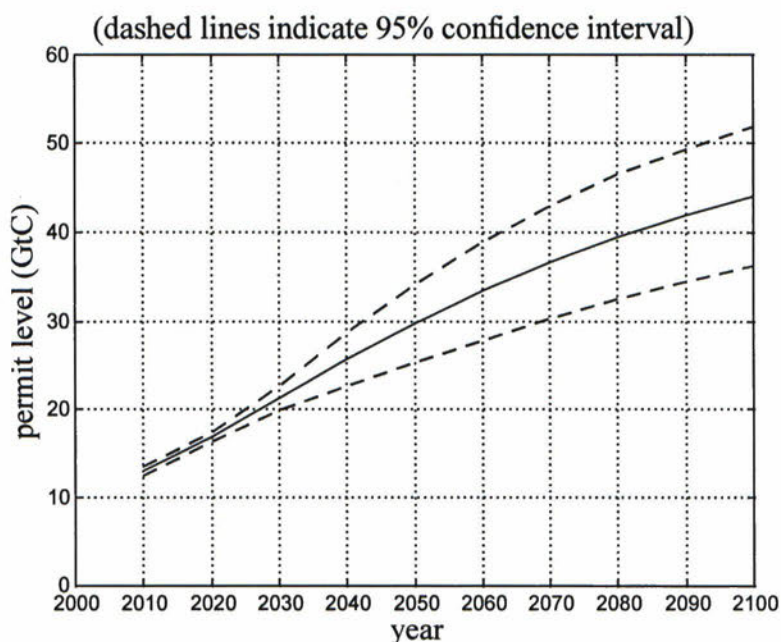
To compute optimal policies, the paths of alternative permit, tax and hybrid permit systems were parameterized with six values describing stringency in 2010 (the first year of implementation), 2020, 2040, 2070, 2110 and 2160. Policies in intervening years are based on smooth interpolations,¹³ except the stringency in 2160 which is allowed to be discontinuous and is held fixed through the end of the simulation (2245). The length of the simulation as well as the spacing of the policy parameters was subjectively chosen to make the policy evaluation in the 2000-2100 interval as accurate as possible, especially the early 2000-2050 period.

The resulting optimized permit policy, which limits global greenhouse gas emission to a specified level, is shown in Figure 9. The policy is not known with certainty due to sampling error – only 8,000 states of nature were used to estimate the policy (this could be reduced with additional computing power).¹⁴ Interestingly, the optimal permit level of 13 GtC in 2010 is roughly the same as the optimal permit level determined in the one-period analysis. Perhaps this is not so surprising

¹³Policies are interpolated to ten-year intervals using a cubic spline; annual policies are linearly interpolated from the ten-year values. The hybrid policy is always interpolated linearly due to sampling error.

¹⁴The stringency was optimized over eight sets of 1,000 states of nature, taking on average 30 minutes to converge. These eight sets were then averaged and the standard deviation among the eight estimates was used to compute a standard error for the average.

Figure 9: Optimized Permit Level – Multi-period Policy



given the fact that initial emission reductions do not substantially affect the GHG stock for many years, at which point the discounted benefits in 2010 will be small.¹⁵

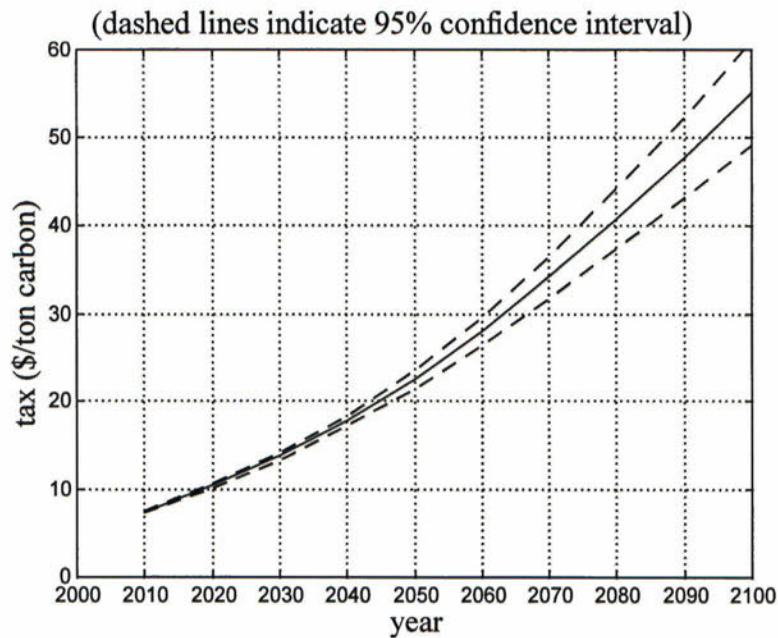
An important observation is that the proposal to reduce emissions to their 1990 levels (roughly 8.5 GtC) is far below the optimal permit level in these simulations. Further, the optimal permit level rises in the future to accomodate growth in population and per capita productivity. While this kind of policy might appear to ignore the possibility that a carbon-free technology becomes not only commercially available but dominant in the next century, it conversely accomodates the possibility that such a technology never gets off the ground.

When the optimal permit policy is implemented it improves welfare on average by \$69 billion (\$1989).¹⁶

¹⁵An important assumption in the underlying DICE model is that damages are continuous and have been occurring since the beginning of industrialization. Thus we are already experiencing the consequences of global warming and current emission reductions are predominately concerned with reducing damages for roughly the next 30 years.

¹⁶This is the net present value of benefits minus costs and has an associated sampling error of \$16 billion. This can be compared to annual global output in 1995 which was \$24 trillion.

Figure 10: Optimized Tax Level – Multi-period Policy



4.2 Optimal Tax Policy

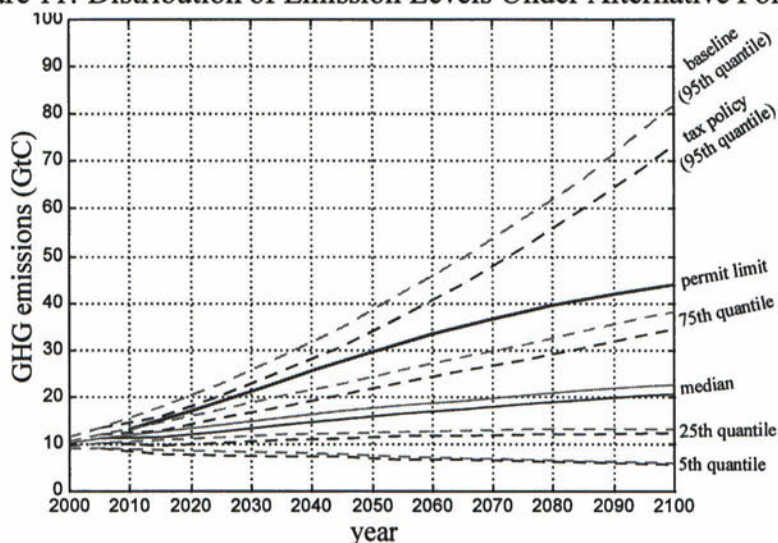
While the permit policy requires that emissions in every state of nature be at or below the specified level, a tax policy instead fixes the marginal cost of emission reductions. Consumers and producers facing a tax on greenhouse gas emissions will reduce emissions until the cost of further reductions equals the cost of paying the tax instead. If costs are particularly low, emissions may be completely eliminated and the marginal cost of the last ton of reductions will lie below the specified tax rate.

Figure 10 shows the tax policy which maximizes expected welfare. The initial tax of \$7.35 is close to, but slightly lower than, the tax computed in the one-period analysis. Unlike the optimal permit policy, which rises and relaxes in stringency in order to accommodate growth, the optimal tax policy becomes *more stringent* in the future. This occurs because, unlike a constant permit level, a constant tax automatically encourages proportionally higher emissions as the economy grows. While some increase in emissions is desirable as the economy grows, a proportional increase is not – therefore the tax must increase in stringency while the permit system must be relaxed.¹⁷

An important difference between tax and permit policies is that taxes do not provide a strict

¹⁷An alternative interpretation of the rising tax rate is that, since emissions in adjacent periods generate essentially the same consequences, the shadow price of emissions must rise with the interest rate.

Figure 11: Distribution of Emission Levels Under Alternative Policies

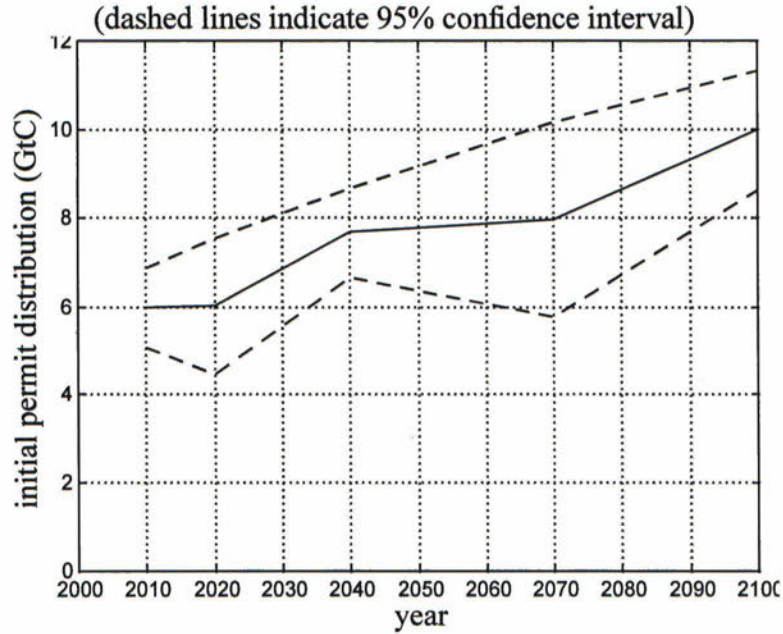


limit on emissions. This, however, should not be viewed strictly as a weakness: relaxing the level of emissions when costs turn out to be particularly high is desirable if the expected marginal benefits of reduction are fairly constant. Figure 11 shows the distribution of resulting emissions with and without the optimal tax policy alongside the optimal permit policy. Note that the optimal permit policy is not binding in over 75% of the states of nature (it lies above the 75th quantile of baseline emissions). Meanwhile the optimal tax policy leads to emissions above the optimal permit level in somewhere between 5 and 25% of the states of nature.

Finally, if the welfare changes associated with the optimal tax policy are averaged across states of nature, the expected welfare improvement amounts to \$338 billion – compared to \$69 for the permit instrument (the standard error in this case is \$21 billion). This represents an expected improvement five times higher than that obtained with the permit system – a large ratio but smaller than the factor of eight determined in the one-period analysis.

Why might this ratio decline when viewed over a longer horizon? As pointed out by Weitzman (1974), discussed later by Stavins (1996), and pointed out in Section 2.4, positive correlation between marginal costs and benefits leads to a preference for quantity instruments (e.g., permits). In the case of a stock pollutant, such correlation is likely over long periods of time due to uncertainty about baseline emissions. In a state of nature with particularly low uncontrolled, baseline

Figure 12: Optimal Initial Permit Distribution for a Hybrid Permit Policy



emissions, the pollutant stock is lower in the future making marginal damages lower. At the same time, lower emissions make any single period target cheaper to obtain. The reverse occurs in states of nature with high baseline emissions. This positive correlation among costs and benefits induces some preference for quantity controls. Based on the fact that price controls still offer a five-to-one improve over quantity controls, however, the empirical consequence of this effect is still quite low.

4.3 Optimal Hybrid Permit Policy

The trigger price path for the optimal hybrid permit policy turns out to be insignificantly different than the optimal tax level. As suggested in Figure 8, the corresponding optimal target is difficult to determine since the expected benefits are relatively flat over a range of values. This occurs because the marginal effect of the policy is derived only from those states of nature where baseline emissions are above the permit level but marginal costs are below the trigger – this turns out to be a relatively small fraction of the sample. The wide confidence intervals in Figure 12 reveals this difficulty. Even with 8,000 states of nature the optimal target is difficult to determine.¹⁸

¹⁸This sampling error could be reduced with additional simulations.

Table 3: Net Benefits of Hybrid Policies with 1990 Emission Targets
(expected NPV in \$1989 billions; policies begin in 2010)

trigger price (\$/tC) ^a	expected welfare gain	sampling error
5	181	6
10	237	9
20	272	13
30	256	15
50	146	19
70	-14	22
100	-287	26
150	-739	32
no trigger price	-3359	104

^aBoth the trigger price and target are fixed from 2010 forward.

Interestingly, the optimal initial permit level remains close to the 1990 emission level (8.5 GtC) for almost the entire forecast period. Setting the initial distribution to 8.5 GtC in every period, in fact, has a negligible effect on the welfare as long as the optimal tax level is used as the trigger price (as was true in the one-period case).

4.4 Sub-optimal Policies

The purpose of this paper has been to compare optimal tax, permit and hybrid policies for reducing GHG emissions. However, many of the policy proposals actually under consideration deviate from those discussed in this paper. For that reason, this section considers the welfare consequences of sub-optimal policies. Specifically, the welfare consequences of hybrid policies involving 1990 emission targets coupled with alternative, fixed trigger prices are presented in Table 3.

Not surprisingly, the “no trigger price” option (e.g., a straight permit solution) entails the greatest losses, on the order of \$3 trillion. In the one-period simulations, a key result was that low quantity targets generate large welfare losses. This result carries over to the multi-period context. Surprisingly, however, trigger prices as high as \$50/tC still generate positive welfare gains even though the optimal price (shown in Figure 10) remains below \$50/tC for the next 100 years.

A second important conclusion from Table 3 is that even as the trigger price approaches

\$100/tC, the expected welfare gain remains an order of magnitude better than the straight permit approach. At \$100/tC, the expected loss is capped below \$300 billion – versus \$3 trillion under the straight permit system. Even with a tax of \$250/tC (not shown), the expected loss is cut in half. This highlights the role of a trigger price as an “escape valve” for adverse cost outcomes. In 2010, there is barely a one-in-four chance that additional permits would be sold at \$100/tC. Yet, the expected loss is reduced by a factor of ten. Regardless of whether one is confident about the exact welfare outcomes presented in this paper, the potential for a hybrid permit policy to reduce extremely adverse cost outcomes should be clear.

4.5 Non-efficiency Issues

While the metric used to compare policies in this paper has been economic efficiency, there are obviously many other features associated with different policies which are important. As noted by Stavins (1989), criteria such as feasibility and provision of dynamic incentives matter both to policymakers and for welfare more broadly defined. In this regard, it is useful to note that the hybrid permit policy offers several advantages over the pure tax and permit alternatives.

In the case of permits, it seems unlikely that a world confronted with exceptionally and unexpectedly high compliance costs would continue to abide by a treaty based on a somewhat arbitrary target (e.g., 1990 emissions). Such a possibility opens the door for strategic behavior under a straight permit policy. Namely, firms have some incentive to make costs look high in order to encourage countries to opt out of treaty commitments – that would benefit the firms since they would stand to gain additional emission rights. In order to make costs look high, innovative research might be deferred and older, less efficient plants might be kept on-line longer.

In contrast, a hybrid permit policy provides an automatic relief mechanism to deal with unexpectedly high costs: additional and unlimited permits are sold at the fixed trigger price. Firms have no incentive to misrepresent costs because, regardless of how they represent costs, their only option is to pay for additional permits at the margin. In other words, the certainty of a trigger price is a much better signal to firms to move forward on new investments and research to reduce

emissions than an uncertain government adjustment of emission targets.

Regarding taxes, as McKibbin and Wilcoxon (1997) point out, the potential tax burden associated with GHG emissions is enormous. With a gigaton of emissions in the U.S. alone and a \$10 tax, this amounts to \$10 billion. If the tax rate were \$100 – still reasonable given a 1990 emission target – the burden would be \$100 billion. Given the U.S. recent experience with the proposed BTU tax, such a policy would appear to be politically infeasible. The hybrid policy, in contrast, would allow any fraction of that burden to be distributed flexibly. By choosing which fraction of the permits to distribute freely and which fraction to auction, policymakers can balance the competing interests of revenue, equity and political feasibility.

5 Conclusion

Discussions of alternative tax and permit mechanisms for combating climate change have generally ignored the fact that the costs and benefits of future reductions are highly uncertain. Such uncertainty can lead to large efficiency differences between the two policies. This paper has explored this question in the context of an integrated climate-economy model capable of simulating thousands of uncertain states of nature.

The resulting welfare analysis indicates that taxes are much more efficient than permits for controlling GHG emissions – by a factor of *five to one* (\$337 billion versus \$69 billion in net benefits). This derives from the relatively flat marginal benefit curve associated with emission reductions. Relatively flat marginal benefits are partially a product of the quadratic damage function and partially a generic feature of stock pollutants like GHGs.

An important observation in this analysis is the risk involved in setting permit level too stringently. Not only does the optimal permit policy involve lower welfare gains, but setting the permit level incorrectly can lead to massive losses. The tax instrument, in contrast, leads to welfare gains over a much wider range of values.

In addition to pure tax and permit systems, this paper explored the possibility of a hybrid permit system. The hybrid policy involves an initial allocation of permits followed by the subsequent sale

of additional permits at fixed trigger price if costs turn out to be high. By making the initial distribution small or the subsequent sale price high, this combined system can be made to mimic either the pure tax or permit system.

The hybrid permit system improves on the optimal tax outcome, but only slightly (by about \$2 billion or 0.5%). However, the hybrid policy offers the flexibility of a permit mechanism in terms of distributing the rents associated with emission rights. Further, a sub-optimal hybrid policy with a stringent target and high trigger price generates much better welfare outcomes than a straight permit policy with the same target. Taken together, the improved flexibility and welfare outcomes enhance the credibility of the hybrid policy relative to either the permit or tax policy alone. Such credibility is critical for the encouragement of private sector activities to reduce emissions as well as abatement costs.

A Model Specification

A.1 Economic Behavior

Economic behavior within each state is derived from a representative agent model where consumption must be optimally allocated across time. In a typical model with constant exogenous productivity growth, agent preferences define a steady state to which the economy converges over time. In the presence of random shocks and slowly changing trends, the economy instead converges to a distribution of states (due to the random shocks) which is itself slowly evolving (due to the slowly changing trends). For the moment we ignore these changing trends and focus on a standard stochastic growth model.

The representative consumer in this model exhibits constant relative risk aversion τ with respect to consumption per capita. Utility is separable across time, discounted at rate ρ and weighted each period by population. With the further assumption that preferences satisfy the von Neuman-Morgenstern axioms, the consumer's optimization problem can be written as

$$\max_{C_t} E \left[\sum_{t=0}^{\infty} (1 + \rho)^{-t} N_t \frac{(C_t/N_t)^{1-\tau}}{1-\tau} \right] \quad (\text{A.1})$$

where C_t is consumption in period t and N_t is population. That is, the consumer maximizes expected discounted utility where each period's utility is population weighted. This consumption program $\{C_0, C_1, \dots\}$ is subject to the resource constraints describing production

$$Y_t = (A_t^* N_t)^{1-\theta} K_t^\theta \quad (\text{A.2})$$

and capital accumulation

$$K_{t+1} = K_t(1 - \delta_k) + Y_t - C_t \quad (\text{A.3})$$

where Y_t is aggregate output, $A_t^* N_t$ is effective labor input and K_t is the capital stock. A_t^* is a measure of productivity distinct from capital but not completely exogenous, as discussed later. The parameter θ summarizes the Cobb-Douglas production technology given in Equation (A.2)

and δ_k reflects the rate of capital depreciation in the capital accumulation equation (A.3). Finally, there is a transversality condition for a balanced growth steady state,

$$\rho > (1 - \tau) \times (\text{asymptotic growth rate of } A_t^*) \quad (\text{A.4})$$

This is always satisfied by assuming zero growth asymptotically.

Even with exogenous constant growth models for N_t and A_t^* , the dynamic optimization problem given by Equations (A.1–A.3) is difficult if not impossible to solve analytically.¹⁹ However, choosing

$$\Delta \ln(K_{t+1}/N_{t+1}) = \alpha_1 + \alpha_2(\ln(K_t/N_t) - \ln(A_t^*)) \quad (\text{A.5})$$

and

$$C_t = K_t(1 - \delta_k) + Y_t - K_{t+1} \quad (\text{A.6})$$

– where α_1 and α_2 are functions of the parameters $(\rho, \tau, \theta, \delta_k)$ – yields a close approximation of optimal consumer behavior around the balanced growth steady state. This technique of approximating optimal dynamic behavior has its origins in the real business cycle literature beginning with Kydland and Prescott (1982). It is also related to the technique of feature extraction discussed by Bertsekas (1995).²⁰

Intuitively, Equation (A.5) approximates behavior around a balanced growth steady state. At such a steady state, $\ln(K_t/N_t) - \ln(A_t^*)$ is constant and $\Delta \ln(K_{t+1}/N_{t+1}) = (\text{growth rate of } A_t^*) = \alpha_1 + \alpha_2(\ln(K_t/N_t) - \ln(A_t^*)) = \text{constant}$. If some unforeseen shock moves the economy away from the equilibrium value of $K_t/(A_t^*N_t)$ and α_2 is negative, e.g., the steady state is stable, then the economy will move back toward the steady state. In particular, when $K_t/(A_t^*N_t)$ is too high, capital accumulation will slow. If $K_t/(A_t^*N_t)$ is too low, capital accumulation will increase. Importantly, even if the growth rate of A_t^* is not constant, this approximation performs well as long as expected productivity growth changes gradually.

¹⁹Long and Plosser (1983) derive an analytic solution for the case of $\delta_k = 1$ and $\lim \tau \rightarrow 1$ (log utility).

²⁰See Appendix A of Pizer (1997) for a simple derivation of expressions for α_1 and α_2 .

A.2 Long-term Growth, Climate Behavior and Damages

This section explains the remainder of the state-contingent model – specifically the evolution of A_t^* and N_t . This includes exogenous growth projections, climate behavior and damages from global warming (based primarily on the DICE model, Nordhaus 1994b). Exogenous labor productivity A_t is modeled as a random walk in logarithms with an exponentially decaying drift. That is,

$$\log(A_t) = \log(A_{t-1}) + \gamma_a \exp(-\delta_a t) + \sigma_a \epsilon_t \quad (\text{A.7})$$

where γ_a is the initial growth rate, δ_a is the annual decline in the growth rate, σ_a is the standard deviation of the random growth shocks and ϵ_t is a standard NIID random shock. This means that productivity growth begins with a mean growth rate of γ_a (around 1.3%) in the first period and eventually declines to zero. In addition, random and permanent shocks change the level of productivity every period. The standard error of these shocks is σ_a .

Net labor productivity A_t^* is distinguished from this exogenous measure A_t by the fact that A_t^* describes the amount of output available for consumption and investment – after output has been reduced by control costs and climate damages. To that end, A_t^* is expressed as A_t multiplied by a factors describing these two phenomena:

$$A_t^* = \underbrace{\left(\frac{\overbrace{1 - b_1 \mu_t^{b_2}}^{\text{control costs}}}{1 + (D_0/9) \cdot T_t^2} \right)^{\frac{1}{1-\theta}}}_{\text{damages}} A_t \quad (\text{A.8})$$

μ_t is the fractional reduction in greenhouse gas emissions at time t (the “control rate”) versus a business as usual/no government policy baseline, while b_1 and b_2 parameterize the cost of attaining these reductions. Since b_1 and b_2 are both positive, additional rates of control involve reductions in net productivity. T_t is the average surface temperature relative to pre-industrialization in degrees Celsius and D_0 is the fractional loss in aggregate GDP from a 3° temperature increase. For temperature changes less than 10°, this is essentially a quadratic damage function.²¹ Additional details about the control cost and damage functions can be found in Nordhaus (1993) and Nordhaus (1994a), respectively.

²¹Over larger ranges, the damage function becomes *S*-shaped.

Population is modeled in the same way as exogenous productivity but without the stochastic element:

$$\log(N_t) = \log(N_{t-1}) + \gamma_n \exp(-\delta_n t) \quad (\text{A.9})$$

where γ_n is the initial growth rate and δ_n is the annual decline in the growth rate. Note that these models predict zero growth asymptotically, though this may occur centuries in the future.²²

The remaining portion of the model explains the link between economic activity (measured as aggregate output Y_t) and warming (measured as the average surface temperature T_t). The first step is linking output to emissions:

$$E_t = \sigma_t(1 - \mu_t)Y_t \left(\frac{A_t}{A_t^*} \right)^{1-\theta} \quad (\text{A.10})$$

where E_t is emission of controllable greenhouse gases,²³ σ_t is an exogenous trend in emissions/output, and μ_t is the rate of emissions reductions induced by the policymaker. The expression $Y_t \left(\frac{A_t}{A_t^*} \right)^{1-\theta}$ reflects raw output prior to the effects of climate damages and control costs. The model of σ_t is, as with labor productivity and population, based on exponentially decaying growth:

$$\log(\sigma_t) = \log(\sigma_{t-1}) + \gamma_\sigma \exp(-\delta_a t) \quad (\text{A.11})$$

where γ_σ is the initial growth rate of emissions/output (a negative number) and δ_a is the annual decline in the growth rate. Note that the annual decline in the emissions/output growth rate is the same as the annual decline in labor productivity growth (δ_a).

Emissions of greenhouse gases accumulate in the atmosphere according to:

$$M_t - 590 = \beta E_{t-1} + (1 - \delta_m)(M_{t-1} - 590) \quad (\text{A.12})$$

where M_t is the atmospheric concentration of greenhouse gases in billions of tons of carbon equivalent. β is a measure of the retention rate of emissions. Low values of β indicate that emissions do

²²For example, the range of parameters used in the simulations (with $\delta_{a/n} \in (0.25\%, 2.5\%)$) leads to a halving of the growth rates every 20 to 200 years.

²³See discussion of controllable versus uncontrollable greenhouse gases in Nordhaus (1994b), page 74. For the most part, controllable greenhouse gases are CO₂ and CFCs and uncontrollable greenhouse gases are everything else.

not, in fact, accumulate while a value of unity would mean that every ton of emitted greenhouse gases remains in the atmosphere. The parameter δ_m plays the role of a depreciation rate: it is assumed that greenhouse gases in the atmosphere above the pre-industrialization level of 590 billion tons slowly decays. This decay reflects absorption of greenhouse gases into the oceans which are assumed to be an infinite sink.

Above average concentrations of greenhouse gases in the atmosphere lead to increased radiative forcings, a measure of the rate of transfer between solar energy produced by the sun and thermal energy stored in the atmosphere. This is modeled according to

$$F_t = 4.1 \times \log(M_t/590)/\log(2) + O_t \quad (\text{A.13})$$

where F_t measures radiative forcings in units of watts per meter squared. The specification is such that a doubling of greenhouse gas concentrations leads to a roughly four fold increase in forcings (since 590 is the concentration before industrialization). O_t in this relation represents radiative forcings due to other uncontrollable greenhouse gases and is assumed exogenous to the model:

$$O_t = \begin{cases} 0.2604 + 0.0125t - 0.000034t^2 & \text{if } t < 150 \\ 1.42 & \text{otherwise} \end{cases} \quad (\text{A.14})$$

Increased forcings lead to temperature changes according to

$$T_t = T_{t-1} + (1/R_1) [F_t - \lambda T_{t-1} - (R_2/\tau_{12})(T_{t-1} - T_{t-1}^*)] \quad (\text{A.15})$$

$$T_t^* = T_{t-1}^* + (1/R_2)(R_2/\tau_{12})(T_{t-1} - T_{t-1}^*) \quad (\text{A.16})$$

where T_t is the surface temperature and T_t^* is the deep ocean temperature, both expressed in changes relative to pre-industrialization levels in degrees Celsius. Note that if $M_t = 590$ and $O_t = 0$ (e.g., pre-industrialization), T_t and T_t^* will equilibrate to zero. The parameter λ describes the equilibrium change in surface temperature for a given change in radiative forcings. In particular, based on (A.13) and (A.15), a doubling of the concentration of greenhouse gases in the atmosphere will lead to a $4.1/\lambda$ rise in surface temperature in the long run. This parameter $4.1/\lambda$ is a measure of the temperature sensitivity of the atmosphere.²⁴

²⁴ λ by itself is referred to as the climate feedback parameter.

The parameters R_1 , R_2 and τ_{12} describe the thermal capacity of the surface atmosphere and deep oceans and the rate of energy transfer between them, respectively.

A.3 Social Welfare

A distinguishing feature of this analysis is the use of an econometrically estimated parameter distribution describing uncertainty in the economic model. However, the consumer's objective function given by Equation (A.1) makes no allowance for uncertainty about the preference parameters ρ and τ which are fixed from his or her perspective. In order to encompass uncertainty about preferences, it is necessary to step back and imagine a social planner who would like to maximize the objective given in (A.1) but is unsure of the parameters. Since a policy change which raises the expected utility for one set of parameters may lower the expected utility for another set, the social planner will need to specify a social welfare function to compare gains and losses across states of nature. This social welfare function provides a single objective specifying how changes in utility measured with different preferences are aggregated.²⁵ It is important to recognize that although parameter values in the representative agent model can be inferred from observed consumer behavior, there is no information available to estimate parameters in a social welfare function. Such information would be revealed only by observing the behavior of an actual social planner. Instead, we must rely on social choice theory and our own sense of fairness to specify the relation.

It is useful to note that the common approach in the climate change literature skirts this issue of preference aggregation by reporting a range of policy prescriptions based on a range of possible preferences and states of nature. For example, Cline (1992) presents benefit-cost analyses for 92 different cases (Tables 7.3 and 7.4). Dowlatabadi and Morgan (1993) integrate out much of the uncertainty in their analysis, but still present results for 48 scenarios. Chapter 8 of Nordhaus (1994b) gives one of the few examples where even preference uncertainty is integrated out, yielding a single welfare metric and a single policy recommendation. In a similar analysis, however, Nordhaus and Popp (1997) choose to fix preferences because of the difficulties with preference aggregation.

²⁵E.g., providing a negative loss function across states of nature for the social planner.

Regardless, these authors ubiquitously observe that uncertainty about time preference has large consequences for optimal policy choice.²⁶ Moreso, in fact, than uncertainty about climate sensitivity and damages. It therefore behooves us to seriously consider how to aggregate over uncertain preferences in the most reasonable way.

In this analysis social welfare is specified as an average of utility measured in each state of nature by Equation (A.1), *rescaled*. The rescaling serves to equate the marginal social welfare of one additional dollar of current consumption in all states of nature. While arbitrary, some adjustment is necessary to prevent the resulting policy prescription from being sensitive to the choice of units in the model.²⁷ Social welfare can then be written as

$$SW(x) = I^{-1} \sum_{i=1}^I u(x, i) \quad (\text{A.17})$$

where $u(x, i)$ is rescaled utility in state i with outcome x and $SW(x)$ is the social welfare associated with x . The rescaling is such that

$$u(+\$1 \text{ in initial period}, i) - u(\emptyset, i) = u(+\$1 \text{ in initial period}, j) - u(\emptyset, j) \quad \forall i, j$$

That is, a policy corresponding to an extra dollar of consumption in the initial period is assumed to have the same utility gain in every state relative to a no policy ($\emptyset$) baseline.

This social welfare function has its origins in the literature on social choice. Harsanyi (1977) shows that in defining social welfare over lotteries, if individual preferences satisfy the von Neumann Morgenstern axioms then social welfare must have this weighted average form. Otherwise, social preferences will fail to mimic individual preferences over lotteries involving only that individual. This functional form can also be derived from the assumption of cardinal unit comparability, as discussed by Roberts (1980). More flexible forms require additional assumptions about level or scale comparability. Our choice of welfare functions is therefore less arbitrary than it might have originally appeared: a more flexible form requires both integrating out uncertainty from the representative agent's perspective (to satisfy Harsanyi's point) and more stringent assumptions about

²⁶See discussion in Arrow, Cline, Maler, Munasinghe, and Stiglitz (1996).

²⁷An explanation of this point is given in Appendix C of Pizer (1997).

the level of comparability (to satisfy Robert's point)²⁸

B Measuring Uncertainty

Estimates of uncertainty in the model come from two sources: econometric analysis and subjective assessment. The model involves nineteen different parameters. Six are parameters describing observable economic activity:

- pure time preference ρ ,
- risk aversion τ ,
- output-capital elasticity θ ,
- productivity growth γ_a ,
- variation in productivity growth σ_a^2 , and
- depreciation δ_k .

A joint distribution for these parameters is estimated with historical data. The remaining thirteen describe emissions:

- emissions rate growth γ_σ ,

climate change:

- CO₂ retention rate β ,
- temperature sensitivity $4.1/\lambda$,
- CO₂ decay rate δ_m ,
- thermal capacities and conductivities R_1 , R_2 and τ_{12} ,

control costs and damages:

- cost function parameters b_1 and b_2 ,
- fractional loss of GDP for 3° temperature rise D_0 ,

and long-term growth trends

- population growth γ_n ,
- productivity slowdown and slowdown in the growth rate of emissions/output δ_a ,
- population slowdown δ_n .

Uncertainty about these parameters is based on subjective analysis.

The econometric analysis of the six economic parameters is based on post-war U.S. data.²⁹

²⁸Additional levels of comparability are especially difficult with the the constant coefficient of relative aversion (CRRA) form in Equation (A.1) where the parameter $\tau \geq 1$. Under these assumptions, utility is alternatively bounded from above or below.

²⁹See Chapter II of Pizer (1996).

Series describing aggregate investment, capital services, output and prices are fit to the model described by Equations (A.2),(A.3) and (A.5). The posterior parameter distribution which arises from this analysis is summarized in Table B.1.

Nordhaus (1994b)³⁰ develops a distribution for the remaining parameters based on a two-step subjective analysis. The first step involves testing his model's sensitivity to each parameter being changed, one at a time, to a more extreme value. Those parameters which produce the largest variance in model output are then further scrutinized. A discrete, five-value distribution is developed for seven of these thirteen variables. The other six are fixed at their best guess values. The distribution of the seven uncertain parameters is summarized in Table B.2. Values of the six fixed parameters as well as initial conditions for the model are given in Table B.3.

C Factors Which Complicate the Weitzman Analysis

In this section the factors which complicate Weitzman's (1974) original analysis are discussed. While these factors do not affect the basic intuition behind his result – that a flatter marginal benefit curve favors taxes – they do qualify it. In particular, the intersection of the expected marginal benefit and expected marginal cost curve can no longer be used to determine the optimal tax policy when there are non-linear marginal costs and non-additive shocks. As noted by Weitzman and others (Stavins 1996), correlation also changes the optimality result, with positive correlation among costs and benefits favoring permits and negative correlation favoring taxes. Other factors such as truncation and discounting further complicate the simple graphical analysis in Section 3.

C.1 Non-linearities and Non-additive Shocks

A simple graphical comparison of expected marginal benefits and expected marginal costs allows one to quickly derive the optimal quantity control. This works because these marginal measures are with respect to the quantity measure *and* expectations are taken holding the quantity fixed.

³⁰Chapters 6 and 7.

Table B.1: Marginal distributions of uncertain economic parameters
(narrow bars indicate values used in simulations without uncertainty)

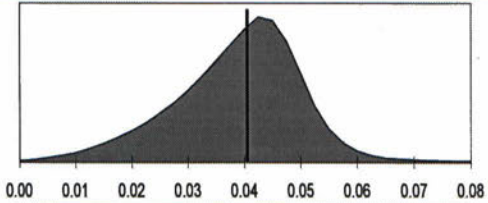
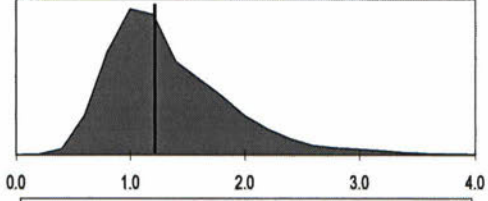
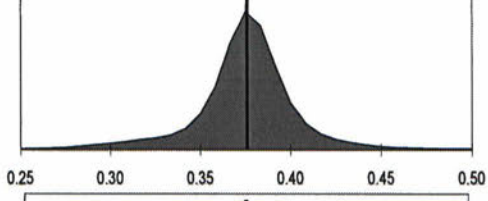
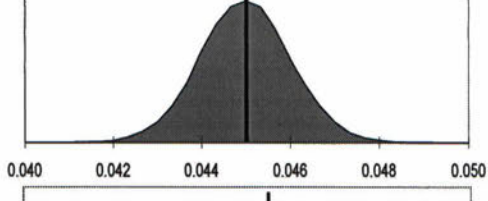
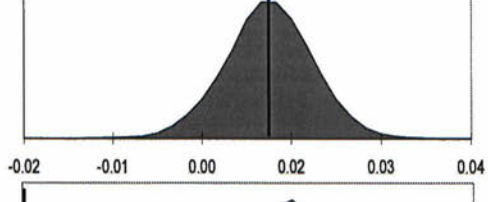
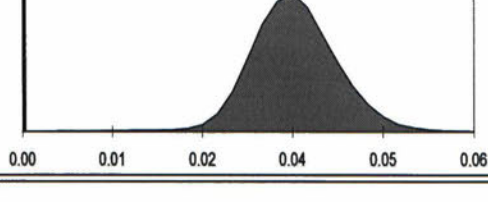
description	symbol	equation	distribution
pure rate of time preference	ρ	(A.1)	
coefficient of risk aversion	τ	(A.1)	
output-capital elasticity	θ	(A.2)	
rate of capital depreciation	δ_k	(A.3)	
initial productivity growth rate	γ_a	(A.7)	
standard error of productivity shocks	σ_a	(A.7)	

Table B.2: Discrete distributions of uncertain climate/trend parameters
(narrow bars indicate values used in simulations without uncertainty)

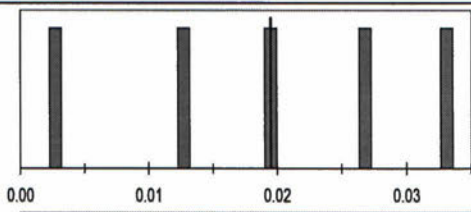
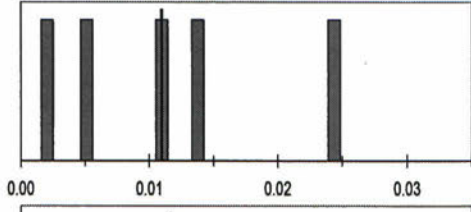
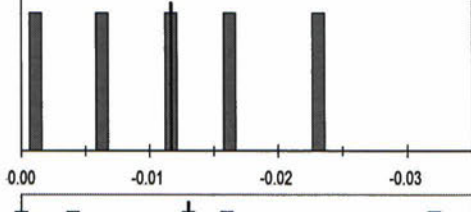
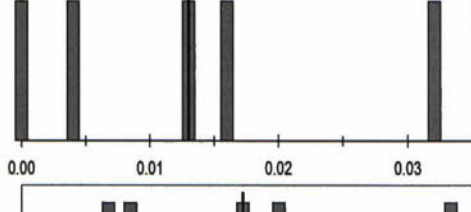
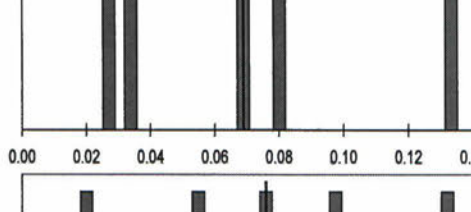
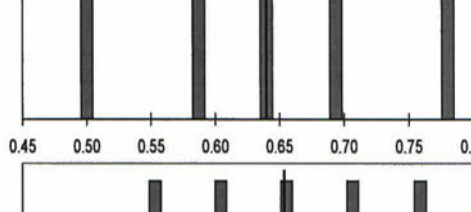
description	symbol	equation	distribution
annual decline of population growth rate	δ_n	(A.9)	
annual decline of productivity growth rate	δ_a	(A.7),(A.11)	
initial growth rate of CO ₂ per unit output	γ_σ	(A.10),(A.11)	
damage parameter (% loss of GDP for 3° temperature rise)	D_0	(A.8)	
cost function parameter	b_1	(A.8)	
retention rate for CO ₂ emissions	β	(A.12)	
temperature sensitivity to CO ₂ doubling (in °C)	$4.1/\lambda$	(A.13),(A.15)	

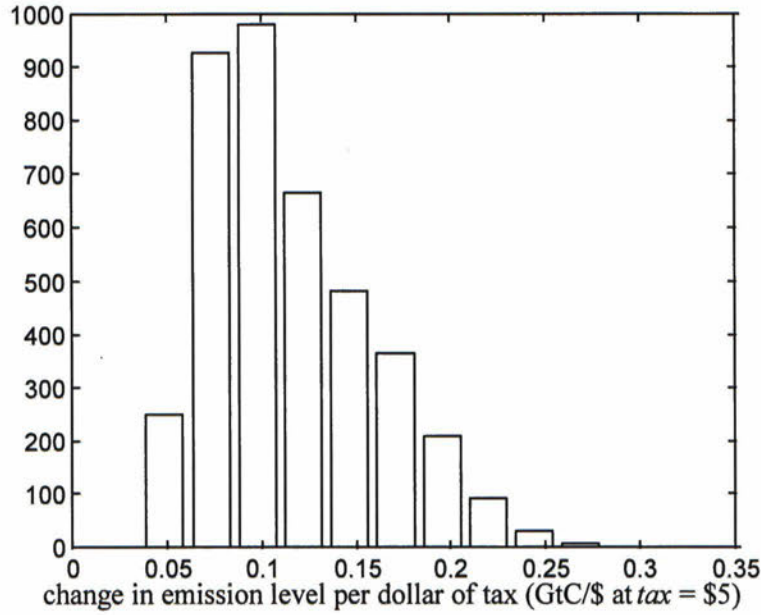
Table B.3: Description of fixed parameters^a

parameter	symbol	equation	units	value
cost function parameter	b_2	(A.8)		2.887
decay rate of atmospheric CO ₂	δ_m	(A.12)		0.00833
1/thermal capacity of atmosphere	$1/R_1$	(A.15)	°C-meter ² /watt-year	0.048
thermal conductivity b/w atmosphere and oceans	R_2/τ_{12}	(A.15),(A.16)	watt/°C-meter ²	0.44
1/thermal capacity of deep oceans	$1/R_2$	(A.16)	°C-meter ² /watt-year	$\frac{0.002}{0.44}$
1995 global population	N_0	(A.9)	millions of people	5590
initial population growth	γ_n	(A.9)		0.0124
initial rate of CO ₂ emissions per unit of output	σ_0	(A.11)	billion tons CO ₂ per \$1989 trillions	0.385
1995 global capital stock	K_0	(A.2),(A.3)	\$1989 trillions	79.5
1995 global output	Y_0	(A.2),(A.3),(A.10)	\$1989 trillions	24.0
1995 atmospheric concentrations of CO ₂	M_0	(A.12)	billions of tons of C equivalent	763.6
1995 surface temperature ^b	T_0	(A.8),(A.15),(A.16)	°Celsius	0.763
1995 deep ocean temperature ^b	T_0^*	(A.15),(A.16)	°Celsius	0.117

^aAll fixed parameters are from Nordhaus (1994b). The parameters that do not depend on time are from Nordhaus' Table 2.4. Initial values for temperature, CO₂ concentrations, and output in 1995, as well as the initial annual growth rate for population, are based on the Nordhaus base case simulation. The 1995 capital stock is adjusted upward to reflect differences in the definition of capital as well as underlying parameter values. The decay rate of atmospheric CO₂ is divided by ten to convert from a decennial to annual rate. The annual thermal capacity of the ocean and atmosphere are from the second line of Nordhaus' Table 3.4b.

^bTemperatures are measured as deviations from the pre-industrialization level, circa 1900.

Figure C.1: Distribution of $\frac{dQ}{d(\text{tax})}$



In contrast, the optimal price control must be derived by taking the expectation of $\Delta\text{benefit}/\Delta\text{tax}$ and $\Delta\text{cost}/\Delta\text{tax}$, holding the tax level fixed, and finding the tax level where *these* two marginal measures are equal. This is not generally revealed by a simple diagram such as Figure 5. It is revealed, however, if the slope of the marginal cost schedule is constant and known. In that case, the condition for the optimal tax reduces to the intersection of the expected marginal cost and benefit curves:

$$\begin{aligned}
 E \left[\frac{\Delta\text{benefit}}{\Delta\text{tax}} \right] &= E \left[\frac{\Delta\text{cost}}{\Delta\text{tax}} \right] \\
 E \left[\frac{\Delta\text{benefit}}{\Delta\text{quantity}} \frac{\Delta\text{quantity}}{\Delta\text{tax}} \right] &= E \left[\frac{\Delta\text{cost}}{\Delta\text{quantity}} \frac{\Delta\text{quantity}}{\Delta\text{tax}} \right] \\
 E \left[\frac{\Delta\text{benefit}}{\Delta\text{quantity}} \frac{1}{\text{MC slope}} \right] &= E \left[\frac{\Delta\text{cost}}{\Delta\text{quantity}} \frac{1}{\text{MC slope}} \right] \\
 E \left[\frac{\Delta\text{benefit}}{\Delta\text{quantity}} \right] \frac{1}{\text{MC slope}} &= E \left[\frac{\Delta\text{cost}}{\Delta\text{quantity}} \right] \frac{1}{\text{MC slope}} \\
 E \left[\frac{\Delta\text{benefit}}{\Delta\text{quantity}} \right] &= E \left[\frac{\Delta\text{cost}}{\Delta\text{quantity}} \right] \\
 E[MB] &= E[MC]
 \end{aligned} \tag{C.18}$$

This condition, that the slope of the marginal cost curve is constant, will be violated if the marginal cost curve is non-linear or there are non-additive shocks. Under these conditions, the

slope of the marginal cost curve cannot be factored outside the expectation, as shown in (C.18). To verify this condition, the slope of the marginal cost curve can be examined across states of nature and at different tax levels to see if it remains constant. Figure C.1 shows the distribution of slopes for a single tax level of \$5/tC.³¹

Given these violations, it will not be possible to determine the optimal tax level from Figure 5 precisely, though it may still provide a rough approximation.

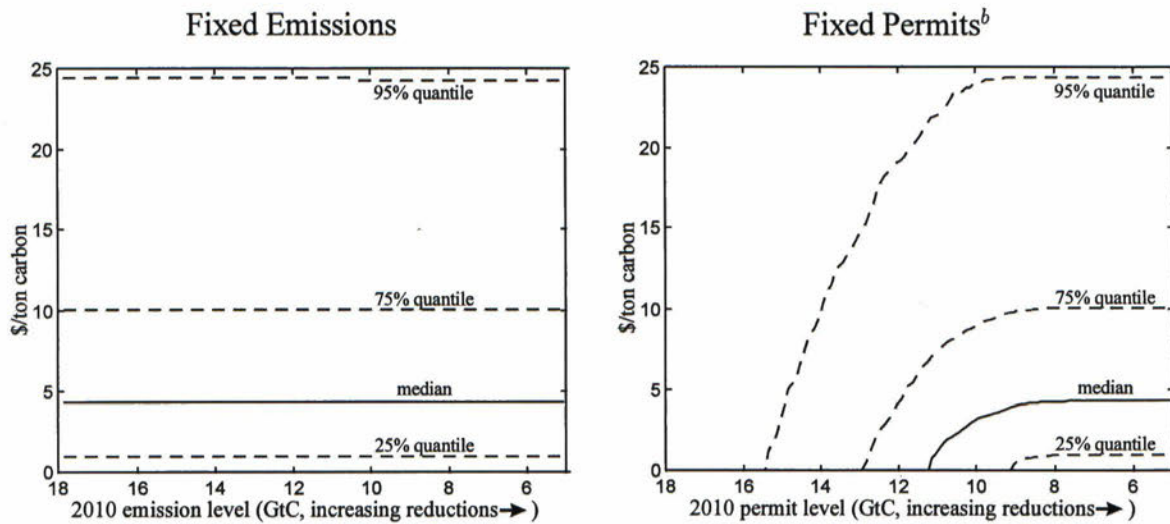
C.2 Truncation

An important point ignored by the Weitzman analysis is whether a particular quantity control is binding in every state of nature. Figure 6, for example, reveals that a quota of 12 GtC in 2010 would lie above the actual emission level roughly half the time. In these states of the world, it is inappropriate to count any benefits from the policy since the policy has no consequence. That is, in order to properly compare the expected marginal cost of a 12 GtC permit policy to its benefits, marginal benefits should only be counted when the policy is binding.

Figure C.2 shows the consequence of this calculation. The left panel (the same as Figure 4) shows the distribution of marginal benefits when emissions are fixed at – rather than limited to – different levels. This calculation ignores the actual level of emissions in 2010. In contrast, the right panel shows the marginal benefit associated with limiting emissions to the specified level (as would occur with a permit system). In those states of nature where uncontrolled emissions are below the value on the x -axis, they remain unchanged and there is no marginal benefit. Therefore at high permit levels (18 GtC) that lie above uncontrolled emission levels in every state, the marginal benefit is zero. Moving to the right, marginal benefits initially rise as additional states become contributing benefits. Eventually, the marginal benefit schedule must slope downwards as the marginal benefit in every state where benefits occur is declining.

³¹From Figure 5 it is clear that the slope also changes at higher permit/tax levels.

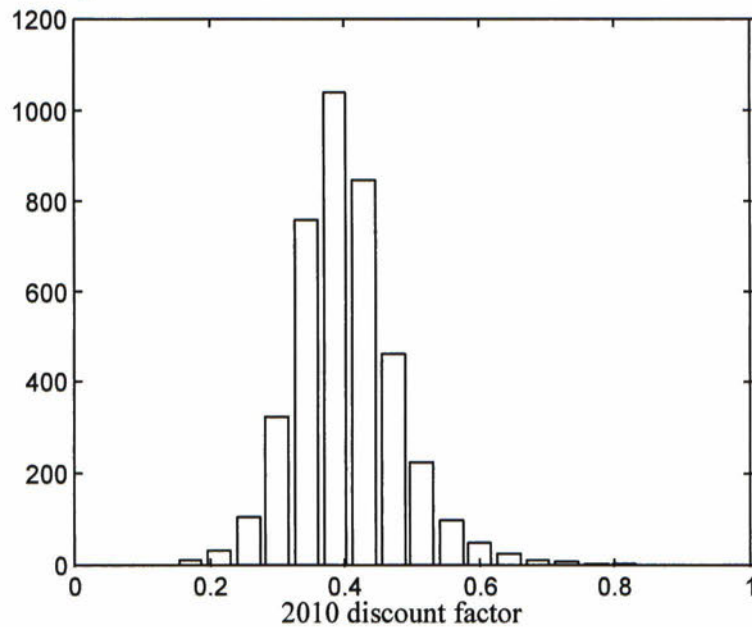
Figure C.2: Distribution of Marginal Benefits in 2010^a



^aThese marginal benefits are based on the discounted (to 2010) value associated with emission reductions in the year 2010 only. Emissions in other periods are held at their uncontrolled levels. Values are expressed in \$2010 and, due to different discount rates across states of nature, will not be weighted equally when balancing costs and benefits.

^aThe left panel indicates the range of marginal benefits obtained by varying the level of 2010 emissions as shown, ignoring the forecast level of uncontrolled emissions. The right panel indicates the range of marginal benefits when permits are used to control the level of emissions at or below the permit level. That is, in cases where uncontrolled emissions are below the indicated level, there is no marginal benefit since emissions are not, in fact, being reduced. As shown in Figure 6, uncontrolled emissions in 2010 are unlikely to be more than 18 GtC. The marginal benefit when the permit level is set to 18 GtC is therefore zero.

Figure C.3: Distribution of Discount Factors in 2010



C.3 Discounting

Discounting is an important issue which is ignored in the simple static case. Even when considering policy in a single period (2010), it is necessary to wonder whether costs and benefits should be measured in 2010 or 1995. This is relevant because different states of nature will involve different discount rates. Specifically, those states with higher growth involve more discounting relative to states of nature with low growth. This follows the basic intuition that extra dollars are more valuable when one is poor than when one is rich.

The static analysis in Section 3 is based on dollar welfare measures in 2010. In contrast, the dynamic analysis in Section 4 is based on dollar welfare measures in 1995. Surprisingly, there is little difference in the initial policy outcome, suggesting the discrepancy is small. Figure C.3 shows the range of discount factors observed in 2010 relative to 1995.

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World Total Carbon Emissions by Region/Country, Reference Case, 1990-2015

Region/Country	Reduction from 2010 Business-As-Usual to 1990(-x)				
	1990(-0)	1990(-2.5)	1990(-5)	1990(-10)	1990(-15)
Industrialized:					
North America	0.244	0.263	0.282	0.320	0.358
United States*	0.223	0.243	0.262	0.301	0.340
Canada	0.247	0.266	0.285	0.323	0.360
Mexico	0.466	0.480	0.493	0.520	0.546
Western Europe**	0.159	0.180	0.201	0.243	0.285
Industrialized Asia	0.312	0.329	0.346	0.381	0.415
Japan	0.339	0.356	0.372	0.405	0.438
Australasia	0.213	0.232	0.252	0.291	0.331
Total Industrialized	0.228	0.247	0.267	0.305	0.344
Non-industrialized:					
EE/FSU					
Former Soviet Union	-0.180	-0.151	-0.121	-0.062	-0.003
Eastern Europe	-0.010	0.015	0.041	0.091	0.142
Total EE/FSU	-0.136	-0.107	-0.079	-0.022	0.035
Developing Countries					
Developing Asia	0.601	0.611	0.621	0.641	0.661
China	0.590	0.600	0.610	0.631	0.651
India	0.622	0.632	0.641	0.660	0.679
Other Asia	0.612	0.622	0.632	0.651	0.671
Middle East	0.356	0.372	0.388	0.420	0.452
Africa	0.363	0.379	0.395	0.427	0.459
Central/South America	0.505	0.518	0.530	0.555	0.579
Total Developing	0.550	0.562	0.573	0.595	0.618
Total Non-industrialized	0.387	0.402	0.417	0.448	0.479
Total World	0.317	0.334	0.351	0.385	0.419

Source: Based on Table A9, "International Energy Outlook 1997," DOE/EIA-0484(97), April 1997.
See DOE/EIA-0484(97), p.124 for additional information about statistical sources.

Notes:

Total carbon emissions, by region/country, generally consist of emissions from use of oil, coal, and natural gas.
US numbers include carbon emissions attributable to renewable energy sources.

*United States includes 50 states and District of Columbia (US territories are included in Australasia).

**Western Europe includes EU15 + Iceland, Norway, Switzerland, and Turkey.

Addenda:

EU15	0.075	0.098	0.121	0.167	0.214
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Source: EC Staff Working Paper, "Climate Change - Analysis of Proposed Emission Reduction Objectives for Kyoto."
According to the EC, the EU15's energy-related emissions will increase from 3200 Mtonnes of CO₂ in 1990 to 3459 Mtonnes of CO₂ in 2010, under Business-As-Usual Assumptions.

II. Executive Summary

A. Global Warming

Belden & Russonello conducted three focus groups, two in Boston and one in Baltimore, which explored ways in which the Union of Concerned Scientists (UCS) may increase the saliency of global warming among voters. As UCS prepares for the upcoming meetings on the Global Climate Change Treaty, we find that the voters in our discussions are somewhat knowledgeable and aware of global warming, its causes, and its impacts. However, like most voters in the country, the participants in our discussion groups do not view global warming as an urgent issue.

The following analysis of the groups offers some insights and recommendations on how UCS may best communicate on this issue to raise voters' concerns.

1. *Some awareness of global warming but low saliency:* The voters in our focus groups are somewhat knowledgeable and aware of the consequences and causes of global warming. They recognize the link between global warming and the burning of fossil fuels and the melting of polar ice caps, desert encroachment, severe weather patterns, and the rise of ocean levels. But, global warming is not a concern for these voters. They do not see how global warming will affect their lives directly, and they question global warming's seriousness because they have heard conflicting scientific reports and they themselves cannot cite local examples of global warming's impacts.

2. *Pollution is seen as the cause of global warming:* "Pollution" from the burning fossil fuels is viewed as the main cause of global warming and something that should be reduced for its own sake. The model many voters use to think of global warming is:

Pollution → Global Warming → Climate Change → Melting Polar Ice Caps, etc.

In addition, the effects of pollution are a more urgent concern than any of the potential impacts of global warming for these voters.

3. *Constructing a definition of global warming:*

The earth's atmosphere relies on a delicate balance of gases which trap the sun's energy in just the right proportion to sustain life on the planet. This balance is being disrupted by global warming, caused by the amount of oil, coal, and natural gas that we are burning in our cars, trucks, power plants and factories. Global climate change, the melting of the polar ice caps, and the expansion of the earth's deserts are just some of the consequences of global warming.

a. The term global warming is most descriptive of the problem. Our voters choose "global warming" over "climate change" and the "greenhouse effect" as the best and most descriptive term for increases in the earth's temperature. Many voters, particularly the young voters, are familiar with the term "global warming," and report that it is more explanatory of the problem. "Climate change" is seen as less descriptive of the overall problem, and "greenhouse effect" is deemed benign.

b. The term climate change communicates global warming's impact. "Climate change" is a useful way to describe global warming's effects on the planet. "Climate change" is preferred over "changes in weather patterns" as a phrase to illustrate the consequences of global warming because it is seen as more serious, more global, a more long term than changes in weather.

c. When defining global warming, be succinct, show the impacts, and add a dash of science. Since voters are most interested in global warming's consequences, a useful definition for them would include examples of global warming's impacts and a short description of the process that is causing the rise in the earth's temperature.

Reminding voters of the impacts -- melting of polar ice caps, desert encroachment, etc. - helps to clarify the issue at hand and confirms for some what they already know. The consequences make global warming more tangible for voters and begin to provide them with the reasons to care.

These voters do not need to fully understand the science to appreciate the problem. Having some science helps, but only if it is short and easy to comprehend. For example, some simple but effective explanations of the science include:

- stating that "there have been dramatic increases in heat-trapping gases over the last 100 years;"
- stating that "the earth's atmosphere relies on a delicate balance of gases which trap the sun's energy in just the right proportion to sustain life on the planet. This balance is being disrupted by global warming;" or
- simply describing global warming's effects on the earth's water cycle.

4. *Increasing saliency of global warming:*

a. **Present a combination of impacts.** Communications on global warming should contain a combination of different types of impacts of global warming, including health and environmental impacts.

The biggest challenge facing a communications campaign on global warming is the long term nature of global warming's effects. When a crisis is not visible or when current examples are lacking in people's own lives, it is easier to reject the urgency of global warming. Close to home examples and ones which people can confirm for themselves are important elements to a communications campaign.

In our focus groups, general health-related impacts are seen as highly personal, but are difficult for voters to connect to global warming. In contrast, the environment's connection to global warming is more readily understood, but environmental effects are less personal. Presenting a combination of health and environmental impacts together enables voters to more easily understand global warming's connections and effects on their lives.

Caution. Citing specific weather events are not as effective as discussing changes in weather patterns and the effect these changes will have on humans. Recent weather events tend to be attributed to natural, cyclical occurrences, whereas changes in *weather patterns* are more easily linked to global warming and are viewed as serious problems by most voters.

b. **Use reference periods.** Including reference periods, such as describing global warming's impacts in the next 20 years, makes the problem more personal and imminent.

When a time frame is used, global warming becomes more immediate and measurable, and consequently, something which can and should be stopped. The reference period, the next 20 years, is useful in raising the saliency of the issue, especially for younger voters who come to see global warming as having an impact during their own lives.

c. **Show solutions which include individuals, industry, and government.** Our voters want to know that there are solutions to the problem of global warming. If reasonable solutions are not readily apparent, voters will disregard the problem as too overwhelming and unfixable.

Voters in the focus groups want individuals, government, and industry *all* working to solve global warming. Solution statements which focus on only one or two of these groups are not as successful as those which acknowledge the need for all three entities to take responsibility to stop global warming.

For many in the groups, the solutions to global warming are important because they will have a broad impact on environmental problems, particularly pollution, regardless of whether or not they stop global warming.

Caution. Voters are skeptical of assertions that we can become energy efficient "at additional cost." Claiming that solving global warming will be painless may serve to reduce the urgency of the issue. Voters need to be educated about energy alternatives before bold claims can be made about them.

d. **Use comparative data and cite sources.** Global warming and its consequences are still uncertain phenomena to these voters. In their search for truth, comparative data and specific sources for information about global warming and its impacts will make the issue more credible and urgent. For example, skepticism about a predicted increase in the melting of polar ice caps may be overcome if voters learn that the ice caps are melting at a faster pace now than before.

Comparative data often needs to be placed in context to be credible and relevant. Describing the increase of .5 to 1.1 degrees in the earth's temperature over the last 100 years lacks relevance for many people unless they hear that the "earth's atmosphere relies on a delicate balance" which is disrupted by global warming.

e. Scientists need credentials to be taken seriously. The public is bombarded with conflicting scientific studies and dueling scientists on numerous issues. The result is that the voters in our groups are not about to believe someone simply because he or she is labeled a "scientist." When presenting the case for global warming initiatives, it is best to be as descriptive as possible in identifying scientific spokespersons. Describing someone as a "climate scientist" helps to add some credibility, as does mentioning an affiliation with the National Academy of Sciences. Citing numbers of scientists, such a "2,500 climate scientists" is impressive, but these voters still want to know the countries and institutions represented by these scientists.

The voters in our groups are more likely to listen to scientists on global warming if provided with information, such as the backgrounds, affiliations, or credentials of the scientists.

f. Do not sound extreme, lead with facts. Since voters do not yet see global warming as an urgent issue, leading with emotional messages which scream urgency is rejected as extreme. The public debate on global warming has left many confused about its seriousness, so voters are searching for the facts on global warming before they decide to act. Stressing the urgency of the issue may best come at the end of a message after the facts have been presented.

g. Do not be overly negative. One-sided communications which point fingers and criticize industry without providing positive solutions will turn off these voters. They strongly support the idea that industry needs to be pushed hard by government and the public to become more energy efficient, but they do not accept a message which simply attacks industry. They believe everyone bears some responsibility for the problem of global warming.

5. *Support for Global Climate Change Treaty:* U.S. participation in the international Global Climate Change Treaty is endorsed by almost all the voters in our discussion groups, because they believe a world-wide problem such as global warming needs a world-wide response. Their support for U.S. participation is not shaken, at least initially, by the fact that developing countries are not bound by the treaty, because they believe we need to start somewhere to reduce fossil fuels emissions. As one young voter said, "If we don't do it, then nothing is going to happen at all. At least if we do it, we get the ball rolling." Since the groups did not include a discussion of all the arguments against participation in the treaty, the strength of support for the treaty should be judged uncertain at this point.

6. *Communicating on global warming:* The low saliency of global warming owes primarily to the distant nature of its impacts. Raising concern over this issue will require a persistent and consistent message that makes global warming's impacts feel closer to voters' lives. As UCS takes up this task, our focus groups offer the following guides:

- ✓ Define global warming mostly in terms of its impacts, since that is what voters care about most.
- ✓ When describing impacts, do not rely on only health-related or environmental impacts. Combining both health and environmental effects adds credibility and urgency to the argument to act on global warming.
- ✓ Whenever possible, link global warming to pollution, since pollution is a problem which generates some sense of urgency for voters and is already seen by voters as a cause of global warming.
- ✓ When describing the problem of global warming, include solutions that involve individuals, government, and industry. When voters see global warming as a difficult but solvable problem for which everyone bears some responsibility, it increases their willingness to act. The solutions to global warming appeal to voters because they are also solutions to the problem of pollution, which voters see as more urgent.

- ✓ Scientists need to spell out their expertise to be effective spokespeople on global warming. Information from scientists in general is too common and may not be considered authoritative, but the views of a large number of scientists with experience on this issue would bear some weight with these voters.
- ✓ Lead with facts rather than emotional appeals, because voters need to hear about impacts first and foremost. Comparative data on how the earth is changing because of global warming can make the issue more relevant, as can a simple description of the science.

Robert N Burt
Chairman and
Chief Executive Officer

FMC Corporation
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Chicago Illinois 60601

Correspondence S
Research
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September 10, 1997

Todd D. Stern
Assistant to the President
Executive Office of the President
1600 Pennsylvania Avenue, NW
Washington, D.C. 20500

Dear Todd:

Enclosed is an article on the global climate issue written at MIT.
The paper analyzes the interaction between the science and
U.S. policy and should be helpful to you as look forward to
Kyoto.

Sincerely,

Bob Burt
Robert N. Burt

pr
enclosure

MIT Joint Program on the Science and Policy of Global Change



Needed: A Realistic Strategy for Global Warming

Henry D. Jacoby, Ronald G. Prinn and Richard Schmalensee

July 1997

The MIT Joint Program on the Science and Policy of Global Change is an organization for research, independent policy analysis, and public education in global environmental change. It seeks to provide leadership in understanding scientific, economic, and ecological aspects of this difficult issue, and combining them into policy assessments that serve the needs of ongoing national and international discussions. To this end, the Program brings together an interdisciplinary group from two established research centers at MIT: the Center for Global Change Science (CGCS) and the Center for Energy and Environmental Policy Research (CEEPR). These two centers bridge many key areas of the needed intellectual work, and additional essential areas are covered by other MIT departments, by collaboration with the Ecosystems Center of the Marine Biology Laboratory (MBL) at Woods Hole, and by short- and long-term visitors to the Program. The Program involves sponsorship and active participation by industry, government, and non-profit organizations.

To inform processes of policy development and implementation, climate change research needs to focus on improving the prediction of those variables that are most relevant to economic, social, and environmental effects. In turn, the greenhouse gas and atmospheric aerosol assumptions underlying climate analysis need to be related to the economic, technological, and political forces that drive emissions, and to the results of international agreements and mitigation. Further, assessments of possible societal and ecosystem impacts, and analysis of mitigation strategies, need to be based on realistic evaluation of the uncertainties of climate science.

This paper is intended to improve public understanding of the climate issue, and thereby contribute to informed debate about the climate issue, the uncertainties, and the economic and social implications of policy alternatives.

Henry D. Jacoby and Ronald G. Prinn,
Program Co-Directors

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Needed: A Realistic Strategy for Global Warming

Henry D. Jacoby, Ronald G. Prinn and Richard Schmalensee*

As the United States, along with other nations, struggles to develop a response to climate change, a swirl of overheated rhetoric and short-term political maneuvering is obscuring the basic features of this issue. One day we hear that all responsible scientists agree that global warming is a dagger at the heart of human civilization and that emissions of carbon dioxide (CO₂) and other greenhouse gases must be slashed immediately to save our planet. The next day we're told that global warming is the illegitimate offspring of sloppy science and green fanaticism and that laying a finger on U.S. CO₂ emissions would wreck our economy and enrich our foreign competitors.

This debate is motivated by intense, ongoing international negotiations on possible near-term CO₂ emission limits. The agenda for these negotiations, the so-called Berlin Mandate, was adopted at the first conference of Parties to the Framework Convention on Climate Change, held in Berlin in 1995. Diplomats were told to devise a set of national ceilings for greenhouse gas emissions for the early years of the next century. To make agreement more likely, developing countries were not to be asked to control emissions, although they account for roughly half the greenhouse emissions now and will emit a larger share in coming decades. These complex negotiations were to be completed in just two years, in time for the third Conference of Parties this December in Kyoto, Japan. Negotiations have become focused on a single question: how much will each of the developed nations promise to cut CO₂ emissions by 2010?

Our aim here is not to settle this near-term question, though the answer (if any) agreed to in Kyoto may be of great environmental and economic importance. Instead, we will show, through a brief look at the science and economics of climate, that if climate change turns out to be a serious threat, an effective response will require a substantial and very long-term global effort. Today's focus on near-term emissions reductions will be counter-productive if it delays development of the institutions and policy architectures that would be necessary to mount and sustain such an effort over much of the next century.

What Do We Know About Global Warming?

Global warming or cooling can be driven by an imbalance between the energy the Earth receives from the sun, largely as visible light, and the energy it radiates back to space as invisible infrared light. The "greenhouse effect" is caused by the presence in the air of gases and clouds that absorb some of the infrared light flowing upward and radiate it back downward. This warming effect is opposed by substances at the surface and in the atmosphere that reflect sunlight directly back into space. These include snow and desert sand, as well as clouds and aerosols from smog and volcanic action. (Aerosols are very tiny, submicroscopic solid or liquid particles suspended in the air. Smoke and fog are familiar examples.)

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The most important greenhouse gas is water vapor, which typically remains for a week or so in the atmosphere. Central to the climate change debate, however, are less important but much longer-lived greenhouse gases, most notably CO₂. Concern arises because the atmospheric concentrations of CO₂ and other long-lived greenhouse gases have increased substantially over the past century. When this happens, the flow of infrared energy to space is reduced, so that, *all else equal*, the Earth receives slightly more energy than it radiates to space. This imbalance, which is often called “radiative forcing,” tends to raise temperatures at the Earth’s surface. These aspects of the greenhouse effect are not controversial. It is also generally accepted that emissions of CO₂ from combustion of fossil fuels (primarily coal, oil, and natural gas) are the most important way humans can affect radiative forcing, and that this emitted CO₂ remains in the atmosphere for a long time, on the order of a century or so. Thus today’s radiative forcing reflects, in small part, the CO₂ emitted when coal was burned to keep President William McKinley warm in the White House.

What is much more uncertain, and the cause of serious scientific debate, is the response to radiative forcing of the complex system that determines our climate. “Climate” is usefully defined as the average of the weather we experience over a ten- or twenty-year time period. In this context, it is important to emphasize that year-to-year changes in weather patterns or storm tracks should not be, but often are, confused with climate change. Some poorly understood processes in the climate system tend to amplify the warming effect of radiative forcing, while others, equally poorly understood, tend to counteract or delay that effect.

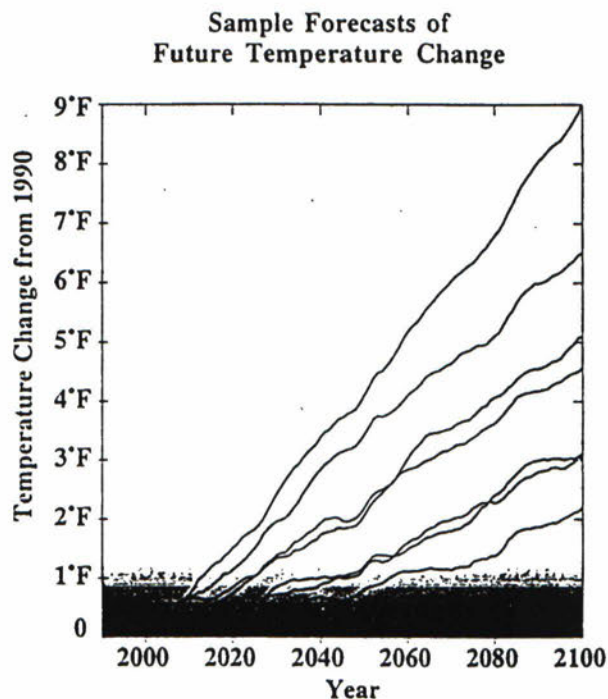
To take a familiar example, clouds in the daytime provide a cooling mechanism by reflecting sunlight back to space. But abundant clouds and high humidity at night help keep temperatures high because they contribute to the greenhouse effect. This is why on clear, cloud-free nights we can get rapid lowering of temperatures by tens of degrees Fahrenheit. Unfortunately, the processes that drive long-term changes in daytime and nighttime humidity and cloud cover are not well understood. Similarly, we know that any global warming will tend to be delayed because it takes a lot of heat to warm the oceans, but we’re quite uncertain exactly how rapidly heat is carried into the deeper parts of the ocean.

Computer models used to predict climate attempt to simulate these and many other important processes on regional and global scales. These models are remarkable in their complexity and are invaluable tools for scientific research. However, their complexity taxes the capabilities of the world’s largest computers. Moreover, they are based on incomplete knowledge about the key processes that control clouds, the ocean circulation, the natural cycles of greenhouse gases, and natural (volcanic) and manmade (smog) aerosols. Current climate models cannot reproduce the succession of ice ages and warm periods over the last 250,000 years, let alone the smaller climatic changes observed over the last century. In addition, climate models are driven by forecasts of emissions of greenhouse gases, and these rest on highly uncertain long-term forecasts of population and economic growth and of technological advance.

To help quantify the uncertainty in climate forecasts, a group of scientists and economists at MIT (including the authors) have recently developed a coupled model of global economic development, climate processes, and ecosystems. This model is unique in its combination of detailed treatments of the relevant natural and economic processes. Within this model, the researchers have explored the consequences of a range of plausible assumptions about future economic development (assuming no regulations are enacted to restrict future greenhouse gas

emissions) and about fundamental climate processes, to produce a family of seven forecasts of climate change over the next century. Each forecast in the family can be defended as reasonable given current knowledge.

To illustrate the range of uncertainty involved in climate forecasts, the first figure shows the predictions for the change in global average surface temperature from its 1990 value. Temperature increases by the year 2100 as small as two degrees Fahrenheit or as large as nine degrees Fahrenheit can be defended as plausible. About two thirds of the overall difference here is due to uncertainty about climate processes; the other third reflects uncertainty about emissions. Despite a great deal of research, we simply do not know which of these paths (or indeed other plausible paths) we are now on. Indeed, there may be rapid climate changes driven by purely natural processes that are not well handled by any current climate models and are not reflected in any of the forecasts shown here.



Unfortunately, we know less about the likely impacts of plausible changes in climate than about either future emissions or the natural processes determining climate. Warming may increase storm damage, for instance, but it may also decrease it. Almost nothing is known about likely (as opposed to possible) impacts on human health or about the ability of unmanaged ecosystems to adapt to climate change. Civilization has adapted to climate change in the past and can, to at least some degree, adapt to future changes. What we do know suggests that the changes summarized by the lowest path in the figure would do little harm over the next century and might even be beneficial on balance for some countries. Most analysts would agree, however, that the highest path would correspond to significant risks to a variety of important natural processes (including ocean circulation, polar glaciers, and unmanaged ecosystems) as well as to agriculture and other human activity.

In some respects the most important finding of climate research is that the range of possible outcomes is enormous. We believe it is impossible to make sound policy decisions in this field without taking explicit account of this profound uncertainty. In addition, it is plainly vital to continue research aimed at improving emissions forecasts, climate models, and impact estimates in order to narrow the range of plausible forecasts. An important component of this work is the search for a so-called "fingerprint" that would reveal human influence on the climate system.

Has Human-Induced Warming Begun?

Last year, the Intergovernmental Panel on Climate Change (IPCC) declared in its *Summary for Policymakers* that "the balance of evidence suggests a discernible human influence on climate." There were some qualifications and hedging in the *Summary* and much more in the detailed

Working Group Report upon which it was based. Nevertheless this statement, largely in isolation, was widely reported and has since shaped policy discussions around the world. But was this isolated, unqualified summary statement, written by governments' representatives, a scientifically defensible conclusion?

To establish a human influence on the global climate, we would ideally want to show that the observed global patterns of climate change over the past 100 years, say, are consistent with those predicted by climate models which include human activities such as production of CO₂ and aerosols from fossil fuels, but are not consistent with the patterns predicted when those activities are omitted. The latter predictions would reflect the natural variability of climate—the “noise” out of which the human “signal” (or “fingerprint”) must arise for a definitive detection. Unfortunately, current climate models are both uncertain predictors of the climate response to human influences and inadequate tools for assessing natural variability. In addition, data on the global climate and human influences in past decades, and our understanding of the cooling effects of manmade aerosols, are far from ideal.

For these and other reasons, some scientists have been skeptical about the IPCC's “balance of evidence” statement from the beginning. This group has grown substantially over time. Even some scientists who were significantly involved in producing the IPCC statement are now publicly expressing doubts. In an important news report on this subject in the journal *Science* in May 1997, Richard A. Kerr describes the growing skepticism about the original IPCC *Summary* conclusion, and the growing realization that it may be a decade or more before the human effects can be discerned above the noise of natural climate variability.

This does not mean that we should wait to take action until and unless human effects on climate are definitively detected. As the discussion above indicates, we know enough to know that significant global warming, with significant adverse impacts, may occur in the future. It would be irresponsible to ignore such a risk, just as it would be irresponsible to do nothing when you smell smoke at home until and unless you see flames. It would also be irresponsible, of course, to call the fire department and hose down all your belongings at the slightest whiff of what might be smoke.

Nevertheless, the search for a definitive detection of human-induced climate change can provide valuable information for the policy process. The figure above provides a simplified illustration of the point involved. The shaded region at the bottom represents a plausible estimate of the range of natural variability or noise in global mean temperature over the course of a century. As the figure shows, the greater the eventual warming, the sooner observed temperatures will rise above this range, and the signal of a human influence will emerge from this noise. (This conclusion holds whatever the noise level; higher noise levels simply imply later detection, all else equal.) The larger the human effects on climate, the sooner it should be possible to find definitive evidence of those effects, and the stronger will likely be the case for substantial emissions reductions.

Should Global Warming Be Stopped?

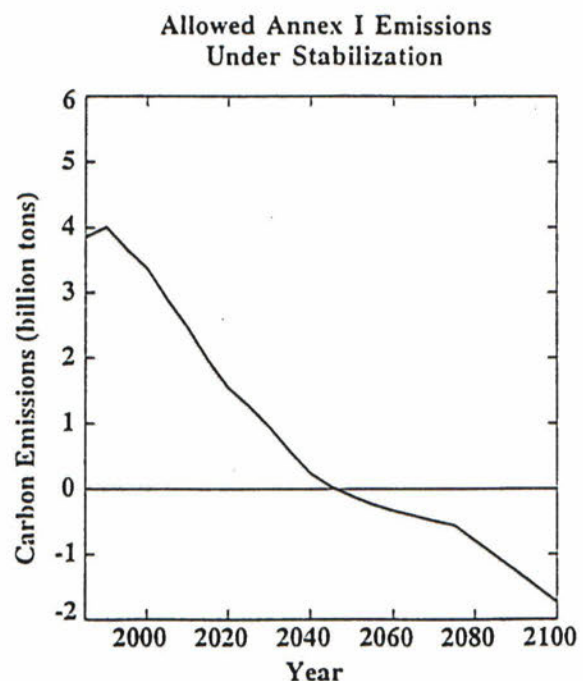
If climate change turns out to be a serious problem, the sorts of emissions reductions being fiercely debated in the run-up to the Kyoto meeting will not *by themselves* do much to solve it. Under the Berlin Mandate, emission reductions are to be sought only from countries listed in Annex I to the original climate treaty: the members of the Organization for Economic Cooperation

and Development (OECD) as of 1990 (Western Europe, the United States, Canada, Australia, New Zealand, and Japan) and the "economies in transition" (Eastern Europe and most of the Former Soviet Union). To illustrate the effects of restrictions limited to these nations, let us consider one of the toughest proposals now on the table: the call by the European Union (EU) to cut Annex I CO₂ emissions to 15% below 1990 levels by 2010.

When measured not in relation to 1990 but against emissions today or those expected in another 13 years, this proposal would require much more than a 15% reduction in most countries. There is little doubt that such sharp cuts in CO₂ emissions over little more than a decade would be very expensive, even if economic growth were to slow from its pace in recent decades. It would be even harder for Annex I nations to maintain the proposed 2010 level of emissions for the rest of the next century. Yet, largely because of projected emissions growth in the developing world, the MIT climate model shows that such a costly effort by the Annex I countries would reduce projected warming in 2100 by only about 20 percent in the mid-range of the forecasts illustrated in the first figure. If climate change turns out to be a serious threat, this response, by itself, would be inadequate; if it turns out not to be a threat, this response would be a large-scale waste of resources.

A policy aimed at reducing near-term emissions may, if properly designed, be a valuable first step toward a more serious (and even more expensive) response strategy that could be used if we learn that human-induced warming is a serious threat. The Framework Convention on Climate Change calls for stabilizing atmospheric concentrations of greenhouse gases at levels that will avoid "danger" to economies and ecosystems. The European Union, among others, has recommended stabilizing the concentration of CO₂ in the atmosphere at 550 parts per million, which is roughly twice pre-industrial levels. Doing this would substantially slow (but not stop) climate change. Following the particular path to stabilization at this level that was estimated by the IPCC would lower the projected warming in 2100 in the mid-range forecast in the earlier figure by only about 30%, though it would have larger relative effects in the following century.

Following this EU recommendation would require sharp cuts in global CO₂ emissions, however, and the Annex I nations almost certainly could not do the job by themselves. We can illustrate the magnitude of the task using a mid-range forecast from the set shown in the first figure, along with the IPCC's estimate of a global emissions path that would lead to the 550 parts per million target. The second figure shows the maximum Annex I emissions consistent with this path, assuming that non-Annex I nations accept no restrictions. (To calculate the emissions allowed to Annex I countries, we simply subtracted the forecasted non-Annex I emissions from the global total.) Without participation by the developing world, emissions by Annex I nations would somehow



have to become negative around the middle of the next century! Even a total ban on all use of fossil fuels in all developed nations within a few decades would not do the job.

Of course, if the richer nations continue to reduce emissions over time some voluntary abatement by non-Annex I nations would probably occur. Over the coming decades, some non-Annex I nations will no doubt become wealthy enough to join the Annex I emissions reduction club voluntarily. But the countries most likely to do this account for only a small fraction of projected non-Annex I emissions. In China, India, Indonesia, Brazil, and other high-population, high-emissions countries, income growth seems unlikely to stimulate voluntary abatement much before the end of the next century. Until then, these nations will be more concerned with feeding themselves and their children than with protecting their grandchildren from potential global warming. Thus, if the rich countries want to stabilize greenhouse gas concentrations, they will have to pay poor countries to reduce their emissions. Rough estimates of the costs that would be involved, even assuming fully efficient abatement policies and neglecting costs of monitoring and enforcement, imply massive international transfers of wealth on a scale well beyond anything in recorded history.

What Should We Do Now?

There is little or no political support today for a long-term commitment to such a Herculean effort. Moreover, since climate change could turn out to be relatively harmless, making such a commitment now would make little economic sense. On the other hand, since climate change may also be a significant threat, it would make no more sense to do nothing. Unfortunately, there are no simple rules that can be relied upon to tell us what to do. We must consider costs and risks and take actions in the face of profound uncertainty about their consequences.

In such a setting, it is important not to lose the long-term perspective. Today's actions should aim to reduce the costs of massive global emissions reductions, in case advances in climate science show such reductions to be desirable. Investments in new technology and in the development of policy architectures and institutions are particularly attractive in this regard. While it is almost certainly too late to agree on investments of this sort before December's Kyoto meeting, that meeting is but one step in what will very likely be a long political and diplomatic process. Whatever else happens there, the participants will produce some sort of "Kyoto Mandate" to guide the next round of international negotiations. That Mandate should focus the process on investments with long-term benefits.

The potential value of investments in new technology is clear. It may well prove impossible to slow warming appreciably without condemning much of the world to poverty unless carbon-free energy sources become roughly competitive with conventional fossil sources. Further, a serious attempt to produce important new technological options would be cheap relative to the cost of controlling emissions resulting from the use of current technologies. The range of possible options is wide, stretching from solar electricity to the continued use of fossil fuels with capture and sequestration of the CO₂ their combustion produces.

Unfortunately, we know too little about what produces fundamental technical change. The available evidence points to the importance of marketplace incentives for private sector research and development and (with somewhat more controversy) to public expenditure on basic research and fundamental technologies. Politicians love to call for more research instead of more regulation, but

we see only a tiny and diminishing commitment to the development of greenhouse-friendly technology by those countries most capable of performing it.

It is at least as important to begin the development of an institutional structure for managing global emissions agreements that can evolve easily over time. Such a structure must be able to adjust the stringency of abatement effort to the evolving science, giving incentives for national participation but accommodating failures along the way, and to provide compensation to induce participation by the developing world.

This is a tall order, and we do not pretend to know the best design. Some useful insight and perspective can be gained from the international trade regime developed under the General Agreement on Tariffs and Trade (GATT), now the World Trade Organization. This regime has grown and evolved over time, adding countries and goods along the way, peacefully resolving substantial conflicts in national economic interests, contributing importantly to global economic growth, and producing a stunning success by the standards of international affairs. But it has taken 50 years of hard work to do this!

In this connection, experimenting with national emission ceilings of the type that are the near-total focus of the Berlin Mandate process may be of long-term value. Naturally, one objective of such an effort is to make actual reductions in the quantities of greenhouse gases we would otherwise put into the atmosphere over the next decade or two. We do not belittle this motivation. But it should not be allowed to completely dominate the design of international agreements in this area. Such experiments will be of long-term value only to the extent that they facilitate development of sets of possible policy measures, a policy architecture if you will, that can, if necessary, contribute to effective and cost-efficient stabilization of greenhouse gas concentrations. This architecture would need to address all important sources and sinks of significant greenhouse gases, not just CO₂ produced from fossil fuels. Such a system would need to provide for reliable emissions monitoring and for some system of sanctions for those who violate their obligations. A host of other important issues must also be confronted.

For example, since global participation will be necessary if global emissions are to be reduced, it is important to structure any Annex I targets and timetables to facilitate the inclusion of non-Annex I countries. This involves, at a minimum, development of a regime to govern climate-related international wealth transfers. In this regard, the Berlin Mandate's exclusive focus on Annex I countries is a double-edged sword. On the one hand, unless the rich nations control their emissions first and support abatement by poor nations, the latter are unlikely even to slow their emissions growth. On the other hand, CO₂ emissions controls will raise the cost of producing energy-intensive goods in Annex I countries, tending to encourage the development of energy-intensive industries in non-Annex I nations. (This is sometimes referred to as "emissions leakage.") Once this has happened, non-Annex I nations will be more reluctant to take actions to curb the CO₂ emissions that have become a more important source of wealth. Attempts by the rich Annex I countries to use trade policies to slow the migration of energy-intensive industries to poorer nations may create major international tensions.

In order to minimize the global cost of CO₂ emissions reductions, the cheapest abatement opportunities should be exploited first. In principle, a regime involving emissions trading, like that used to control sulfur dioxide pollution in the U.S., could contribute substantial savings. But this approach, which has been advanced by the U.S. in the ongoing negotiations, runs into a problem

if participation is restricted to Annex I countries. Trading can only work effectively among countries that have agreed to emissions caps. Without the participation of the developing countries, where most observers agree that many of the cheaper emissions reductions are to be found, the advantages of trading are drastically reduced.

Finally, agreeing to lower future emissions may increase incentives to develop energy-saving consumer devices, along with low-carbon energy sources. But commitments to modest, short-term emissions reductions may focus R&D efforts on small advances over current technologies. Credible commitments to substantial, long-term reductions may be necessary to stimulate the fundamental research necessary to produce needed breakthroughs in energy technology. Lack of adequate political support seems to rule out making such commitments now, however, and the inability of any government to bind its successors would limit the credibility of any long-term commitments that were made.

* * *

Unless climate scientists discover soon that greenhouse warming is definitely not a threat, the struggle to devise a global response will occupy our children, along with their children and grandchildren. We have discussed three legacies that our generation could leave that would make this struggle easier: (1) an international climate agreement that could, if necessary, reduce greenhouse gas emissions substantially, at least cost, while being responsive both to changes in our scientific understanding and to evolving political and economic conditions, (2) enhanced technical options that could, if necessary, ease the task of maintaining economic growth while controlling greenhouse gas emissions, and (3) an international system that could, if necessary, transfer substantial sums to developing countries to assist their participation in an emissions control effort. Building these legacies is a huge challenge, but this task merits at least the same sense of urgency that has motivated pre-Kyoto negotiations about short-term CO₂ emissions reductions.

Research

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Science News, May 4, 1991

May 4, 1991

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LENGTH: 578 words

HEADLINE: NAS: act now to reduce global warming; National Academy of Sciences report

BYLINE: Walker, Tim

BODY:

Despite uncertainties in the science of predicting global climate change, the National Academy of Sciences (NAS) urges immediate action to curb greenhouse-gas emissions by reducing fossil-fuel consumption, promoting energy conservation, and improving solar and nuclear-energy technologies. For a very low cost, says NAS President Frank Press, the United States could reduce its greenhouse-gas emissions by 10 to 40 percent.

According to White House Science Adviser D. Allan Bromley, the NAS recommendations "are very similar to actions already taken or being proposed by the Bush administration." Both Press and Bromley testified before the Senate Committee on Commerce, Science and Transportation last week.

"The possibility of ecological disaster due to an increase in global temperature is sufficient reason to act now," Press warned. Outlining recommendations in "Policy Implications of Greenhouse Warming," an NAS report released April 10, he advocated a variety of low-cost steps aimed at reducing emissions of the major greenhouse gases -- carbon dioxide, methane, chlorofluorocarbons and nitrous oxide.

For instance, the academy report recommends adopting nationwide energy-conserving changes in building codes for residential and commercial structures, boosting the average automobile-fuel efficiency 18 percent (to 32 miles per gallon) and substituting compact fluorescent lights for incandescent bulbs in homes and businesses.

Together, the measures described in the new report are designed to head off a predicted 1 degree to 5 degrees C increase in global temperature by the year 2050, Press said. Enactment of these steps -- which the report estimates would cost between \$ 4 billion and \$ 30 billion -- could reduce the heat-trapping equivalent of 3.6 billion metric tons of carbon dioxide emissions per year, or about one-third of last year's U.S. greenhouse-gas emissions.

However, the report cautions that even at reduced emission rates, total greenhouse gases might still increase if population and industrial activity increase faster than predicted.

The NAS recommendations "parallel" actions specified in the President's National Energy Strategy released in February, Bromley testified. But committee member Sen. Albert Gore Jr. (D-Tenn.) disagreed, charging instead that many administration policies are "simply in opposition to the recommendations in this report." He warned Bromley that "history will judge the Bush administration harshly if its current inactivity on global warming continues."

While the NAS report stopped short of calling for penalties and higher taxes for major producers of greenhouse gases -- which some European nations have imposed -- environmental groups generally approve of the new recommendations. "This report should remove any lingering doubts that more time is needed to study global warming before we act," says William A. Nitze, president of Alliance to Save Energy.

Though most environmental groups support the NAS report's call for increased funding for development of new renewable technologies, many also object to some of the report's higher-cost recommendations, including the replacement of most fossil-fueled power plants with a new generation of lightwater nuclear reactors now under development. "We are strongly opposed to any effort that puts forth nuclear power as a panacea for the greenhouse effect," says Eileen Quinn of the Union of Concerned Scientists.

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"The United States needs to realize that although unilateral actions can contribute significantly to the reduction of greenhouse gases ... national efforts alone would not be sufficient to eliminate the problem," the report said.

Carbon dioxide, the principle greenhouse gas, is a waste produced mainly by burning gasoline, oil, coal and other carbon-based fuels. Thus, reducing the burning of these fuels can reduce the amount of carbon dioxide in the atmosphere.

Other greenhouse gases include chlorofluorocarbons, or CFCs, which are used principally as refrigerants and in manufacturing, and halons, which are used in fire extinguishers. Methane, or natural gas, is another major greenhouse gas. It enters the atmosphere from agriculture practices, landfills, some types of natural decay and oil field leaks.

LANGUAGE: ENGLISH

Research S

The Associated Press

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June 14, 1991, Friday, AM cycle

SECTION: Washington Dateline

LENGTH: 749 words

HEADLINE: Report Examines Ways of Reducing U.S. Effects on Global Warming

BYLINE: By PAUL RECER, AP Science Writer

DATELINE: WASHINGTON

BODY:

There are simple and relatively painless ways that the United States could reduce emissions of greenhouse gases nationwide by about 40 percent, the National Academy of Sciences said in a report Friday.

The report said that actions such as switching to more efficient light bulbs in homes and businesses, improving energy use in buildings and industry, and phasing out gas-guzzling cars would drop America's polluting gases perhaps by 40 percent.

"It is readily apparent that a significant reduction in 1990 emissions can be achieved at relatively low cost," said Thomas Lee, chairman of a committee that spent two years studying ways the nation could lower the risk of climate change due to global warming.

Arthur H. Rosenfeld, a University of California, Berkeley, professor and one of the 19 co-authors of the report, said all of the measures could be accomplished with no change in the American life style and with little or no net cost.

"All of these investments will save you money and they save huge amounts of carbon dioxide," he said.

Carbon dioxide and some other manmade gases set loose in the atmosphere are known to trap the sun's heat energy near the Earth, in much the same way as glass panes trap heat in a greenhouse.

These gases have been increasing in the planet's atmosphere since the rise of the industrial age and many scientists now believe that the Earth can overheat if the trend continues.

The scientists' study examined dozens of measures the country could follow to reduce greenhouse gases. The report puts the options into three categories based on their cost and their potential for reducing the target gases.

Category 1, the cheapest approach, "are things that would have no impact on our life style," said Rosenfeld. Most of these measures center on reducing the demand for electricity and gasoline.

Category 2 options include measures that are more expensive and could cause significant social or industrial changes. These include forced changes in transportation systems, such as reducing available inner city parking to cause greater use of mass transit by commuters; forced changes in agricultural practices; forced changes in auto design, and mandatory switching in the types of fuels used by industry and power companies.

In category 3 are options that would either screen sunlight or increase the natural absorption of carbon dioxide. These include shading the Earth with space mirrors or fleets of balloons, or by shooting dust into the stratosphere with naval guns or rockets. To absorb more carbon dioxide, the committee said forests could be planted and nutrients dumped into the ocean to trigger a bloom of sea plants.

"Although some of these proposals have an aura of science fiction, they do have a potentially high ability to mitigate against greenhouse warming," said Lee, a professor emeritus from Massachusetts Institute of Technology. Some of the category 3 measures, he said, could have dangerous side effects and "a great deal of research is needed before their feasibility can be fully understood."

Lee said "there is no single silver bullet" to avoid the risk of global warming for the planet, and he noted that the ultimate approach probably will include a mixture of the measures explored by the committee.

He also said there remains a great deal of scientific uncertainty about how serious greenhouse warming will become and the U.S. response to the problem may be adjusted as more is learned about the phenomenon.

The report said that although the United States is the world's largest producer of carbon dioxide and other greenhouse gases, the problem of global warming must be combatted by every nation.

"The United States needs to realize that although unilateral actions can

contribute significantly to the reduction of greenhouse gases ... national efforts alone would not be sufficient to eliminate the problem," the report said.

Carbon dioxide, the principle greenhouse gas, is a waste produced mainly by burning gasoline, oil, coal and other carbon-based fuels. Thus, reducing the burning of these fuels can reduce the amount of carbon dioxide in the atmosphere.

Other greenhouse gases include chlorofluorocarbons, or CFCs, which are used principally as refrigerants and in manufacturing, and halons, which are used in fire extinguishers. Methane, or natural gas, is another major greenhouse gas. It enters the atmosphere from agriculture practices, landfills, some types of natural decay and oil field leaks.

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