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Subgroup/Office of Origin: Council of Economic Advisers
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Subseries:

OA/ID Number: 13725
FolderID:

Folder Title:
[Reports] to GCC [Global Climate Change]

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THE KYOTO PROTOCOL
AND THE
PRESIDENT'S POLICIES TO
ADDRESS
CLIMATE CHANGE:

ADMINISTRATION
ECONOMIC ANALYSIS

July 1998

January 3rd, 1997

Dear Colleague,

As you may know, representatives of the world's nations will convene in Kyoto in December, 1997 to negotiate an international agreement addressing the threat of global climate change due to greenhouse gas emissions. This presents a significant opportunity for the United States to exercise a leadership role in ensuring our long-term well-being. Conversely, a failure on the part of the U.S. government to put forward a well-reasoned position would be a major environmental, economic, and diplomatic setback.

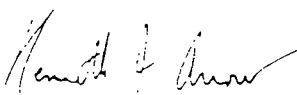
As the climate debate unfolds, it is imperative that public policy be guided by sound economics rather than misleading claims put forward by special interest groups. For this reason, we invite you to join us in endorsing the attached non-partisan consensus statement on the economics of climate change.

Once this statement has been signed by a large number of economists, it will be widely disseminated to leaders in the public and private sectors, and to the general media. This effort is being coordinated by Redefining Progress, a non-partisan, non-profit public policy organization.

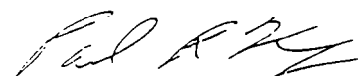
Attached please find an endorsement form for your consideration. This letter and endorsement form are being sent to the membership of the American Economic Association. Please feel free to circulate it to your colleagues in case they are not on the AEA mailing list.

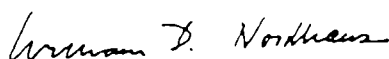
We thank you for your prompt attention to this critical issue.

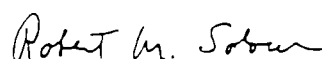
Sincerely,


Kenneth J. Arrow


Dale W. Jorgenson


Paul R. Krugman


William D. Nordhaus


Robert M. Solow

ECONOMISTS' STATEMENT ON CLIMATE CHANGE

*Endorsed by Over 2000 Economists
including six Nobel Laureates*

I. The review conducted by a distinguished international panel of scientists under the auspices of the Intergovernmental Panel on Climate Change has determined that "the balance of evidence suggests a discernible human influence on global climate." As economists, we believe that global climate change carries with it significant environmental, economic, social, and geopolitical risks, and that preventive steps are justified.

II. Economic studies have found that there are many potential policies to reduce greenhouse-gas emissions for which the total benefits outweigh the total costs. For the United States in particular, sound economic analysis shows that there are policy options that would slow climate change without harming American living standards, and these measures may in fact improve U.S. productivity in the longer run.

III. The most efficient approach to slowing climate change is through market-based policies. In order for the world to achieve its climatic objectives at minimum cost, a cooperative approach among nations is required—such as an international emissions trading agreement. The United States and other nations can most efficiently implement their climate policies through market mechanisms, such as carbon taxes or the auction of emissions permits. The revenues generated from such policies can effectively be used to reduce the deficit or to lower existing taxes.

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Yale University

ECONOMISTS' STATEMENT ON CLIMATE CHANGE

Among the over 2,300 economists who have endorsed the Economists' Statement on Climate Change are the following, they include scholars at top universities and economists from top corporations.

Michael C. Barth	ICF Kaiser	Laurence J. Kotlikoff	Boston University
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Steven Neil Braun	Council of Economic Advisers	Mordecai Kurz	Stanford University
W. A. Brock	University of Wisconsin, Madison	Steven G. Lanning	Bell Labs-Lucent Technologies
Martin Bronfenbrenner	Duke University	Lester Lave	Carnegie Mellon University
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Dallas Burtraw	Resources for the Future	Gerald M. Meiser	Stanford University
Trudy Ann Cameron	University of Los Angeles California	John R. Meyer	Harvard University
Jian Cao	AT&T	Christopher J. Monroe	AT&T
Carl F. Christ	Johns Hopkins University	Richard R. Nelson	Columbia University
Gerard Debreu	University of California at Berkeley	Richard B. Norgaard	University of California at Berkeley
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Franklin M. Fisher	Massachusetts Institute of Technology	Roy Radner	New York University
Peter J. Francis	CNA Corporation	Gordon Rausser	University of California at Berkeley
Victor R. Fuchs	Stanford University	Kenneth Rogoff	Princeton University
Claudia Goldin	Harvard University	David Romer	University of California at Berkeley
Edward Gramlich	University of Michigan	Michael Rothschild	Princeton University
Jerry R. Green	Harvard University	Daniel Rubinfeld	University of California at Berkeley
Frances Hammond	General Motors Corporation	Vernon W. Ruttan	University of Minnesota
John C. Harsanyi	University of California at Berkeley	Jeffrey Sachs	Harvard University
Oliver Hart	Harvard University	Thomas Sargent	University of Chicago
James J. Heckman	University of Chicago	F.M. Scherer	Harvard University
Albert O. Hirschman	Institute for Advanced Study	T. Paul Schultz	Yale University
Jack Hirshleifer	University of Los Angeles California	M.M. Shahjahan	PEPCO
Robert Hunt	World Bank	Steven Shavell	Harvard University
Leonid Hurwicz	University of Minnesota	A. Michael Spence	Stanford University
Christopher Jencks	Harvard University	Robert Stavins	Harvard University, Kennedy School
Gale D. Johnson	University of Chicago	Bruce Stram	Enron Corporation
Carl Kaysen	Massachusetts Institute of Technology	James Tobin	Yale University
Robert Kirchner	PEPCO	Gordon Tullock	University of Arizona
Lawrence R. Klein	University of Pennsylvania	Hal R. Varian	University of California at Berkeley
J. Kmenta	University of Michigan	W. Kip Viscusi	Harvard Law School
		Oliver E. Williamson	University of California at Berkeley

Environment

GLOBAL WARMING

GREENHOUSE GASES: THE COST OF CUTTING BACK

How much and how soon? The experts are still battling over what to do

As delegates from the world's nations prepare to negotiate a treaty on global warming in Kyoto starting Dec. 1, the debate over what to do might itself generate enough hot air to raise Earth's temperature. On one side are the auto, coal, and oil industries. They argue that a proposal to cut U.S. emissions of carbon dioxide and other gases back to 1990 levels over the next 13 years will devastate the economy. To prove it, they brandish sophisticated economic models showing the policy would slash gross domestic product in 2010 by as much as 2.5%. It would also raise gas prices by 50¢ per gallon, send the trade deficit soaring, "and throw a record-shattering number of American families out of work," warns Cecil Roberts, president of the United Mine Workers.

Ridiculous, say environmentalists and companies selling fuel-efficient technologies. They say energy-efficient technologies and alternative fuel sources—from fuel cells to photovoltaic panels to wind power—are already out there, waiting to be used. "It's a myth that the costs of action are high," says Joseph Romm, assistant secretary for energy efficiency at the U.S. Energy Dept. Indeed, a new study from Worldwatch Institute concludes the reverse: that greenhouse gas reduction will boost the global economy by spurring innovation. Amory Lovins, director of the Colorado-based Rocky Mountain Institute, an environmental think tank, agrees. "The bottom line is that reducing energy use is a competitive advantage," he argues.

Who's right? It's exceedingly difficult to know. Past predictions of the cost of environmental protection have often been far off the mark, and the same could be true here. "If there were a single answer it would have floated to the top by now," says Craig E. Ebert, senior vice-president of Virginia-based consultants ICF Kaiser International Inc. Economists admit that their models fall far short of simulating something as complex as the U.S. economy—they

have a hard enough time predicting next year's GDP. And the assumptions modelers make are crucial. Carnegie Mellon University economist Hadi Dowlatabadi finds that changing a few assumptions can make the predicted costs of slashing CO₂ emissions vary by a factor of 20.

If economists can't pin down the costs, how does the world arrive at a rational climate policy? Some economists have a clever solution. Dowlatabadi and Peter J. Wilcoxon of the University of Texas at Austin suggest that policymakers stop

focusing on cutting emissions to a specific level, as the Clinton Administration and many delegates to Kyoto advocate. Instead, governments should increase the price of oil, gas, and coal just enough to encourage a shift to lower CO₂ emissions without causing widespread dislocations. A carbon tax or emissions-trading program (where companies buy and sell rights to emit greenhouse gases) that limits costs to \$10 to \$15 per metric ton of carbon emitted might do the trick. That's equivalent to about a 10% to 15% rise in the wholesale price of energy,

THE ENERGY-EFFICIENT FUTURE

The energy-saving technologies shown on this "best practice" commercial building should be widely available by 2010. If they are widely adopted, the commercial building sector could cut its fuel consumption by 13.5%, reducing carbon dioxide emissions and saving \$33 billion a year in fuel costs.

REFLECTIVE ROOFING

COMMUNICATIONS AND CONTROL
■ ENERGY MANAGEMENT
■ UTILITY PURCHASING
■ CENTRAL COMPUTING

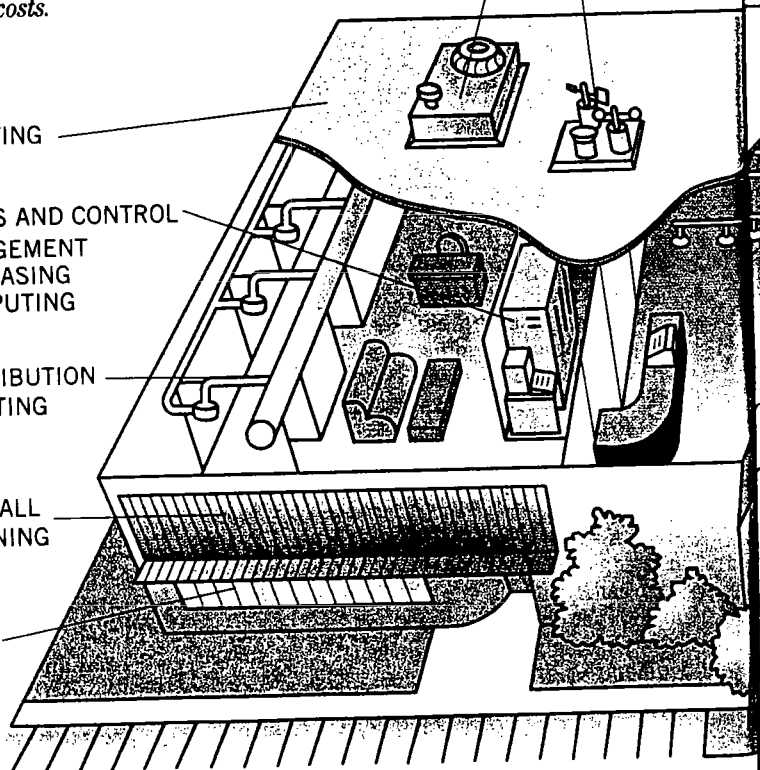
FRESH AIR DISTRIBUTION
WITH LOCAL HEATING
AND COOLING

PHOTOVOLTAIC WALL
PANELS AND AWNING

VARIABLE
TRANSMISSIVITY
WINDOWS

HYBRID
GAS/ELECTRIC
SPACE
COOLING

WEATHER
SENSORS



explains Yale economist William D. Nordhaus.

Such modestly higher prices for energy would accomplish two things. Companies and consumers would have an economic incentive to cut emissions. And the economy's response would help resolve the huge debate over the cost of climate policies. Once it's clear how much a given boost in energy prices does reduce greenhouse gas emissions, it would be possible to fine-tune the price later to hit any desired emissions target.

But the talk at Kyoto will likely be on emissions limits. The European nations want a rollback of emissions in 2010 to well below 1990 levels—and are busy bashing the U.S. for not signing on. But the U.S. is resisting deeper cuts—and will point the finger at rapidly developing countries such as China, which haven't agreed to sign on. Some fear the Kyoto talks will fail utterly, as nations blame each other for scuttling the proposed targets. Others hope there will be progress on such key issues as targets and timetables for cuts, along with a plan for the developing world.

The talks in Kyoto might get further, though, if politicians and consumers better understood the following sources of disparity in the cost claims.

THE MODELS

Most economic models try to mimic the entire economy from the top down. As individuals react to changes in the price of a key commodity like energy, the model's equations calculate the impact on the overall economy. Such models, however, can be unreliable.

Clinton Administration economists used one prominent macroeconomic model to conclude that stabilizing greenhouse gas emissions at 1990 levels by 2010 would raise the price of a metric ton of carbon by \$100—doubling the wholesale price of energy. Another use of the same model, done for industry groups by the consulting firm WEFA Inc., put the increase at \$200 per metric ton.

Can either figure be believed? The problem is that macroeconomic models become less accurate as they look further ahead, in part because behaviors can change in unexpected ways. That's one

reason the St. Louis-based modeling firm Macroeconomic Advisers turned down requests to model climate policies. "We couldn't possibly run something like this through and come up with anything meaningful," says chairman Joel Prakken. Even WEFA Senior Vice-President Mary H. Novak, who insists her group's forecasts are valid, admits that "if you look at all the estimates over the last 30 years, we really miscalculated prices."

THE ASSUMPTIONS

Another problem is that estimates of costs vary dramatically depending on the underlying assumptions.

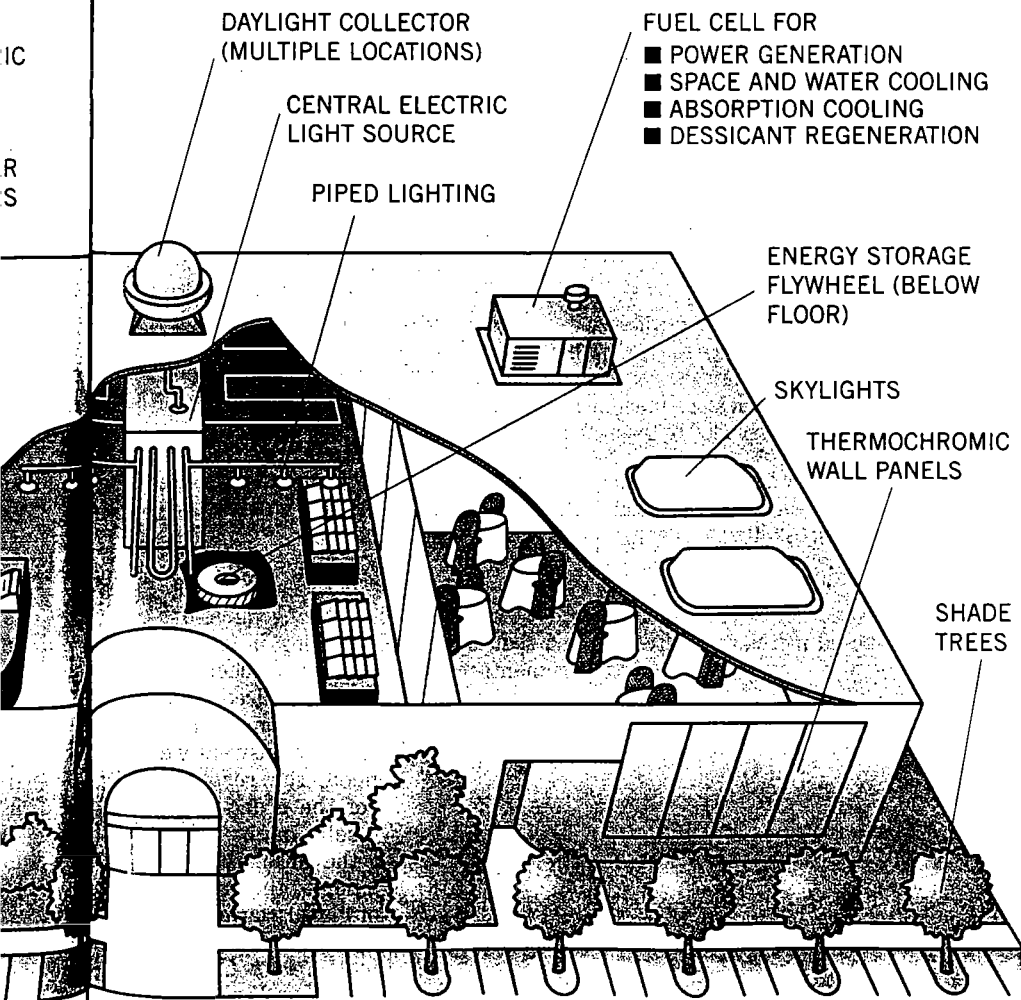
One key issue is what the models assume about tax policies. Most economists agree that market-based measures such as a carbon tax or an emissions-trading program would be more efficient—and cheaper—than so-called command-and-control regulations that simply order emissions be cut to a certain level. World Resources Institute economist Robert Repetto argues that there are further gains to be had from recycling the revenues from a carbon tax or emissions permit auction back into the economy in a way that spurs investment. That would boost the economy at the same time it prevented damage from climate change. But such a fundamental shift in the tax code is hardly a given. "We don't have the political will," says Massachusetts Institute of Technology economist Richard Schmalensee.

Then there's the question of benefits. The WEFA model and others that predict high costs do not include benefits that might emerge from slowing greenhouse gas emissions. Environmentalists believe curbing global warming will prevent droughts, flooding, and the spread of disease. Reducing fossil fuel use should also slash pollution. Throw in those benefits, and the net cost of a climate policy plummets. "Yet in the models, the benefits have been arbitrarily set to zero," complains Repetto. "If that's the right number, then what the hell are we doing?"

THE TECHNOLOGY

Perhaps the biggest controversy concerns the pace of technological change. Yet another type of model looks at the economy from the bottom up, asking what new energy-efficient technologies are cost-effective at today's and tomorrow's prices. How fast can they be adopted? And what would be the impact on CO₂ emissions?

A new study from the Energy Dept. concludes that the potential impact of innovative new approaches could be enormous. High-mileage cars already near-



ing production could slash U.S. carbon emissions by a total of 87 million metric tons per year by 2010—20% of the way toward stabilizing emissions at 1990 levels. More efficient buildings could cut 59 million more metric tons per year. Advances in electric generation—such as converting coal plants to natural gas—could cut 136 million metric tons more. Some of these make sense even at today's prices, and others need only a modest boost in the price of energy, the study says. "Any company or business or building can reduce emissions by 20% to 25% now—and cut its costs," asserts the Energy Dept.'s Romm.

Romm says the top-down economic models ignore innovation—they assume that a given boost in energy prices will stimulate the same increase in energy efficiency as past price rises did. "But technology is what makes the future not like the past," explains Romm.

Modelers retort that claims of a technological "magic bullet" are hopelessly rosy. A bedrock assumption of economics is that markets are efficient. Any better and cheaper strategies and technologies should have already been adopted. If they haven't, "that means the technologies are more expensive to commercialize than people think or they're just lousy technologies," says WEFA's Novak.

THE SOLUTIONS

The fact that neither economics nor technology can pinpoint the cost of climate policies may seem like a fatal blow to developing a rational approach. But there is a solution.

Most participants in the debate agree on two points. First, if the world wants to reduce global warming risks, it must send a clear economic signal now. President Clin-

THE UNDERLYING DEBATE

Competing economic studies put the cost of reducing greenhouse gas emissions to 1990 levels by 2010 at anywhere from near zero to \$200 per metric ton of carbon. The reason: different assumptions.

ISSUE Will future emissions growth follow current trends if there are no policy changes?

► Changes in the economy, such as productivity growing more rapidly in lower-emitting industries, or pollution-control policies would reduce baseline emissions, making it cheaper to hit climate targets

► Such changes can't be predicted, so shouldn't be included in the economic models

ISSUE What's done with the revenue from carbon taxes or emissions permit auctions will have a big impact on the economic reaction

► Using the money to offset payroll levies and other market-distorting taxes can give the economy a boost

► Tinkering with the tax code is politically unlikely, so shouldn't be included in the economic calculations

ISSUE Should economic models include estimates of the benefits of both reduced climate warming and lower pollution?

► Because emissions reductions would both curb warming and cut pollution, benefits are huge and must be counted

► Because these benefits are far off and highly uncertain, there's no point in trying to put them in the models

ISSUE Will the pace of technological change increase?

► Global warming policies will trigger rapid innovation, which can dramatically cut the estimated costs of CO₂-reduction efforts

► There's no evidence from past experience to suggest that the pace of innovation will accelerate, so such an assumption shouldn't be included in the models

ton's plan preaches new technology and voluntary reductions—but it doesn't call for economic measures, like a scheme to trade emission permits, until 2008.

The second point of consensus: Any greenhouse gas reduction plan should rely on market-based mechanisms. Econ-

omists generally agree that a carbon tax or an auction of emissions permits will stimulate innovative ideas at far lower cost than any other approach. The idea is to let the market "choose" the best technological solutions.

The crucial issue, then, is where to set the price of emitting a metric ton of carbon. Raising that to \$200 per metric ton to stabilize emissions at 1990 levels is a political non-starter. "We should do something modest, like \$10 per metric ton," says Yale's Nordhaus, which would add only 0.25% to the cost of living. "That would get people to think about substitutes."

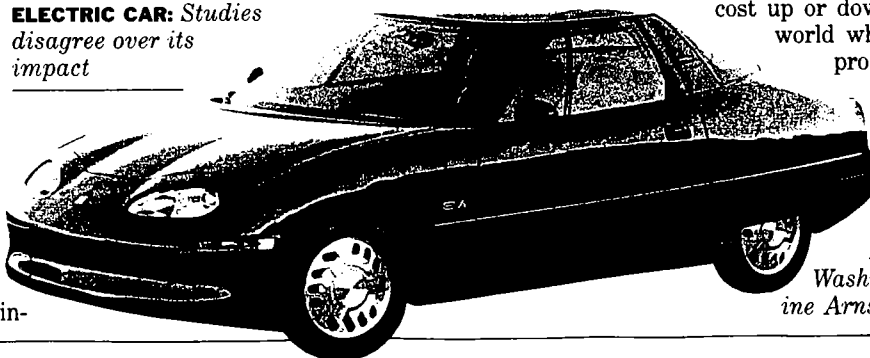
In other words, the best tack may be to decide what price we're willing to pay, not pick a target for emissions reduction. One approach would be a carbon tax. But Australian economist Warwick J. McKibbin and Texas' Wilcoxon have a clever, less intrusive scheme. It would use a permit-trading scheme with a built-in safety valve. Companies and industries would buy and sell emissions permits. But if the cost of emissions reduction went too high, companies could buy permits instead from their governments for a set price, say \$10 or \$15.

Environmentalists generally dislike the idea because it doesn't commit governments to specific levels of emissions cuts. But once such a policy is in place, the world would be able to measure its effectiveness in both cutting emissions and reducing global warming. Then governments could decide to ratchet the cost up or down as required. In a world where economics can't

provide the answers we need, the response of the economy itself might offer the ultimate solution to the problem of global warming.

By John Carey in Washington, with Catherine Arnst in New York

ELECTRIC CAR: Studies disagree over its impact



EDITED BY OWEN ULLMANN

TAX REFORM: GET READY FOR A CLASSIC CLINTON TURNABOUT

If there was one thing Bill Clinton was sure of, it was this: He held the high ground in the tax-reform debate. By casting Republicans as defenders of the rich—and trumpeting his tax breaks for the middle class—the President thought he could keep all those crazy flat-taxers and income-tax bashers in their cages.

But congressional hearings into Internal Revenue Service abuses made electrifying political theater, catching Clinton off guard and forcing him to accept Republican proposals to reform the IRS. And if that wasn't enough, tax issues helped the GOP sweep key elections on Nov. 4.

That's why Administration complacency has been replaced by near panic. Despite Treasury Secretary Robert E. Rubin's reluctance, Clinton may do an about-face. Rather than opposing change, he is now looking to promote his own version of reform, perhaps as soon as in his State of the Union Address in January.

"WE'VE GOT TO RESPOND." Just by getting in the game, Clinton vastly increases the odds of a tax restructuring before he leaves the Oval Office in 2001. Without the President's backing, tax reform would be a hot issue in 1998 and 2000 campaigns—but it would go nowhere. "Fundamental reform has to be bipartisan," says Barry K. Rogstad, president of the American Business Conference, a group of midsize companies. "You need a chief executive to take this to the American people."

What's behind Clinton's abrupt change? Al Gore, for starters. The Vice-President's potential rivals for the 2000 Presidential

nomination, eager to counter the GOP clamor for a new tax code, already are pushing their own plans. And congressional Democrats, worried about their '98 races, are eager to stake out a position.

"After the IRS debate, there was a fierce determination not to get stuck with the short end of the stick," says a senior White House official. "We've got to respond to the tax debate." So a team of Clinton advisers—led by Deputy Treasury Secretary Lawrence H. Summers and National Economic Council Director Gene Sperling—is working up options. "We're marching through every reform idea," says Sperling.

While New Democrats and Republicans agree on many economic issues, Clinton's version of reform could be very different from the GOP alternatives. He's likely to focus on making the tax code simpler while preserving progressivity.

That puts the President at odds with two leading GOP proposals—a 17% flat tax championed by House Majority

Leader Dick Armey (R-Tex.) and a national sales tax embraced by House Ways & Means Committee Chairman Bill Archer (R-Tex.). Republicans say their plans would simplify taxes and spur economic growth, but Clintonites insist both plans favor the rich.

Clinton could lift key elements from plans offered by Senate Budget Committee Chairman Pete V. Domenici (R-N.M.) and House Minority Leader Richard A. Gephardt (D-Mo.), considered Gore's chief rival in 2000. Domenici backs a consumption tax, and Gephardt's proposal would set a 10% rate for families earning \$60,000 or less.

Afraid that he'll find himself alone among candidates defending the status quo, Gore has been a major catalyst for the White House's new-found interest in tax reform. By the time the Veep hits the primary trail, he needs to have a plan of his own. "It's close to an imperative," says one Gore insider.

SHIFTING SANDS. But first the Vice-President and other tax-reform advocates will have to win over in-house skeptics. Some White House politicians still hope a bitterly divided GOP will fail to reach consensus on a reform proposal, allowing Clinton to duck his own tough choices. "Maybe we'll all agree to just debate this in the abstract until 2000," says one strategist.

Clinton no longer wants to take that chance, however. And with marching orders coming directly from the Oval Office, even the Treasury Secretary is going along. "He is not wildly for reform,"

says a White House aide. "But he has agreed to see what they can come up with." For now, Rubin says, "Whether the President will have anything to say in the State of the Union is very much unresolved." But down the road, he could live with a plan like the Tax Reform Act of 1986, which cut rates and dumped loopholes but preserved the income-tax framework.

For now, the best bet is that the President will reprise the strategy that worked so well for him in the balanced-budget debate. Once he senses public support for reform, Clinton will try to get ahead of the GOP with a middle-of-the-road plan of his own while painting the Republican alternatives as "radical." To set the stage for such a step, he could use his State of the Union address to issue a call for a tax code based on the principles of progressivity and simplicity—with details to come later. By just embracing the concept, Clinton will go a long way toward turning tax reform talk into reality.

By Howard Gleckman, with Mike McNamee



TIM GRAJEK

'THERE'S NO REASON WHY WE CAN'T WORK OUR WAY THROUGH THIS'

U.S. Treasury Secretary Robert Rubin talks about Asia

He looks weary from dealing with Asia's financial woes, but U.S. Treasury Secretary Robert E. Rubin sounds confident about the outlook for stanching the crisis. In a Nov. 25 interview with *BUSINESS WEEK* Washington Senior News Editor Owen Ullmann and Economics Correspondent Mike McNamee, Rubin said Asia seems to be coming to grips with the need for economic reform. And he predicted that the crisis won't infect the healthy U.S. economy. Key excerpts:

Q: Was the U.S. slow to recognize the magnitude of the problems in Asia?

A: No. We have been ahead of the curve from the beginning. We were focused on Thailand long before there was general recognition of its problems. We played a very constructive role.

Q: The U.S. has been criticized for its reluctance to provide aid of its own. What should the U.S. role be?

A: It's a case-by-case situation. In Thailand, the IMF [International Monetary Fund] package was sufficient, and there wasn't yet the atmosphere of contagion that developed by the time we got to Indonesia. So I think we did exactly the right thing.

Q: How is the U.S. leading now?

A: We have people in Indonesia. The Manila program [a new IMF fund] was framed by a letter [Federal Reserve Chairman] Alan Greenspan and I sent that reflected the importance of having a sound approach to dealing with the problems of the region.

Q: Do you see signs that the contagion is still raging? When does it end?

A: It's very hard to judge. I think what's not hard to judge is what is the right thing to do. That is for each of



RESTORING CREDIBILITY

“The lesson is: When there are problems, deal with them quickly”

— ROBERT E. RUBIN

these countries to implement policies that will put them on a sound footing. There's a very healthy recognition that the path out of this is for countries to implement sound policies and to stick with them. The sooner that happens, the sooner we'll get through this period.

THE ASIAN CRISIS

Q: Is China possibly next?

A: Um. Well, I think I'm not going to get involved

in individual countries. But I think it's worth noting that the Chinese government has set forth an ambitious and market-oriented program for their economy.

Q: How threatened is the world financial

system by what's happening in Asia?

A: There's no reason why we can't work our way through this.

Q: Is Asia facing a liquidity squeeze or a structural crisis?

A: At heart these are structural and macroeconomic issues. Those are the issues that South Korea needs to focus on.

Q: Does the IMF have sufficient resources to handle these problems?

A: The resources exist to deal with the issues we face, assuming that countries do what they need to do. If they re-establish credibility and confidence, then capital will begin flowing again.

Q: You recently wrote a letter to your Japanese counterpart, Finance Minister Hiroshi Mitsuzuka. What did you say?

A: I discussed the importance of domestic demand-led growth, not having sustained trade imbalances, and getting ahead of the curve with respect to financial-sector problems.

Q: Japan's 10th-largest bank and fourth-largest brokerage have failed, with more failures expected. How should Tokyo deal with its financial woes?

A: They should learn from mistakes we made. If you go back to the [U.S.] savings and loan crisis, we didn't get ahead of the curve. As a result, it was much more expensive. The lesson is: When there are problems, deal with them quickly.

Q: How sick are Japan's banks?

A: I don't think it's for me to speculate. The key is for them to take appropriate measures quickly.

Q: Some Wall Street traders fear Japanese banks will dump Treasuries, sending U.S. interest rates soaring. How likely is that possibility?

A: It's certainly not the way I look at it. There may be people who need liquidity. There also may be others who want to reallocate funds more toward what they think the safest places may be. So long as our fundamentals and our policies are in good shape, I'm not concerned about our bond market. Also, the federal government's net financing requirements are going down enormously.

Q: How will the problems in Asia affect the U.S. economy?

A: I don't think anything that has happened so far would change my view that the most likely scenario is solid growth and continued low inflation.

BY GENE KORETZ

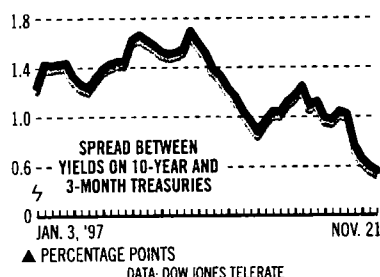
THE INSCRUTABLE YIELD CURVE

Is it really signaling a slowdown?

Kee your eye on the yield curve—the spread between the interest rates of debt securities with different maturities. One of the most sensitive economic barometers, its behavior in recent months is stirring a hot debate among economists.

In assessing the yield curve's implications, the general rule is that an upwardly sloping curve (the usual condition, in which yields are higher as maturities lengthen) points to an expanding economy, while a flat or down-

THE YIELD CURVE HEADS SOUTH



ward-sloping curve means a slowing or contracting economy. And changes in the slope signal changes in the future pace of economic activity.

What's currently causing a stir is that the yield curve has flattened dramatically in recent months—and for unusual reasons. Indeed, since *BUSINESS WEEK* first discussed this development a few weeks ago (BW—Nov. 17), the yield gap between 10-year and 3-month Treasury securities, which had narrowed since early April from 1.64 to only 0.73 of a percentage point, has plunged even more, to 0.56 of a percentage point.

Ordinarily, such a flattening of the yield curve would foreshadow a sharp slowdown in growth, and that in fact is what many experts predict. The curve's "unambiguous message" is that less exuberant activity lies ahead, says Bruce Steinberg of Merrill Lynch & Co., who sees growth slowing to 2.5% in 1998, with "the risks on the downside."

Economist Joseph Carson of Deutsche Morgan Grenfell, however, notes that the current narrowing of spreads is atypical: Usually, it is the Federal Re-

serve that sets the process in motion by pushing up short-term interest rates closer to long rates. But this time around, short rates have been relatively stable since March, while long rates have fallen in apparent response to investors' expectations that growth would slow and inflation would stay low.

"History shows that when the yield curve flattens in response to investors' expectations, rather than to monetary tightening, it loses accuracy as a leading indicator," says Carson.

Noting that the economy has grown by about 4% over the past year, Carson's colleague Joseph LaVorgna points out that the economy slowed from such a pace only six times since 1962, and in each case the Fed pushed up rates significantly. Thus, Carson and LaVorgna think the economy will continue to expand briskly in coming quarters—until the Fed finally acts to slow things down.

Time may prove them right, but many economists are dubious. In a recent article in *Business Economics*, Robert D. Laurent of the Federal Reserve Bank of Chicago argues that short-term rates reflect the supply of credit, whereas long-term rates reflect demand. Thus, if long rates decline while short-term rates are steady, the implication is that a slowdown lies ahead.

It has happened before. In the second half of 1985 and early 1986, notes Laurent, when long-term rates fell sharply in the face of a stable federal funds rate, most economists were expecting buoyant growth ahead. Instead, first-quarter growth in 1986 came in at just 0.6% and the Fed had to lower rates four times in subsequent months to revive the flagging economy.

THE HIGH COST OF CORRUPTION

It's a "tax" on foreign investment

The recent agreement by major industrial nations to a treaty outlawing bribery of foreign government officials should actually help many developing nations to attract much needed foreign direct investment. That's an implication of a new study by Harvard University economist Shang-Jin Wei of the impact of corruption on investment flows from 14 source countries to 45 recipient countries in the early 1990s.

Other things being equal, Wei finds that corruption levels act like taxes in deterring foreign investment. He estimates that an increase in a country's

level of corruption from that of Singapore, where it is low, to that of Mexico, where it is relatively high, reduces foreign investment as much as a 20-percentage-point increase in the tax rate on foreign corporations.

Despite rumors to the contrary, Wei also finds that corruption in East Asia turns off foreign investors as much as it does in other parts of the globe. And he finds that investors from many other industrial countries besides the U.S. are averse to host country corruption.

Even China, which has attracted a high level of investment despite significant corruption, has received relatively little capital from major industrial countries. Over 60% of its foreign investment in the past decade, notes Wei, has come from overseas Chinese, who "may be able to use personal connections to substitute for the rule of law."

U.S. INVESTMENT ABROAD PAUSES

Only Asian factories got more in '96

After soaring 80% in 1995, U.S. foreign direct investment leveled off last year at \$85.6 billion—just \$500 million more than the 1995 total, reports Deloitte & Touche. Beneath the surface, however, was a sharp shift in sectoral flows, with manufacturing investment plunging by 33%, or \$14 billion, as investment in financial services surged by 140%, or \$17.5 billion.

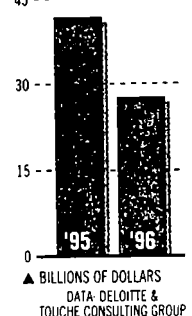
In manufacturing, Europe remained by far the favorite target but garnered 30% less dollars than in 1995. And such investment in Latin American facilities

declined by 70% in the wake of sharp currency volatility. Indeed, the only region posting an increase in 1996 was the Asia-Pacific area, led by Japan, where the inflow for manufacturing operations nearly doubled, to \$1.5 billion.

As for 1997, Deloitte reports that currency turmoil in East Asia has caused some U.S. manufacturers to defer investment there. But it also notes that investment picked up in Latin America this year, suggesting that a similar rebound in Asia may not be far off.

LESS U.S. INVESTMENT IN FOREIGN FACTORIES

DIRECT INVESTMENT IN MANUFACTURING OVERSEAS



CLIMATE ISSUES BRIEF



RESOURCES
FOR THE FUTURE

CLIMATE CHANGE RISKS AND POLICIES: AN OVERVIEW

Michael A. Toman

Climate Issues Brief No. 1

March 1997

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Climate Issue Briefs are short reports produced as part of RFF's Climate Economics and Policy Program to provide topical, timely information and analysis to a broad nontechnical audience.

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CLIMATE CHANGE RISKS AND POLICIES: AN OVERVIEW

Michael Toman, Senior Fellow, Resources for the Future

INTRODUCTION AND SUMMARY

A great deal of controversy surrounds the issue of climate change. Some participants in the debate say that climate change is one of the greatest threats facing humankind, one that calls for immediate and strong controls on greenhouse gases, particularly carbon dioxide emissions from fossil fuel burning and releases of other gases such as methane. Others say that the risks are weakly documented scientifically, that adaptation to a changing climate will substantially reduce human vulnerability, and that consequently little action is warranted other than further study and development of future technological options. The same kinds of divides arise in discussing policy options to reduce greenhouse gas emissions, with some predicting net benefits to the economy and others fearing the loss of several percentage points of national income.

These disagreements surface in the ongoing efforts of the international community to negotiate goals and actions under the 1992 Framework Convention on Climate Change. They reflect not only different interpretations of the evidence but different interests as well. Article 2 of the Framework Convention requires signatories to take actions to “prevent dangerous anthropogenic interference with the climate system” from greenhouse gas emissions (and other actions such as deforestation). However, the term “dangerous” in Article 2 does not have an unambiguous, purely scientific definition; it is inherently a question of human values.

To help sort through the tangle, in this paper I attempt to summarize some ways to think about climate change risks and policies that can be useful for considering both international agreements and actions by the United States. The paper starts with some background on the current state of the knowledge and then presents a six-step decision framework. The steps include the following:

- Think comprehensively about risks and costs.
- Think long term.
- Address adaptation.
- Think internationally.
- Keep distributional issues in mind.
- Estimate control costs realistically.

Using this framework, I also suggest some points for enhancing the effectiveness of climate policies:

- Allow flexibility in the timing of cumulative emissions reductions to reduce overall costs.

- Incorporate economic incentives into emissions-reduction policy.
- Provide opportunities for emissions reductions wherever possible.
- Encourage development of the climate change knowledge base and improved technology for emissions reduction.
- Increase the emphasis on adaptation.

Each of these points is elaborated on in the paper. However, as an overview, the discussion necessarily is somewhat abridged. Other Issues Briefs to be produced for RFF's Climate Economics and Policy Program will explore in greater detail the issues raised here. I conclude with some brief comments on the draft protocol promulgated by the Clinton Administration in January 1997.

BACKGROUND

In its recent Second Assessment, Working Group I of the Intergovernmental Panel on Climate Change (IPCC)—a body of several hundred distinguished scientists established by the United Nations—concluded that a human cause for the climate change now observed is likely, not just possible. This is a much stronger conclusion than the one the IPCC reached in its First Assessment several years ago, although it is dogged by skepticism from some who feel that dissenting views were not adequately represented in the process. In its First Assessment, the IPCC stated that although all signs pointed to human-induced climate change, crucial evidence for cause and effect was not yet available. The evidence at the time indicated that atmospheric greenhouse gas concentrations had increased in the previous 130 years and that the global climate had warmed; however, when applied retrospectively, complex computer simulations of climate change predicted a larger warming than had actually occurred and did not adequately represent climate changes in different regions and at different altitudes.

The latest generation of models can now replicate the past with greater realism. In particular, new models include analysis of the cooling effect of aerosols—tiny particles—in the air formed during the burning of fossil fuels. By including in their analyses the cooling effects of aerosols and stratospheric ozone depletion, most of the latest studies have detected a significant climate change. The Summary for Policymakers of the Working Group I report states that “the observed warming trend is unlikely to be entirely natural in origin.... The balance of evidence suggests a discernible human influence on global climate.”

While the improved capacity of climate models to track past events increases confidence in their capacity to explain observed changes, future changes in climate could depart from the models' predictions. In particular, the change may be neither gradual nor continuous, but abrupt and surprising. Despite recent improvements, however, climate models are still unable to project the details of climate change on a regional scale, complicating assessment of potential impacts and response options.

In the latest assessment, Working Group II of the IPCC addresses many potential impacts of climate change, including the effects on agriculture, forestry, terrestrial and marine

ecosystems, hydrology and water resource management, human health, human infrastructure, and financial services. While the potential impacts of climate change are broad, some aspects of human society are more sensitive than others. In particular, more highly managed systems like agriculture, where skills and resources for investing in adaptation are available, may be less sensitive than less managed systems like wilderness areas. By the same token, some of the adverse effects of climate change may fall disproportionately on poorer parts of the world where adaptation capacity is more limited. Particularly if climate change were very rapid, damage could be severe and long-lived, perhaps irreversible. However, such rapid change may be unlikely and is difficult to predict.

In any event, the ability to quantify future damage and adaptation potential varies greatly across sectors. The physical consequences of a given magnitude of sea level rise, or the impacts of climate change on agricultural yields and forest conditions, can be projected with higher confidence than, say, impacts on wetlands and fisheries. Yet even when confidence is high that a certain effect will occur if climate changes, its magnitude cannot be predicted precisely. In addition, already significant damage to ecosystems and human structures arising from population growth, industrial expansion, and changes in land use may be of more immediate concern than how best to respond to climate change risk. Over the longer term, however, these forces could combine with the effects of climate change to push already stressed systems “over the edge.”

In evaluating the context for climate change policies, several points need to be kept in mind.

Some degree of climate change appears inevitable. Given current emissions trends and the inertia of the climate system, even if emissions were stabilized or substantially reduced, the scientific models suggest that climatic changes and their consequences would continue. To stabilize atmospheric concentrations of greenhouse gases and thus their effects would eventually require very large cuts in emissions from current levels (let alone future levels implied by continued economic growth under a “business as usual” scenario). For example, to stabilize carbon dioxide concentrations at something over twice pre-industrial levels would require emissions ultimately to fall by over 70 percent from their *current* level.

The problem is global. Rich and poor countries argue over how the burden of greenhouse gas emissions reductions should be allocated. However, no solution can be effective in the long term unless it ultimately leads to reductions in total *global* emissions, not just emissions in selected countries.

It is the human consequences of climate change that will animate public support for policies. The findings of climate scientists or studies of physical impacts from climate change cannot drive policy alone. This simple but important point often seems to be overlooked in debates about “what the science says,” and it leads to our next major topic—what kind of framework is useful for evaluating climate risks and policies?

DECISION FRAMEWORK

Although substantial scientific and socioeconomic uncertainties exist about the risks that climate change poses, these uncertainties do not justify taking no action. At the same time, priorities must be set in how the public's scarce resources will be used. At the broadest level, there must be some weighing and balancing of the benefits and costs of different actions in response to climate change risks. The values served by reducing the risks from climate change can only be appreciated in comparison with other values to which society devotes its scarce resources.

The need for such balancing casts doubt on the usefulness of a strict "safety first" framework that puts a high premium on any and all forms of risk reduction. We cannot devote disproportionately huge amounts of resources to reducing climate change risks while, for example, utterly ignoring health care needs. Moreover, not all the effects of climate change are likely to be equally serious, so it is not helpful simply to argue that the risks of climate change should be minimized.

Some analysts argue that we can enjoy the benefits of reduced climate change risks without significant economic costs or even with net benefits from economic and environmental improvements arising from greenhouse gas control. They suggest that pervasive but latent markets exist whose failure to operate, once fixed, will yield substantial economic and environmental benefits. Many people who have examined this argument—including participants in IPCC Working Groups II and III—seem to agree that some low-cost reductions in greenhouse gases are feasible through revitalized markets for new product development. However, for reasons discussed below, I believe that some skepticism is warranted regarding sweeping claims about the potential for low-cost emissions reductions.

If a strict "precautionary principle" of the type sketched above is of limited practical use for evaluating the risks of climate change, there are also limits to what can be gleaned from conventional benefit-cost analysis. Climate change risks and policies inherently have substantial distributional effects that may operate both within generations (who bears what share of response costs) and across generations (how much the future benefits from our actions to reduce climate change risks). In addition, uncertainty surrounding the risks and costs of climate change is especially large, and there is at least the possibility of very large-scale impacts that human responses will have a hard time mitigating. These issues are not easily handled through normal benefit-cost calculations that calculate expected net benefits over time.

While there is no easy cookbook answer to what should go into a climate change decision framework, and no approach that commands universal agreement, several elements seem useful.

Think comprehensively about risks and costs. Given the number of risks associated with climate change, efforts to gauge the benefits of reducing them should be as broad as possible. Elements to consider include the impacts on market goods like agriculture; effects on human health; effects on nonmarket resources like wilderness areas and wetlands that provide both recreational values and ecological functions; and the ancillary benefits of greenhouse gas reduction such as improved air quality.

Given the current state of knowledge, it will be difficult to attach monetary values to many of these risk reductions. This uncertainty is likely to persist for many risk categories (especially those related to ecological impacts) even if uncertainty about the physical manifestations of climate change declines. Nevertheless, these risks are important to consider; lack of information about a risk should not be confused with that risk being negligible. Where economic assessments are problematic, information about the likelihood, potential magnitude, and timing of impacts still is useful for decisionmakers. In this connection, an assessment of climate change risks should go beyond a sequence of “best guess” estimates of atmospheric changes, biophysical impacts, and socioeconomic impacts. It is necessary to consider the variability of possible consequences as well. At the same time, the assessment should not be limited only to severe but unlikely effects in “worst case” scenarios.

Assessments of the costs of response options should similarly be broad and sensitive to uncertainties. For example, the overall economic costs of abatement policies that distort existing patterns of employment, investment, and innovation may be a multiple of direct out-of-pocket compliance costs. By the same token, technical progress over time in reducing greenhouse gases can lower abatement costs. Cost assessment should also address ancillary effects of policy responses—some positive, like reduction of conventional air pollutants with reduced energy use, and some negative, like increased indoor air pollution from tighter insulation, or increased pressures to develop hydroelectric capacity on scenic rivers. Finally, a comprehensive approach must be concerned with other greenhouse gases besides carbon dioxide (such as methane from pipeline leaks and landfills), and with changes in carbon sequestration in forests due to shifting land use patterns.

Think long-term. The risks posed by climate change depend on the path of changes in the atmospheric concentration of greenhouse gases over many decades and centuries, not just on the emissions of these gases over a relatively short period of time. The long-term aspect of climate change means that we are dealing with the cumulative effect of many smaller influences on the biosphere, a process with a great deal of natural inertia. Having to deal with the distant future greatly complicates risk assessment and the development of consensus for policy actions. To be effective, at least some actions must be taken in anticipation of long-term impacts, before all of the scientific evidence is clear. Our political system arguably is less effective at responding to such issues than to a single large and immediate concern. On the other hand, the long-term nature of climate change risks means we also have time to hone our scientific understanding and policy responses over time; we need not do everything right away.

Address adaptation. In a number of areas such as agriculture, managed forestry, and human settlements, intuition and experience in other contexts suggest a medium-to-high degree of potential adaptability to natural changes, given enough lead time and investment. Adaptation possibilities include development of new plant varieties and crop patterns, changes in irrigation technology, relocation of coastal infrastructure, and expanded protection of wetlands to compensate for their potential future damage. Failure to account for adaptation as a viable response to climate change will cause climate change risks to be overstated.

Adaptation may be difficult in other cases, for example in response to potential damage to natural ecosystems whose functions are not well understood. Even where adaptation seems

problematic, it should not automatically be treated as negligible. Improving the capacity to adapt where it is weak—as in many poor developing countries—may be the one of the most effective ways to respond to some climate change risks, at least until the cost of stabilizing atmospheric concentrations of greenhouse gases falls.

Think internationally. Long-term global climate change risks will not diminish to any significant degree until total *global* emissions are reduced. This will require global cooperation, not just action by today's rich countries. This point deserves to be underscored in light of the likely future decline in the share of total emissions from advanced industrial countries (currently about 50 percent) as economic growth proceeds in other areas. The efficacy of any policies the United States pursues to reduce climate change risks thus will depend on the actions taken by others.

No simple rules of thumb exist as to how the international burden of emissions control should ultimately be allocated. Developing countries note that rich countries are responsible for the vast bulk of emissions to date. They assert that allowing developed countries to maintain high emissions levels while constraining the growth of emissions in developing countries to reduce climate change risks would impose unacceptable burdens on the latter countries' economic development. Developed countries note that most emissions growth will occur in developing countries, that past economic progress has had at least some global benefits, and that simply treating all countries as having equal rights to carbon emissions (after adjusting for population differences) would impose unacceptably high control costs on developed countries. The ongoing tension over the responsibilities of different parties to the Framework Convention can only be resolved by negotiation among the parties themselves.

Keep distributional issues in mind. Climate change risks and response capacities vary with income level. There is also a fundamental asymmetry between the timing of response costs—which will be borne to a significant extent by the current generation—and the benefits of reduced climate change—which will largely accrue to future generations. This asymmetry complicates a comparison of benefits and costs, since we cannot simply compare the costs of reducing the risk with the value of enjoying the ultimate benefits. Instead, we must assess both the costs members of the current generation would bear and the strength of our concerns for the well-being of future generations—not just our own descendants, but all those who would be vulnerable in the future. These are economically and ethically complex questions about which we know little and which require a very mature political debate.

Some analysts have argued that intergenerational equity concerns should be incorporated into climate risk assessments by applying a lower “philosophical” discount rate to the evaluation of benefits received by future generations, so as to not trivialize these benefits relative to current costs. A weakness of this approach is that it attempts to reduce a very complex ethical debate to the value of a single parameter. A more general approach is to carry out the best possible assessment of the costs to be borne in the short to medium term (taking into account various effects on productivity and economic growth as well as such benefits as reduced air pollution), combined with the best possible enumeration of the potential advantages (physical and economic) of our actions for future generations. Such an approach would give policymakers the

information they need to make more explicit, well-informed judgments about the desired level of risk reduction.

Estimate control costs realistically. As already noted, some people argue that market inefficiencies are so rife, and opportunities for innovation so plentiful, that emissions abatement is actually a low-cost proposition that might even benefit the economy. This point of view is in sharp contrast to the outputs of economic models indicating that stabilizing emissions may cost as much as several percent of a country's gross domestic product (implying that deeper cuts in emissions to reduce greenhouse gas concentrations in the atmosphere would be even more expensive). This divergence of opinion reflects in part a long-standing disagreement about the cost of improving energy efficiency. Energy analysts have argued that opportunities for large and low-cost improvements in technical efficiency have been missed because of market failures that require government action, while economists have generally assumed that most of the supposed failures to act were actually rational responses to factors such as the likelihood that a new technology was not going to perform as expected.

Most people who have looked at the debate seem to agree that some low-cost improvements in energy efficiency exist. Reducing subsidies and other distortions in energy markets that encourage excess energy use can reduce greenhouse gas emissions while improving economic and environmental well-being. However, it is open to question whether these opportunities are substantial compared to, say, the amount of abatement needed to stabilize greenhouse gas emissions. Against the backdrop of future increases in global energy demand, the cost of longer-term reductions in greenhouse gas emissions cannot help but rise unless further progress occurs in the development of nonfossil energy alternatives. In assessing medium-to-long-term costs, it is a mistake to treat technical progress as a panacea for reducing abatement costs, or to assume no technical progress.

Another argument offered in the debate over the cost of greenhouse gas emissions reductions is that our tax system is so distorted that we can use energy taxes to reduce greenhouse gas emissions and use the proceeds to lower other taxes that hamper economic growth. However, recent analysis calls into question this "double dividend. While the technical details can be complicated, the basic point is that broader-based taxes like the income tax tend to cause less overall economic distortion than narrower-based taxes like energy taxes. Adjusting other taxes might soften the economic bite of an added carbon tax, but not to negligible levels. Moreover, any tinkering with the tax system is possible only if politicians take the difficult step of imposing higher energy taxes in the first place.

Most studies of greenhouse gas abatement costs assume the application of idealized least-cost policy measures like a comprehensive "emissions trading" program or a comprehensive carbon tax. The costs of meeting any particular emissions reduction goals likely will be significantly higher if less well-designed measures are followed. The debate about which greenhouse gas reduction targets are appropriate cannot be conducted independently of discussions about what concrete measures can and should be used to actually restrict emissions.

POLICY LESSONS

In assessing climate change policies, we must consider complex “portfolios” of actions that include abating emissions, investing in technical innovations to reduce emissions sources and increase adaptation capacity, and improving risk assessment. In putting together a portfolio of policies, it is important to consider the synergies among them, such as the effects of economic incentives to reduce greenhouse gas emissions on the rate of innovation for new energy sources and other types of emissions reduction options. Because of the long-term nature of the climate change problem, the ultimate goals for responding to it also must be long-term. Such a perspective offers increased opportunities for implementing low-cost strategies to reduce emissions and promote adaptation opportunities through new investment.

Beyond these general observations, the decision framework developed above has several implications for how to formulate policy.

Allow flexibility in the timing of cumulative emissions reductions to reduce overall costs. This approach takes into account the inertia in the economic system that makes rapid adjustments more costly; for example, it may be cheaper to replace long-lived electricity generating capacity more slowly while also achieving improved energy efficiency when the capital is replaced. It also provides increased scope over time for investments in knowledge to enhance technological change. The cost savings from intertemporal flexibility in meeting long-term emissions reductions goals depend on the assumptions made, but it appears that savings of at least 20 percent or more are possible.

Taking this approach does not mean that all or even most policy actions are deferred to the future. It simply means that the emphasis is placed on sequential decisions that add up to avoiding unacceptable damage from anthropogenic greenhouse gas emissions. Some actions will be appropriate in the short term as first steps down the policy path, or to enhance the domestic or international credibility of policy agreements. Other actions may be more useful later. Unless we start with a longer-term perspective, it is impossible to consider these tradeoffs.

Incorporate economic incentives into emissions-reduction policy. Such incentives are crucial to both short- and long-term policy successes because they make emissions limitations less expensive. Both a large body of analysis and a small but growing body of evidence in areas other than greenhouse gas control show that incentive-based policies help bring about the lowest-cost options and stimulate innovative new methods for abatement. (Both Articles 3 and 4 of the Framework Convention support the concept of such cost-effective policies.)

The main alternatives for incentive-based policies (beyond “no regrets” actions like reductions in energy subsidies) are carbon taxes on energy sources, and various forms of “tradable permits” systems. The latter approach would effectively establish quotas on emissions but allow trade in emissions, so that sources with higher control costs could (in effect) pay emitters with lower control costs to assume more of the reduction burden. A full discussion of the pros and cons of different tax and tradable permit schemes is beyond the scope of the paper. It should be noted, however, that both types of policies have advantages, and neither should be written off. Moreover, there are many policy combinations that might be relevant in future policy

debates (such as a mixture of emissions trading with command and control for different sectors) whose performance is largely unknown.

Provide opportunities for emissions reductions wherever possible. Given the international nature of the problem and the need for international action to solve it, policies should seek to provide abatement opportunities everywhere, not just in the industrialized countries that constitute the “Annex I” group under the Framework Convention—the group that already is committed to emissions reductions targets. One example of such opportunities is “joint implementation” (JI) programs, whereby emitters in, say, the United States, can satisfy any emissions reductions requirements they face through actions that reduce emissions in non-Annex I countries. The emissions reductions are achieved through the transfer of technology and investment to a host country in order to reduce emissions below some established baseline level. Formal emissions trading programs among sources in countries with quantified emissions reduction targets also are possible.

A number of analyses indicate that the cost savings from using JI and other forms of international emissions trading to meet emissions reduction goals could be very large. As with intertemporal flexibility, the savings depend on the assumptions made, but savings of 50 percent or more seem possible. At the same time, properly designed JI projects should convey considerable economic development and environmental benefits to host countries.

A number of practical problems need to be addressed in pursuing JI. There must be international agreement that such actions count toward meeting emissions reduction requirements, or else incentives to generate the reductions will remain weak. Procedures must also be established to ensure that large-scale JI trading volumes could occur without excessive red tape, while also ensuring that credible emissions reductions occur relative to some well-defined baseline. Last but not least, the credibility and appeal of JI to potential host countries in the developing world must be increased.

Encourage development of the climate change knowledge base and improved technology for emissions reduction. The flow of technology transfer and new investment occurring as a matter of course in world markets presents plenty of opportunities for greenhouse gas limitations. Particularly in a number of developing countries and economies in transition to market systems, many opportunities exist to improve energy and economic efficiency at the same time. Even where there are some costs to upgrading capital stock and improving energy efficiency, they may be more than offset by the gains from improved environmental quality. To realize these gains requires policymakers worldwide to come to grips with broader handicaps that thwart economically sound and environmentally sustainable development.

Even if we do all the best things possible to reduce emissions given the current state of knowledge, economic growth—especially in developing countries—will continue to push up greenhouse gas emissions and atmospheric concentrations. Unlike limiting pollutant gases such as sulfur dioxide, for which a variety of technical control options is available, limiting carbon dioxide emissions requires either reduced energy use (greater energy efficiency) or substitution of energy sources with lower carbon content. To avoid unacceptable climate change risks ultimately will require a fundamental change in our energy systems toward much greater reliance

on other energy sources—solar, biomass, and possibly nuclear. Such a transition would be too costly now, given the current state of knowledge. To make the transition economically manageable will require continued or enhanced investments in basic and applied knowledge.

The government has an inescapable role to play, not just in creating the incentives for private parties to seek better technologies but also in funding the development of basic knowledge about technology as well as climate change impacts. At the same time, we must recognize that our understanding of what policy can actually do to induce climate-friendly innovation is weak at best. We must also recognize that diverting resources from other areas to research on low-carbon energy systems may well reduce innovation elsewhere in the economy—technical progress is not a free good.

Increase the emphasis on adaptation. Adaptation is part of an optimal response strategy in any event. Indeed, it is the means of transcending the narrow concern about our vulnerability to climate change from greenhouse gas emissions to a broader concern with global-scale changes that place stress on natural systems and pose threats to human well-being. Furthering human capacity to adapt to climate change entails investment in improved understanding of the options and their international diffusion. It also entails adjusting economic and other distortions that limit adaptation potential (such as assistance programs that subsidize coastal development or water use). In many cases, the best climate policy may have little to do with greenhouse gases or climate per se, and much more to do with developing better basic social infrastructure for natural resource conservation and use and public health protection.

CONCLUDING REMARKS: THE U.S. DRAFT PROTOCOL

The “U.S. Draft Protocol Framework” which the Clinton Administration issued on January 17, 1997 embraces a number of policy ideas that, if implemented, could significantly enhance the cost-effectiveness with which any emissions reduction targets are achieved. To comply, countries agreeing to emissions limits would be allowed to average emissions over a number of years (though a precise number is not proposed in the framework). They would be able to trade emissions internally and internationally (not just within specified groups, like the European Union), and they would be able to bank emissions for future use. To smooth out the cost of emissions reductions over time, they could borrow from the future to meet current obligations. (Both unspecified limits on volumes borrowed and a significant (20 percent) “repayment premium” on borrowed emissions allowances are included to help ensure that the achievement of long-term emissions reductions goals would not be undermined. However, the use of both tools for this purpose is redundant, and the high repayment premium will cause uneconomically early emissions reductions.)

Developing countries would be encouraged to participate in several ways. Joint implementation with countries not yet accepting national emissions targets would be fully sanctioned, including fully usable and transferable credits for emissions reductions. In addition, developing countries would be required to identify and adopt “no regrets” measures for greenhouse gas reductions, and all countries would be required to “facilitate investment in climate-friendly technologies,” although these important action areas are not spelled out in any

detail. Emissions reporting procedures and practices also would be strengthened. Finally, while no future emissions targets for developing countries are specified, the proposal does call (in Article 16) for all countries to accept some quantified emissions limitation targets (which could be different from the targets accepted by developed countries) by a particular future date (2005 is suggested in the draft). This proposal is consistent with the idea that comprehensive participation ultimately is required for success in avoiding unacceptable impacts of climate change, though it is bound to be controversial among developing countries who do not currently have any emissions limitation targets.

In establishing international emissions targets among industrialized countries (a new “Annex A” group that includes the current Annex I countries), the U.S. proposal calls for all such countries to reduce their emissions over time by common (not yet specified) percentages of their respective baseline levels. Other countries that either have achieved substantially greater energy efficiency improvements earlier or believe that such reductions may simply be too costly in light of their fossil fuel use hotly contest this approach. It remains to be seen whether the United States can secure agreement for its approach or will be forced to modify it.

The U.S. Administration has stated that it will accept and support legally binding emissions reductions. The draft protocol does not specify any concrete emissions targets (although it does call for periodic review of whatever targets are established). The actual targets remain to be negotiated, and the proposal does not indicate what criteria should be used to determine acceptable targets from the U.S. perspective.

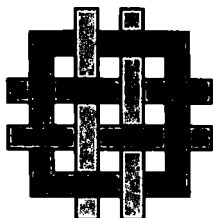
Last but not least, the draft protocol does little to address adaptation. This neglect reflects not a weakness in the proposal so much as a broader weakness in the Framework Convention, which has viewed adaptation as an individual country concern. Adaptation must gain greater prominence in the debate over climate policies.

The U.S. draft protocol is an important contribution to the negotiating process and to domestic debate over U.S. climate policies. However, further discussion of the issues identified above—and of the analyses the Administration and others are performing to determine what it will cost to meet different emissions reductions targets—is a prerequisite to building broader understanding of climate change risks and policies, and political support for a new climate agreement.

FURTHER READING

For a broad overview of all climate change issues, some perusal of the three volumes of the IPCC Second Assessment Report is essential. All three have the main heading “Climate Change 1995” and the following subtitles: “The Science of Climate Change” (Working Group I), “Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analysis” (Working Group II), and “Economic and Social Dimensions of Climate Change” (Working Group III). Each volume contains a Summary for Policymakers that is quite informative (though not a perfect guide to the contents of the volume), and the first two volumes contain Technical Summaries as well. The main body of each report contains a wealth of information and analysis, though some

of it is quite technical and, in some cases, a little dated. The reports are published by Cambridge University Press (fax: 212-691-3239). Find out more about the IPCC at <http://www.unep.ch/ipcc/ipcc-0.html>. Find out more about RFF's Climate Economics and Policy Program at <http://www.rff.org>.



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June 17, 1997

Jeffrey A. Frankel
Chief Economist
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Dear Jeff:

In the months before the parties to the Climate Change Convention meet in Kyoto this December to negotiate targets and timetables for reducing greenhouse gas emissions, the potential impacts on the U.S. economy will be strongly debated.

A new WRI report, *The Costs of Climate Protection: A Guide for the Perplexed*, by Duncan Austin and myself, provides an essential perspective on this debate. It examines the sixteen economic models most widely used to analyze climate policy options, including the three used by the Clinton administration's analytical taskforce. The report draws on all sixteen to show the range of possible macroeconomic impacts under best and worst-case assumptions.

Even more usefully, our report identifies seven key assumptions that together account for more than 80 percent of the differences in economic predictions across the sixteen models and shows how changing each of these affects the predicted cost of meeting carbon dioxide emissions targets. Under worst-case assumptions on all seven points, the models jointly predict that stabilizing CO₂ emissions at 1990 levels by the year 2010 and holding them steady thereafter would decrease GDP by 2.4 percent in the year 2020. However, under a more reasonable set of assumptions, the models imply that economic impacts would be minimal or, if reduced environmental damages are taken into account, modestly favorable.

This new WRI study identifies two significant areas of policy agreement among the various models. First, the economic impacts will be more favorable if policy instruments such as carbon taxes or auctioned-off emission permits are used to reduce carbon dioxide emissions and the revenues are used to cut other more burdensome taxes. Second, international joint implementation could reduce the overall costs of CO₂ abatement significantly.

This report is the first in a series to be produced by the Climate Protection Initiative -- a partnership between WRI and private firms to identify acceptable policies and business strategies for achieving strong climate protection goals. This institute-wide effort is motivated by the belief that climate protection and a sound economy can be positively linked. For additional information on the Climate Protection Initiative, visit WRI's website at: "<http://www.wri.org/wri/>".

I hope you will find *The Costs of Climate Protection: A Guide for the Perplexed* helpful and I welcome your comments.

Sincerely,

A handwritten signature in black ink, appearing to read 'R Repetto', with a stylized flourish at the end.

Robert Repetto
Vice President

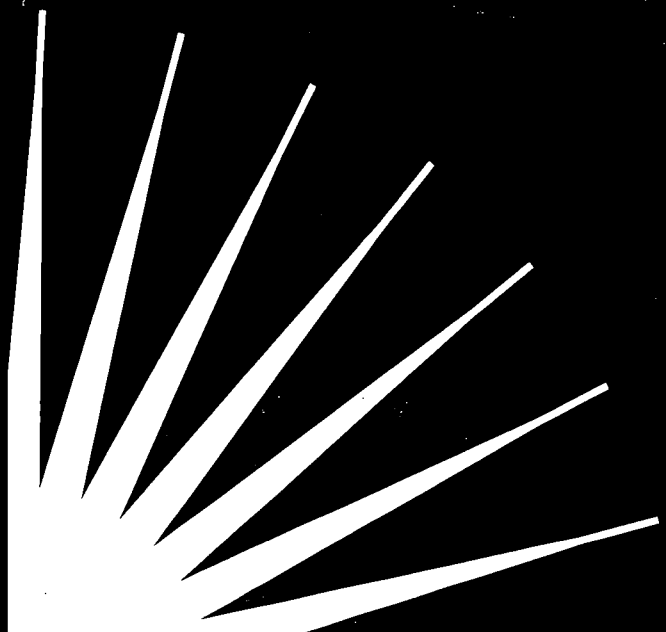
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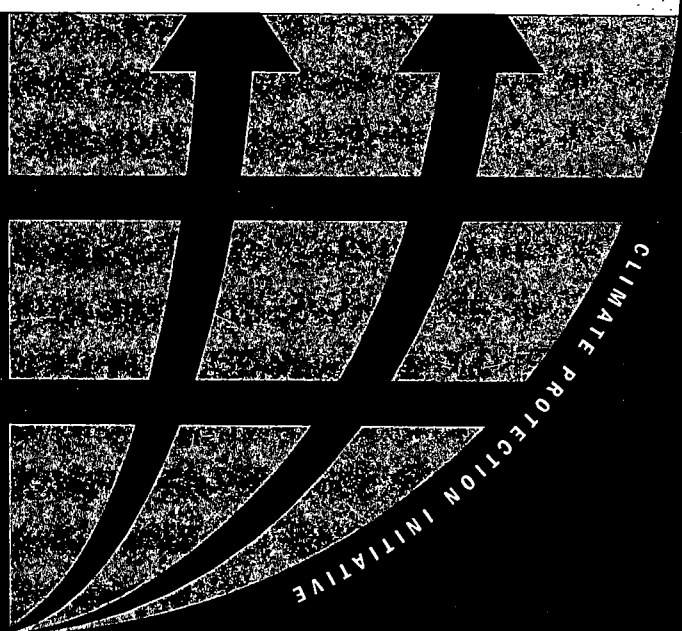
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WORLD RESOURCES INSTITUTE



THE COSTS OF CLIMATE PROTECTION:

A GUIDE FOR THE PERPLEXED



ROBERT REPETTO AND DUNCAN AUSTIN

State - Dismal Scientist - April 17, 1997



Earth Day is upon us once again. Like most people who think at all about how much burden their way of life places on Spaceship Earth, I feel a bit guilty. But my conscience is clearer than usual this year--and so are those of 2,500 other economists.

Let me explain. A few months ago an organization called Redefining Progress enlisted five economists--the Nobel laureates Robert Solow and Kenneth Arrow, together with Harvard's Dale Jorgenson, Yale's William Nordhaus, and myself--to circulate an "Economists' Statement on Climate Change," calling for serious measures to limit the emission of greenhouse gases. To be honest, I agreed to be one of the original signatories mainly as a gesture of goodwill, and never expected to hear any more about it; but the statement ended up being signed by, yes, more than 2,500 economists. Whatever else may come of the enterprise, it was an impressive demonstration of a little-known fact: Many economists are also enthusiastic environmentalists.



Partly this is just because of who economists are: Being by definition well-educated and, for the most part, pretty well-off, they have the usual prejudices of their class--and most upper-middle-class Americans are sentimental about the environment, as long as protecting it does not impinge on their lifestyle. (I'm happy to reuse my grocery bags--but don't expect me to walk to the supermarket.) But my unscientific impression is that economists are on average more pro-environment than other people of similar incomes and backgrounds. Why? Because standard economic theory automatically predisposes those who believe in it to favor strong environmental protection.

This is not, of course, the popular image. Everyone knows that economists are people who know the price of everything and the value of nothing, who think that anything that increases gross domestic product is good and anything else is worthless, and who believe that whatever free markets do must be right. (A recent example of how this stereotype gets perpetuated is the article by garden-shop entrepreneur Paul Hawken in the current *Mother Jones*. I'm sorry to say that some of the people at Redefining Progress published an impressively ill-informed diatribe along the same lines in the *Atlantic* back in 1995.)



But the reality is that even the most conventional economic doctrine is a lot more subtle than that. True, economists generally believe that a system of free markets is a pretty efficient way to run an economy, *as long as the prices are right*—as long, in particular, as people pay the true social cost of their actions. Environmental issues, however, more or less by definition involve situations in which the price is wrong—in which the private costs of an activity fail to reflect its true social costs. Let me quote from the textbook (by William Baumol and Alan Blinder) that I assigned when I taught Economics 1 last year: "When a firm pollutes a river, it uses some of society's resources just as surely as when it burns coal. However, if the firm pays for coal but not for the use of clean water, it is to be expected that management will be economical in its use of coal and wasteful in its use of water." In other words, when it comes to the environment, we do not expect the free market to get it right.

So what should be done? Going all the way back to Paul Samuelson's first edition in 1948, every economics textbook I know of has argued that the government should intervene in the market to discourage activities that damage the environment. The usual recommendation is to do so either by charging fees for the right to engage in such nasty activities—a.k.a. "pollution taxes"—or by auctioning off rights to pollute. Indeed, as the extraordinary response to the climate-change statement reminds us, the idea of pollution taxes is one of those iconic positions, like free trade, that commands the assent of virtually every card-carrying economist. Yet while pollution and related "negative externalities" such as traffic congestion are obvious problems, in practice, efforts to make markets take environmental costs into account are few and far between. So economists who actually believe the things they teach generally support a

much more aggressive program of environmental protection than the one we actually have. True, they tend to oppose detailed regulations that tell people exactly how they must reduce pollution, preferring schemes that provide a financial incentive to pollute less but leave the details up to the private sector. But I would be hard pressed to think of a single economist not actually employed by an anti-environmental lobbying operation who believes that the United States should protect the environment less, not more, than it currently does. (The signers of the climate-change statement, incidentally, included 13 economists from the University of Chicago.)

But won't protecting the environment reduce the gross domestic product? Not necessarily--and anyway, so what?

At first sight, it might seem obvious that pollution taxes will reduce GDP. After all, any tax reduces the incentives to work, save, and invest. Thus a tax on exhaust emissions from cars will induce people to drive cleaner cars or avoid driving altogether. But since it will also in effect lower the payoff to earning extra money (since you wouldn't end up driving the second car you could buy with that money anyway), people will not work as hard as they would have without the tax. The result is that taxes on pollution (or anything else) will, other things being equal, tend to reduce overall monetary output in the economy--which is to say, GDP.

But things need not be equal, because there is already a whole lot of taxing and spending going on. Even in the United States, where the government is smaller than in any other advanced country, about a third of GDP passes through its hands. So existing taxes already discourage people from engaging in taxable activities like working or investing.

What this means is that the revenue from any new taxes on pollution could be used to reduce other taxes, such as Social Security contributions or the income tax (but not, of course, the capital-gains tax). While the pollution taxes would discourage some activities that are counted in the GDP, the reduction in other taxes would encourage other such activities. So measured GDP might well fall very little, or even rise.

Does this constitute an independent argument for taxing pollution, quite aside from its environmental payoff? Would we want to have, say, a carbon tax even if we weren't worried about global warming? Well, there has been an excruciatingly technical argument about this, mysteriously known as the "double dividend" debate; the general consensus seems to be no, and that on balance pollution taxes would be more likely to reduce GDP slightly than to increase it.

But so what? "Gross domestic product is not a measure of the nation's economic well-being"—so declares the textbook as soon as it introduces the concept. If getting the price of the environment right means a rise in consumption of nonmarket goods like clean air and leisure time at the expense of marketed consumption, so be it.



Isn't this amazing? Not only do thousands of economists agree on something, but what they agree on is the warm and cuddly idea that we should do more to protect the environment. Can 2,500 economists be wrong? Well, yes—but this time they aren't. The Great Green Tax Shift—a shift away from taxes on employment and income toward taxes on pollution and other negative externalities—has everything going for it. It is supported by good science and good economics, as well as by good intentions.

Inevitably, then, it appears at the moment to be a complete political nonstarter. The problem, as with many good policy ideas, is that the Great Green Tax Shift runs up against the three I's.

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SUMMARY

Climate change presents the decision maker with a set of formidable complications: large uncertainties, the potential for irreversible damages or costs, a very long planning horizon, long time lags between emissions and effects, a global scope, wide regional variation, and multiple greenhouse gases of concern. Irrespective of the possible consequences of climate change, policies that mitigate or assist adaptation to climate change and have zero or negative net costs (*no-regrets* policies) are clearly justified. If the evidence suggests that damages can be expected from climate change, then the expectation of damages provides a rationale for going beyond no-regrets policies to those that incur positive net costs. The principles of risk aversion and portfolio balancing provide a rationale for further steps.

The atmosphere is an international public good, in that all countries benefit from each country's reduction in greenhouse emissions; greenhouse gases are an international externality, in that emissions by one country affect all other countries to some extent.

Both public goods and externalities require a legal framework within which the problems they pose can be addressed. Mechanisms for control of international public goods may include the definition of property rights, the definition of limits to emissions, and a consensus for distributing the same in a fair and equitable manner. If, on the other hand, each agent acts in its individual interest, the result will be too little of the public good and too much of the externality.

A decision process for climate change should be sequential. It should also be able to respond to new information with midcourse corrections and to include insurance arrangements, hedging strategies, and the option value of alternative courses of action. The challenge today is to identify short-term strategies in the face of long-term uncertainty. The question is not, what is the best course over the next 100 years, but rather, what is the best course for the next few years, knowing that a prudent hedging strategy will allow time to learn and change course.

Policy measures to reduce risks to future generations include (1) immediate reductions in emissions; (2) research and development related to new supply and conservation technologies; (3) continued research on how much change is likely and what its effects will be; and (4) investments to assist in adaptation if significant global warming occurs. A well-

chosen portfolio of policies will yield greater benefits for a given cost than any one option undertaken by itself. Striking the appropriate balance requires taking into account costs, benefits, and risks.

In an interrelated global economic system, an attempt to reduce greenhouse gas emissions in one region or one sector of the economy may be offset by increases in other regions or sectors. This may occur through the loss of comparative advantage in the carbon-intensive sectors of the regions that limit emissions, through the relocation of industries, or through changes in world energy prices and the resulting shift in consumption. Any control strategy must account for these global effects.

For the purposes of analysis it is useful to separate efficiency from equity. The Framework Convention on Climate Change (FCCC) requires all parties to formulate and implement programmes to mitigate climate change and facilitate adaptation to climate change on the basis of their common but differentiated responsibilities, and taking into account their specific national and regional development priorities, objectives, and circumstances. Developing countries are more likely to be adversely affected economically than the developed countries; moreover, developing countries often lack the financial and technical resources to respond to these changes.

Efficiency requires that emission reductions occur where their cost is lowest, irrespective of who bears the financial responsibility. Efficiency calls for removing energy subsidies, reforming and clarifying property rights that affect energy use and carbon storage, and reducing nongreenhouse externalities that have the side benefit of reducing greenhouse emissions. Efficiency may also be promoted, and greenhouse emissions reduced, by better information dissemination and by addressing capital market imperfections that inhibit the adoption of energy-efficient technology. Dynamic analysis indicates large potential gains from flexibility in the timing of greenhouse reductions to allow for the economical turnover of capital stock and to allow time for the development of low-cost substitutes. Policies that promote efficiency by requiring nations to face the full costs of their actions will also address equity concerns. International mechanisms, such as joint implementation, coordinated economic instruments, carbon taxes, and tradable permits, if appropriately implemented, would promote efficiency.

PHOTOCOPY
PRESERVATION

1.1 Introduction

In recent decades, atmospheric emissions of greenhouse gases have risen significantly. Concentrations are currently about 25% greater than at the beginning of the Industrial Revolution. If current trends continue, concentrations will double from preindustrial levels before the end of the next century and, if unchecked, continue to rise thereafter (IPCC, 1990a).

The scientific community has noted the potentially serious effects of increased concentrations. These climatic effects could, in turn, have further effects on the biosphere, including an increase in mean global temperature, an increase in sea level, changes in agricultural yields, forest cover, and water resources, and a possible increase in storm damage.

Increased concentrations of greenhouse gases are the result of fossil fuel burning, deforestation, livestock raising, and other human activities. Concerted action on the part of individuals and governments will be required to slow the increase in concentrations. Changes in greenhouse gas concentrations and the analysis of the climatic and other physical consequences of those changes lie within the purview of the physical sciences. The role of human activity in generating greenhouse gases, the consequences of those changes for humans, and possible responses lie within the purview of the social sciences.

Climate change impacts are likely to vary dramatically from country to country. A warmer climate could benefit sectors of the economies of some mid- and high-latitude countries. It is possible that anthropogenic warming might heat the atmosphere enough to prevent or delay another ice age. On the other hand, even modest economic losses averaged over the globe could mask large regional losses: a rising sea level and the possibility of increased storm surges could threaten the survival of some small island states and coastal areas and could increase the risk of midcontinent drought and desertification for inland areas on the periphery of deserts. Such changes could promote human migration and major conflicts as well as famine, disease, and increased mortality.

Within the past decade, a consensus has emerged on some key issues in the economics of climate change. This report describes areas of consensus as well as areas of disagreement, the sources of disagreement, and further research that could narrow the range of disagreement. This chapter frames the issue of climate change largely from the point of view of economics but also from that of other social sciences, introducing the more detailed discussions in the chapters to follow.

At least two arguments have been offered to justify the commitment of resources to mitigate climate change. The first arises from fundamental values, the second from decision analysis. They may be summarized as follows:

- (1) We have only one planet. Some changes are largely irreversible and may occur rapidly. Prudence calls for avoiding a large-scale experiment with the planet. Thus, avoiding anthropogenic climate change lies beyond the scope of normal economic calculation.
- (2) The potential exists for the occurrence of sudden, largely irreversible, nonlinear changes in the global

ecosystem. These would have major economic effects, which would be particularly severe in some countries or regions.

Even if the first view is adopted, economics has much to contribute to the discussion, for the question of cost-effective emission reductions must still be addressed. If the second view is adopted, economics and cost-benefit analysis will clearly be relevant, both in deciding how much mitigation to undertake and in designing the measures.

This chapter, and others in this Assessment Report, draw on the findings of the IPCC's Working Groups I and II, and follow the guidelines provided by the Framework Convention on Climate Change (FCCC). The Convention leaves open a number of important questions that must be addressed at the political level through future negotiations, including reviewing the adequacy of commitments. It is hoped that the findings of this chapter, and the assessment report more broadly, will contribute to these future negotiations by providing an understanding of the costs and consequences of alternative actions and their scientific basis.

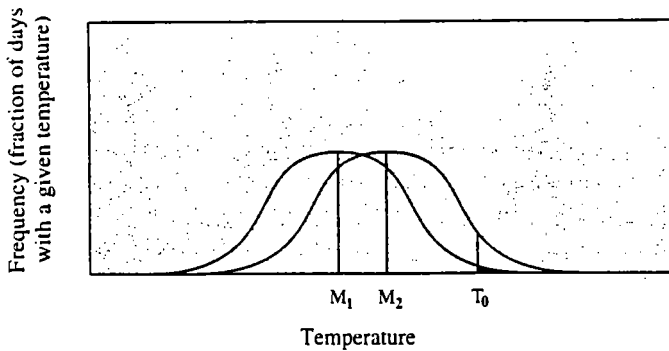
1.2 Features of Climate Change

Climate change could impose a variety of impacts on society. Volume 2 of this report analyzes these impacts in detail. They include effects on agriculture, forests, water resources, the costs of heating and cooling, the impact of sea level rise on small island states and low-lying coastal areas, and a possible increase in extreme events (e.g., storms). Although most attention to date has focussed on negative impacts, some impacts will be positive. Beyond these tangible impacts are a variety of intangible impacts,¹ including damages to existing ecosystems and the threat of species losses.²

Climate change presents the analyst with a set of formidable complications: large uncertainties, the potential for irreversible damages or costs, a very long planning horizon, long time lags between emissions and effects, a global scope, wide regional variations, and multiple greenhouse gases of concern.

Large uncertainties. Although natural scientists agree that greenhouse gas concentrations are rising, there remain major uncertainties about the impacts on temperature and climate. These are reflected in a wide range of estimates of future global mean temperature increases and in uncertainties about regional climate changes. Estimates of net economic losses for the most likely range of warming over the next century, and the great uncertainties associated with such estimates, are discussed in Chapter 6. Social scientists do not agree on the size of the behavioural responses or economic effects that would follow or on the effect of these changes on human well-being (Manne and Richels, 1992; Peck and Teisberg, 1993; Nordhaus, 1993).³

Nonlinearities and irreversibilities. Nonlinearities occur when changes in one variable cause a more than proportionate impact on another variable. Irreversibilities are changes that, once set in motion, cannot be reversed, at least on human timescales. For example, some have suggested that even a modest increase in atmospheric greenhouse gas concentra-



Note: As average temperature increases from M_1 to M_2 the number of days when the temperature exceeds T_0 increases significantly.

Figure 1.1: Effect of an increase in average temperature on the number of days that exceed a specified threshold.

tions could, beyond a certain point, trigger a substantial increase in temperature. Some have hypothesized that “runaway warming” could be triggered by a disruption of the North Atlantic thermohaline circulation or by methane release from thawing of permafrost.⁴ Alternatively, even a modest increase in average temperature might significantly increase weather-related agricultural losses because, for many crops, extra days of extreme heat severely limit yields. In Figure 1.1, if the threshold temperature for crop damage is T_0 , then even a small increase in the mean temperature, from M_1 to M_2 , may greatly increase the number of days above the threshold, represented by the area under the curves to the right of T_0 .⁵ On the other hand, spending large sums to reduce the risk of climate change may also have largely irreversible consequences, slowing development as it drains resources from other efforts to improve the human condition.

Long planning horizon. Greenhouse gas concentration changes occur over a long period of time; the full consequences of actions taken over the coming decades will be felt increasingly over the next century and in future centuries. The truly long-term nature of the problem is one of the distinctive aspects of greenhouse gas warming. Seldom has the world consciously faced a set of decisions likely to affect our descendants one, two, or three centuries from now.⁶ Because the costs of taking action today are borne by the current generation, whereas the benefits that accrue will be felt possibly hundreds of years in the future, the world community is now faced with issues of intergenerational equity on an unprecedented scale. Although society has addressed similar problems concerning trade-offs over periods of fifty or even a hundred years, the long planning horizon for climate change puts the analytic questions at issue in a new light. The length of time involved has one further implication: changes in technology, as well as population and consumption patterns, become of paramount importance.

Long life of capital stock. Every country has made large capital investments in its cities, farms, ports, and other assets. Some of this investment cannot be changed without large costs: low-lying port cities, for example, cannot easily be rebuilt. For other investments, the cost of change will be small.

For diversified agricultural economies, the cost of switching from one annual crop to another will be small if the temperature increase is modest; for less diversified economies, the costs may be larger. In short, both mankind and ecosystems have adjusted to the current climate, and adjustments to accommodate climate change may be costly.

Inertia in the climate system. Atmospheric concentrations, rather than emissions, determine the amount of warming projected by climate models. Concentrations change much more slowly than emissions, meaning that affected nations might not have enough time to prevent impacts from climate change, or to mitigate economic impacts after the effects of climate change become evident. In this respect, the risks of climate change are unlike those of earthquakes or floods. Long time lags and the difficulty of detecting climate change increase the difficulty of reliably determining the magnitude and timing of future effects before they begin to occur.

Global scope. Climate change is a global challenge, which cannot be answered by a single country acting by itself. Mitigation must be coordinated globally. In an interlinked world economy, not only are the actions of a single country, or group of countries, not likely to be sufficient to address the problem, they are likely to be largely offset by actions of other countries. If, for instance, one group of countries reduces timber cutting to increase carbon absorption, the price of lumber will rise, which may induce other countries to increase cutting in their forests.

Moreover, whereas economic analysis generally takes the point of view of a single decision maker or government, the important decisions on climate change will, of necessity, be made by many sovereign governments. Economic and decision sciences are not yet able to predict the outcome of bargaining problems of this type.⁷

Regional variation. Impacts are likely to vary greatly both within and among countries. Some countries and regions will suffer from warming; others will benefit, at least in some sectors. Some cold countries will benefit from a reduction in heating costs and an increase in the length of growing seasons; some warm countries will see a drop in yields from agriculture and forestry; low-lying states are likely to suffer from increased storm surges and flooding.

Aggregation. For the world as a whole, the net effect at any time will be the sum of local effects at many points on the globe, some positive and some negative. Analysts have no way to estimate this sum without detailed local calculations (summarized in Chapter 6).

Multiple gases of interest. The enhancement of the greenhouse effect depends on the concentration of all greenhouse gases, even though most economic modelling to date has limited itself to the implications of changes in CO_2 . Because greenhouse gases differ in radiative efficiency and atmospheric lifetime, analysts have devised measures of global warming potential (IPCC, 1990a, 1995) that seek to allow radiative forcing from changes in the concentration of all greenhouse gases to be measured in a commensurable fashion.⁸ Studies also demonstrate the important role of sulphur and other aerosols, which cause negative radiative forcing (i.e., cooling) by reflecting incoming solar radiation.⁹

Importance of net emissions. Because greenhouse gas concentrations depend on net rather than gross emissions, changes in forests and other greenhouse gas sinks must be taken into account.¹⁰

Efficiency vs. equity. From an economist's perspective, how much to reduce emissions is a matter of efficiency (because achieving the proper level of emissions raises net well-being), but who pays is a matter of equity. Economics has much to say about the former, but much less about the latter. Nonetheless, equity considerations will drive many of the policy decisions made under the Framework Convention on Climate Change.

1.3 Contribution of Economics

Economics and the social sciences offer perspectives on climate change not provided by the physical sciences. In the classic definition, economics is the study of the allocation of scarce resources that have alternative uses. Economics emphasizes the importance of trade-offs between different uses of resources, and the forgone value of other uses of a resource, called the opportunity cost. In the context of climate change, this means that (1) costs and benefits matter; (2) resources are not free; and (3) resources used for one purpose are no longer available for other purposes.

This chapter sets out the logic of cost-benefit analysis as applied to climate change. Standard cost-benefit analysis requires (1) a valuing of costs and benefits over time, using *willingness to pay* as a measure of value and (2) a criterion for accepting or rejecting proposals.¹¹ The standard criterion is the *compensation principle* (Kaldor, 1939; Hicks, 1939), which says that if the project yields positive net benefits, then those made better off could compensate those made worse off with something extra left over. As long as compensation is paid, the result is an unambiguous gain in welfare, without the necessity of weighing effects on different individuals.

Climate change raises difficulties with both requirements. Valuation is difficult because of the difficulty in valuing environmental amenities, which are generally not traded in the market. And the compensation principle will not apply if mechanisms for affecting transfers do not exist, either between countries or regions in one generation, or – especially – between generations. If transfers are not feasible, then the analysis must assign weights to different individuals (for example, the utilitarian welfare function gives equal weight to each person). Only then can conclusions be drawn about net benefits for society as a whole. This issue is addressed in the discussion of equity in Section 1.4.

Beyond these fundamental concepts are ideas, originally from other areas of economics, that may be applied directly to the study of climate change; these include work on risk, dynamics, sequential decision making, public goods and externalities, taxation, and general equilibrium.

1.3.1 Risk

In the past thirty years, much new economic research has focussed on rational responses to risk,¹² including three areas

important to a systematic examination of and rational response to climate change: portfolio theory, insurance, and decision analysis.

1.3.1.1 Portfolio theory

A portfolio manager attempts to get the best return for a given level of risk. One approach is to buy several types of assets whose returns are not correlated or are negatively correlated (that is, whose prices move either independently or in opposite directions). In this respect, climate change policy decisions can be compared to investment portfolio decisions.

When faced with a risk, an individual may (1) act to reduce the chance the unfavourable event will occur; (2) act to reduce the cost if the event does occur; or (3) spread part of the risk to others through insurance. In response to the threat of climate change, nations may (1) reduce the chance that warming will occur by reducing greenhouse emissions (mitigation); (2) adjust to climate change if it does occur (adaptation); or (3) spread part of the risk through insurance. A portfolio approach can be expected to include both mitigation and adaptation actions. These may include government policy reforms, such as reducing fossil fuel subsidies; increased carbon sequestration; reducing emissions of methane and other non-CO₂ greenhouse gases; research and development, which can promote emission reductions or make it easier to adapt to any changes that do occur; and international actions, including joint implementation (one country funding emission reductions in another country) and technology transfer.

A well-chosen portfolio of climate change investments will yield greater benefit for a given cost than any one option undertaken by itself. For an individual country, the issue is how to choose the portfolio of policy measures best suited to its circumstances and to adjust the portfolio over time in response to new developments. Governments will be making climate change decisions for several decades at least. This means that they will have many opportunities to adjust the size (total resources) and mix (choice of measures) of their portfolios of responses. Portfolios may differ from country to country.

1.3.1.2 Risk aversion

Individuals and societies are generally risk-averse when facing large risks; that is, they are willing to pay something to reduce the likelihood of a large risk. The amount they are willing to pay is called the *risk premium* (see Box 1.1).

That individuals and societies are *risk-averse* means that average utility (well-being) is increased by pooling risks, or, equivalently, that people are willing to pay to reduce the risks they face. If society as a whole is risk-averse, then some investments with a negative expected return, for example, a particular investment in climate change mitigation, should be undertaken if they reduce the probability of a loss or the costs of future adaptation.

The magnitude of those expenditures depends on society's degree of risk aversion and the magnitude of the risk. The *risk premium* – the extra amount that society is willing to pay to reduce a risk – is small if the stakes (say, the maximum loss) are small, and large if the stakes are large. An investment of a

BOX 1.1: RISK AND UNCERTAINTY

Uncertainty arises when a decision can lead to a range of outcomes.

Expected return or *expected value* of a decision is the mean of the distribution of returns, the amount a person would on average receive as a consequence of the decision.

Risk aversion measures an individual's unwillingness to take risks.

Risk premium is the amount an individual would pay to replace the uncertain distribution of outcomes with the expected value.

Certainty equivalent is the amount that makes an individual indifferent between it and a risky proposition; for a risk-averse person, the certainty equivalent is higher than the expected return; the difference is the risk premium.

dollar is justified if it reduces the loss of expected utility by more than a dollar, and not justified if it reduces the loss by less than a dollar. Thus, results reported below focussing on the expected loss of GDP from climate change do not directly address the risk premium. If a possible outcome is a loss of 10%, even though the expected loss is only 3%, then the *certainty equivalent* loss will exceed 3%. A dollar investment that reduces this certainty equivalent loss by more than a dollar should be undertaken. Such an investment could either reduce the average loss, for example, by reducing the probability of the loss occurring (through mitigation actions), or reduce the variance of the loss. For example, some actions that reduce extreme losses will have more than proportionate returns.

Ascertaining the magnitude of the risks, or how they are affected by any particular action, is often difficult in a dynamic setting. One key consideration is how the particular action affects the remaining options – the set of actions available in the future – along with their costs and benefits. Risk-reducing expenditures are referred to as *precautionary investments*. Making precautionary investments has the same effect as buying conventional insurance.

The insurance expenditures associated with mitigation actions and investments are, in a sense, only the differences between the actual expenditures and the *no-regrets* benefits (the benefits other than those associated with greenhouse gas emissions). Thus, investments in fuel-efficient cars may have a direct benefit in reducing the cost of running a car and in reducing its emissions of local air pollutants. The mitigation investment is only the additional investment for climate purposes.

Irrespective of the possible consequences of climate change, policies that mitigate against or assist adaptation to climate change and have zero or negative net costs (no-regrets policies) are clearly justified. If the evidence suggests that damages can be expected from climate change, then the expectation of damages provides a rationale for going beyond no-regrets policies to those that incur positive net costs. The principles of risk aversion and portfolio balancing provide a rationale for further steps. The costs of such policies might be

justified as a risk premium to be paid for the added security of reducing the likelihood of climate change.

Traditional insurance rests on two principles: pooling risks and transferring risks to those more willing or better able to bear them.¹³ Because the risks associated with climate change are correlated, pooling risks is less effective than it is in other situations. Nonetheless, differences in predicted regional impacts, implying less than perfect correlation in climate change risks, make possible some degree of risk pooling. This holds irrespective of who pays the cost, because wealthier individuals and countries are better able to bear risk.¹⁴ Many countries likely to be most adversely affected will be developing countries, whereas many of the countries least affected (or positively affected) will be the industrialized countries, which could provide insurance for effects of climate change that might fall harder on less developed economies.¹⁵

Insurance markets, however, face three problems in addressing climate change. First, they lack a mechanism to transfer some of the risk from those likely to bear it (future generations) to the current generation. Second, losses associated with climate change are likely to be both correlated and large, compared to losses absorbed in a single year by the commercial insurance industry (which itself has been hard pressed in recent years to handle natural disasters). Third, the long-term nature of climate change insurance raises the problem of contract enforcement: Will contracts signed today be enforceable tomorrow? Will the insurers be around to pay claims fifty or one hundred years from now? (Even in the industrialized countries, private markets may be inadequate to insure against losses from a major national disaster today.)

These considerations suggest that private markets will not be able to insure fully against climate change. One possible solution would include international action to establish insurance markets, perhaps with government reinsurance. Should such an insurance market be established, careful attention will have to be given to ensuring that the insured parties engage in appropriate adaptation actions, reducing the losses that might be associated with any greenhouse gas warming.¹⁶

1.3.1.3 Precautionary investments

A business makes precautionary investments to reduce the total risk of its portfolio. Numerous policy measures are available to reduce risks to future generations from climate change. Four have been most often discussed in recent years: (1) immediate reductions in emissions to slow climate change; (2) research and development focussing on new supply and conservation technology to reduce future abatement costs;¹⁷ (3) continued research to reduce uncertainties about how much change will occur and what effects it will have; and (4) investments in actions to assist human and natural systems to adapt to climate change if it occurs.

Precautionary investments may reduce the risk of climate change itself (mitigation), or they may enhance the ability of future generations to respond, in one of two ways. First, by analogy, an individual may set money aside in a "rainy day fund" when things are going well and allow it to grow over time in order to make it easier to adapt to difficulties that may occur later. Similarly, by increasing investment in productive

assets now, countries will have a richer economy to draw on should climate change damages occur later. A policy of precautionary investments means investing more than would otherwise have been invested. Second, investments can be made (including investment in research and development) that would enhance the economy's ability to adapt should climate change damages occur.

Precautionary investments may also enhance the ability of future generations to react. An important reason that people establish savings accounts is to reduce the impact of unfavourable events in the future. Similarly, a society may elect to accumulate capital against the possibility of a large loss from climate change. This is one thread of the debate over discount rates discussed in Chapter 4. Those who argue for a discount rate close to the opportunity cost of capital point out that society may choose between immediate greenhouse gas mitigation, at a cost, and delayed mitigation, with some of the money saved put aside as a savings account for our grandchildren in the event of large climate-induced damages.

1.3.2 Sequential decision making

As a policy question, global climate change is sometimes posed as a choice between (a) doing nothing at all or (b) committing to all-out effort. Given the large current uncertainties about the costs and benefits of greenhouse mitigation, this is the wrong way to frame the issue, as it obscures the choices that should be evaluated. Moreover, in part because option (b) may be perceived as too expensive to get political support, policy paralysis often results.

A more useful formulation is: "Given current knowledge and concerns, what actions should we take over the next one or two decades to position ourselves to act on new information that will become available?" (Lind, 1994). For example, decision makers would like to know if the possibility of irreversible damages, such as might be suffered by low-lying states, justifies undertaking an aggressive abatement programme immediately.¹⁸

Climate change demands a decision process that is sequential and can incorporate new information. Timing will be a key element, and the date of resolution of uncertainty an important element of the analysis. Figure 1.2 shows schematically the progression from a simple decision to a sequence of linked decisions. In this example, the simple decision might be whether to take aggressive abatement actions now. Let us assume that the uncertainties are resolved in 2005. In the case of sequential decisions, Decision 1 (in 1998) could be whether to take aggressive abatement actions now; Uncertainty 1 (resolved in 2005) might be the cost of mitigation; Decision 2 (in 2010) might be whether to tighten abatement programmes already in place; and Uncertainty 2 (resolved in 2020) might be the relation between greenhouse concentrations and temperature increase. Since both climate change and new knowledge (learning) are continuous processes, actions to address climate change should be adjusted continuously in the light of new information.

A sequential decision-making strategy aims to identify short-term strategies in the face of long-term uncertainty. The next several decades will offer opportunities for learning and

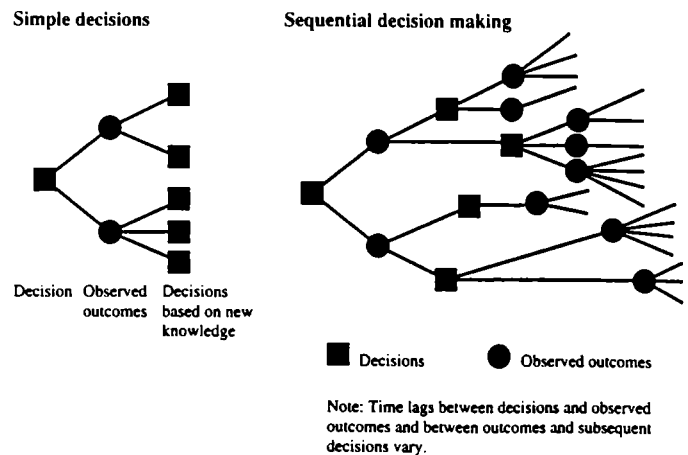


Figure 1.2: Sequential decision making.

making mid-course corrections. The relevant question is not "What is the best course for the next 100 years?" but rather, "What is the best course for the next few years?" because a prudent hedging strategy will allow time to learn and change course.

For example, the choices might be (1) immediate investment in new plant and equipment, (2) aggressive research and development on greenhouse abatement technology, or (3) deferring large investment for ten years, when the nature and size of the threat are better understood, when costs will presumably have dropped owing to the availability of improved technologies, and the job can be done more efficiently.

Inappropriate interim goals increase the total cost of addressing the problem (Richels and Edmonds, 1993). For example, a commitment to certain levels of emissions in certain years fails to take into account the effects of temporary economic disturbances on GDP, and thus on emissions and, hence, on the cost of controls.

Because of the high cost of being wrong in either direction, the *value of information* about climate change is likely to be great. In particular, the value of information about the sensitivity of temperature to CO₂ increases, the temperature damage function, the GDP growth rate, and the rate of energy efficiency improvement is likely to be high (Chao, 1992; Peck and Teisberg, 1992; Manne and Richels, 1992; Nordhaus, 1993).¹⁹

The presence of uncertainty along a dynamic path creates an *option value*, the value of preserving choices for the future. In climate change, the term has been used in two different ways. One stresses the irreversibilities of climate change: mitigation expenditures now preserve the option of avoiding adaptation expenditure later. The other stresses irreversibilities in investment and the cost of premature turnover of capital. Any action taken today changes the options available later or, more precisely, changes the consequences of any future action. Sequential decision making focusses on how those consequences are affected if one action is taken today rather than another, and on how these consequences are affected if actions are taken in parallel rather than serially.

1.3.3 Dynamics

The problem of greenhouse gas warming involves additions to concentrations resulting from net emissions over extended

periods of time. Thus the analysis must focus on dynamics. Dynamic analysis involves three stages: the dynamic processes involved, the trade-offs, and judgments concerning those trade-offs.

Dynamic analyses have led to important insights. For example, atmospheric concentrations of greenhouse gases and, therefore, their effect on temperatures depend on the total amount emitted over a period of years. A given concentration target can be achieved by a variety of emission timepaths. Timepaths that provide for the economical turnover of existing capital stock and time to develop low-cost substitutes are likely to be less costly. This suggests large potential gains from flexibility in the timing of emission reductions.²⁰

1.3.3.1 Kaya identity

The driving forces in emissions of any greenhouse gas can be seen in the following identity for carbon dioxide emissions (Kaya, 1989):

$$\begin{array}{ccccccc} \text{CO}_2 & = & \text{CO}_2/E & \times & E/Q & \times & Q/L & \times & L \\ \text{carbon} & & \text{carbon} & & \text{energy} & & \text{output} & & \text{popu-} \\ \text{dioxide} & & \text{dioxide} & & \text{per unit} & & \text{per} & & \text{lation} \\ \text{emissions} & & \text{emissions} & & \text{output} & & \text{capita} & & \\ & & \text{per unit} & & & & & & \\ & & \text{energy} & & & & & & \end{array}$$

or, expressed in rates of change:

$$d \ln \text{CO}_2 / dt = d \ln \text{CO}_2 / E / dt + d \ln E / Q / dt + d \ln Q / L / dt + d \ln L / dt$$

that is, the percentage rate of change in carbon dioxide emissions is equal to the rate of change in carbon dioxide emissions per unit energy plus the rate of change in energy requirements per unit output plus the rate of change in output per capita plus the rate of change in population.²¹

This identity clarifies different approaches to reducing emissions. For a developed country with a stable or slowly growing population, as long as the ratio of emissions to output declines at least as fast as productivity rises, CO₂ emissions will not increase. Because of the substantial potential for energy efficiency improvements, this seems feasible for most developed countries. Many opportunities exist for increasing end-use efficiency, represented by the second term on the right-hand side – for example, a shift from cars to public transportation and from less to more fuel-efficient cars and homes.²² (The same term may also reflect structural shifts in the economy, as in the case of a shift away from energy-intensive industries.) Fuel switching (for example, from coal-based electricity to oil, gas, hydroelectric, wind, or geothermal), represented by the first term, also offers the potential to limit CO₂ emissions in many countries.

For many developing countries, emissions will increase unless energy efficiency and greenhouse gas emissions per unit of energy change to offset growth in per capita output and population. For many developing countries with rapidly growing populations, pressures for economic development will make it difficult to direct capital from investments with higher greenhouse gas emissions to those with lower greenhouse gas emissions.²³

Evidence for two other essential issues is currently limited. First, to what extent will improvements in energy efficiency require net increases in investment beyond the resources saved from reduced energy usage; in other words, how much does aggressive emission reduction depress economic growth? Order-of-magnitude calculations suggest the presence of only limited trade-offs, at least for the near term. Second, do developing countries have the institutional capacity to achieve the desired increases in emission efficiency?

1.3.3.2 Nonrenewable resources, backstop technologies, and emission reduction strategies

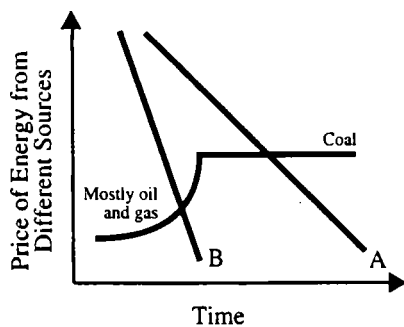
In principle the atmosphere is a renewable natural resource. However, the longevity of the greenhouse gases and the relationships between stocks and flows mean that, for practical purposes, it may be better treated as an exhaustible natural resource, although one in which welfare depends not just on the flow out of the stock but on the stock itself.²⁴

The central problem with natural resources, whether renewable or not, is timing. Many renewable resources possess a maximum sustainable rate of exploitation. Exploitation cannot long exceed this maximum rate without depleting the stock and ultimately reducing the harvest. Corresponding to the sustainable flow rate is a steady-state stock. If, initially, the actual stock exceeds the steady-state stock, then the flow can exceed the maximum sustainable flow for a while. The question is how to distribute this excess over time. In addition, even when the stock is at the sustainable level, it may be desirable in times of emergency to exceed the maximum sustainable flow. For a renewable resource, this can be done, though only at the expense of decreased flows later.²⁵

Timing of reductions in greenhouse gas emissions should reflect differences in costs, discounting (to evaluate those costs), and risk. If technological change will make future emission reductions much less costly, some reductions should be postponed.²⁶ Conversely, research on learning effects shows that if actions taken today will lower costs faced tomorrow, then these dynamic benefits should be included in the calculus (Arrow, 1962; Atkinson and Stiglitz, 1980). In the context of climate change, if emission constraints stimulate technical or other developments that help to lower the costs of continuing or additional emission abatement, then reductions should be accelerated (Grubb *et al.*, 1993a, 1993b, 1995). If discount rates are high, the costs borne by future generations will carry less weight than if discount rates are low. In the presence of risk, nonlinearities, or irreversibilities, the principle of risk aversion suggests a strategy of early mitigation.

The theory of nonrenewable resources contains a second set of lessons for climate change policy. Suppose primary energy sources are divided into four groups: coal, gas and oil, biomass, and noncarbon sources. As a first approximation, gas and oil may be taken to be exhaustible. This means that total carbon emissions from gas and oil are fixed, or at least confined to narrow bounds; the question is not how much will be consumed, only when.²⁷

As an example, Figure 1.3 depicts three phases of fuel use in an economy. In the first phase, the economy relies on nonrenewable resources, such as oil and gas; in the second, on coal and perhaps nuclear power; in the third, on backstop



Note: If the price of the nonfossil backstop technology is given by A, all oil and gas reserves will be exhausted and coal will be used for some time before being displaced by the backstop technology. If the price of the nonfossil backstop is given by B, it will be adopted before the oil and gas reserves are exhausted, resulting in lower greenhouse gas emissions.

Figure 1.3: Influence of the cost of backstop technologies on energy use and greenhouse gas emissions.

technologies,²⁸ such as biomass combined with noncarbon sources. The switch points depend on rising energy prices and improving technology, which lowers the costs of the backstops. The figure shows alternative long-run scenarios. In alternative A, the price of the backstop technology falls sufficiently slowly that, for a time, the economy relies on coal. In alternative B, the price of the backstop technology falls fast enough to eliminate the intervening stage of primary reliance on coal.

Since, to a first-order approximation, the total carbon load from oil and gas is fixed (and limited), the total carbon load on the atmosphere is ultimately primarily related to coal usage. From this perspective, an important uncertainty is the pace at which the cost of the backstop decreases. If it decreases fast enough, the intermediate stage of coal dependence will be short, and the total carbon load low, whereas if the price decreases slowly, the carbon load could be much larger.

From this perspective, rational use of gas and oil is an important part of a risk strategy, for it provides insurance against the possibility of a delay in the arrival of backstop energy sources.²⁹ This, in turn, has important implications for the “leakage” debate, which asks whether, in the event that the developing countries impose carbon taxes but the undeveloped countries do not, the latter’s response will largely offset emission reductions made by the former. It is also possible that lower prices for gas and oil will induce coal-rich countries to decrease their reliance on coal, thus possibly producing negative leakages. But to the extent that such leakage occurs, the insurance provided by greater conservation of oil and gas is eliminated, and it is this insurance that should be an essential part of a dynamic strategy. If the backstop arrival is delayed, then earlier fuel switching by China and India, to mention the most pertinent examples, will yield no long-run benefits. On the other hand, if the backstop arrival is early, the whole issue is largely moot. Thus, leakage needs to be looked at, not from the static perspective of what occurs in a single year, but from a dynamic perspective that corresponds to the long-run nature of the global climate problem.

1.3.4 International public goods

The atmosphere is an *international public good*, in that atmospheric concentrations are the result of combined actions by all countries. A pure public good (Samuelson, 1954) has two properties: *nonrivalry* and *nonexcludability* (see Box 1.2).³⁰ The atmosphere has both characteristics. That means that if one country’s greenhouse gas reductions thwart global warming, all countries benefit.³¹

Since countries will be affected differently by climate change, the benefits of avoiding greenhouse warming will also differ from country to country. Further, some actions will simultaneously affect local atmospheric conditions (providing local public goods) and greenhouse concentrations. For example, actions that reduce urban driving improve local air quality and at the same time reduce greenhouse gas emissions.³²

1.3.4.1 Property rights

An important strand of economic thought associates externalities with a failure to assign property rights (Coase, 1960). Assigning property rights to the atmosphere is particularly difficult, however, since this would require the agreement of many sovereign states. Tradable greenhouse emission permits, discussed below, can be thought of as an attempt to resolve the problem by explicitly assigning property rights to greenhouse emissions.

Establishing property rights for emissions is not the same thing as considering the climate system itself as a public good. The FCCC refers to the climate system (not the atmosphere) as a “common concern of humankind.” Atmospheric concentrations are the net result of emissions plus the contributions and effects of other factors such as the oceans, forests,

BOX 1.2: PUBLIC GOODS AND EXTERNALITIES

Externality: An externality, or spillover, arises when the private costs or benefits of production differ from the social costs or benefits. Because the social costs or benefits are external to the private costs that firms face, the economy will tend to produce too little of a public good (like education) and too much of a public bad (like pollution).

Public good: A public good has two properties: nonrivalry and nonexcludability. Nonrivalry means that additional consumers do not have to compete with each other to use the good and therefore drive up its cost: the marginal cost of an additional individual using the good is zero. Nonexcludability means that the marginal cost of exclusion – of stopping an individual from enjoying the good – is prohibitive. Public goods thus permit “free riding.” Lighthouses, for example, are public goods: when lighthouse services are provided to one person, others may enjoy the same services without cost.

Market failure: Private markets may sometimes fail to provide a good at the most desirable level: private markets alone will likely provide too few lighthouses and too much pollution.

and agricultural activity. Establishing property rights over emissions does not provide guidance for the consideration of these other influencing factors. Thus, establishing property rights for the atmosphere is only one of the mechanisms necessary to regulate climate change.

1.3.4.2 *Paying for an international public good*

Who should pay for a global public good? Every country faces this question internally in determining who should pay for the public goods it provides. Who should, for instance, pay for pollution control within a country? Economists generally agree on the following principles:

First, for the purposes of analysis, *it is useful to separate efficiency from equity*. The implication of this principle is that because pollution is a social cost of production (and consumption), everyone should be made to pay the full social costs of the pollution they generate. Thus, if there is a social cost to a unit of greenhouse gas emissions, that cost is the same no matter who produces the emissions. All should pay the full social costs of their actions, whether rich or poor. In this perspective, corrective (Pigouvian) taxes should be imposed uniformly.

Second, *it is inappropriate to redress all equity issues through climate change initiatives*, although climate change should not aggravate disparities between one region and another.

No scientific consensus exists on the framework for deciding the burden of financing mitigation and adaptation. At least four approaches have been proposed to determine how the burdens of taxation should be shared. One approach looks at *benefits*: Just as those who benefit from private goods must pay for them, those who benefit from a public good should be made to pay for it. The principle has some force when large differences in preferences exist within any income class. Providing a particular public good benefits some of those individuals more than others, creating inequalities in the absence of benefit taxes. A major problem frequently encountered, particularly for pure public goods, is that it may be difficult to determine who benefits. It is, in general, possible to ascertain the *economic benefits* of mitigation, and these are likely to be quite unequally distributed. But this principle, by itself, does not fully determine who should bear the costs. Appropriately designed mitigation strategies will produce a surplus of benefits over costs, a surplus that must somehow be divided.

A second approach looks at ability to pay. It is often held that richer countries (or individuals) should pay more than poorer ones. This approach sometimes rests on the claim that all people are entitled to a certain minimum consumption (Dasgupta, 1982). But this principle does not answer the question of how much extra the richer countries should pay.

A third approach is based on contribution to the problem. Because the industrialized countries have contributed more than two-thirds of the stock of anthropogenic greenhouse gases in the atmosphere today, this approach seems to suggest that they have a larger responsibility for bearing the costs. On the other hand, by the time greenhouse gas concentrations double from preindustrial levels, the developing countries are projected to be contributing more than half of annual emis-

sions, and roughly half of the total stock in the atmosphere (IPCC, 1990a; Cline, 1992). Thus, under this criterion, the developing countries might eventually pay far more of the mitigation costs than under the other principles described earlier.

Economists have turned to a fourth approach – the social welfare function – to answer the question of how much extra different parties should pay, as well as the question of how to distribute the surplus. The discussion of equity below differentiates between the Rawlsian and utilitarian approaches. In this case, both approaches yield similar results: In the absence of incentive problems, both imply that all of the surplus should be allocated to the poorer countries, or that all of the burden of effort should be borne by the richer countries.³³

Yet a different approach holds that social scientists as such have nothing to say about these ethical issues. Coase (1960), for instance, approaches the problem of externalities by emphasizing that (a) in the absence of bargaining costs, an efficient solution can be obtained by assigning property rights³⁴ and (b) this solution is independent of how property rights are assigned.³⁵ Coase also emphasizes the importance of transaction costs, which will often influence the choice of policies.

A simple approach that yields efficiency but does not require redistribution (and is thus consistent with the two principles enunciated above) requires coordinated tax rates so that all countries face the same energy prices. This approach makes the cost of emitting an extra tonne of carbon equal across all countries, with each country retaining the revenues thus generated.³⁶ The net cost of such a tax (ignoring the benefits from reduced greenhouse gas emissions) will, in general, be smaller for poorer countries, as a percentage of their national output. The burden of the tax is progressive in its distribution across countries, even though the tax is levied at the same rate in all countries.³⁷

Accounting for past emissions. Article 3.1 of the Framework Convention on Climate Change directs the Annex I (i.e., developed) countries to take the lead in responding to the threat of climate change “on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities.” Some have argued in addition that because the industrialized countries have been the major contributors to current levels of greenhouse gases, they should bear most of the costs of mitigation. This view says that costs should be borne, not in proportion to benefits expected, but in proportion to contribution to pollution. This argument, however, is not based on the principle of economic efficiency. Efficiency requires that incentives be prospective (forward looking), not retrospective.³⁸ No incentive effects result from imposing charges based on *past* actions. Whether to charge nations that contributed CO₂ to the atmosphere is an issue of ethics, not efficiency.³⁹

The controversial issues of population growth and consumption patterns, although central to economic development, bear on climate change largely through their effects on emissions. Population growth in developing countries may also exacerbate the ecological and socioeconomic impacts of climate change. At the same time, high per capita consumption in industrialized countries, where populations have nearly stabilized, will also affect mitigation and adaptation

costs and strategies. The relation of population to sustainable development, although important, is beyond the scope of this paper.⁴⁰

1.3.4.3 Enforcement

Both externalities and public goods need a legal framework within which the problems they pose can be addressed. Without compulsory taxation, there is an incentive for each individual to be a free rider, though there is some empirical evidence that the free rider effect may not be as significant as economists have previously assumed (Bohm, 1993). In the absence of compulsory taxation, externalities can only be addressed with well-defined property rights (Coase, 1960)⁴¹ and a legal system that enforces compensation for externalities.

Enforcing compliance with international legal agreements presents a number of legal and political problems. Many states resist compulsory use of the judicial process; this provides an incentive for free riding. The FCCC provides several means of settling disputes, including judicial recourse and arbitration. It also requires the parties to consider establishing a "multilateral consultative process" to assist in implementation of the Convention and to anticipate and prevent confrontations concerning compliance and enforcement.

1.3.4.4 Knowledge

A key element in addressing the problem of global warming is knowledge – knowledge about climate science as well as about the economic and social aspects of impacts, mitigation, and adaptation. Much of this knowledge is in the nature of an international public good. Developing ways of increasing energy efficiency will benefit all countries. Although in some cases, those countries engaged in the research will be able to appropriate for themselves a significant fraction of the *private* benefits (mostly in reduced energy costs), they will not be able to appropriate the broader social benefits, except through an energy tax (or permit fee) that is high enough that the price fully internalizes the emissions externality. Even then, the social benefits of innovation tend to far exceed the private benefits.

This suggests the need for an international agreement to fund basic research and subsidize applied research, particularly in energy-related technologies for the developing countries. There need not be a central funding agency, or a central directorate determining which research should be undertaken. This calls for some mechanism, possibly including joint implementation, for sharing research results and for ensuring that the fruits of this research are made available.

1.3.5 Efficiency

With some exceptions noted below, efficiency and equity can be analyzed separately.⁴² Analysts agree that any actions responding to climate change should be cost-effective: no matter who bears the cost of emission reductions, reductions should occur where their cost is lowest.⁴³ Because of the low energy efficiency in many developing countries, many have proposed that more attention be paid to emission reductions there.

Mechanisms for reducing emissions equitably and efficiently, including joint implementation, tradable permits, and coordinated tax policies, are discussed below and in Chapter 11. All these approaches, however, attempt to confront all individuals and producers in all countries with the same cost of emissions. Emission control is an international public good, in that greenhouse emission reductions have the same effect wherever they occur. Just as efficiency in the production of steel or any other commodity requires that all consumers and producers face the same price, so too with emissions. This can be achieved either through coordinated energy taxes or through tradable permit requirements; but unless the rules are applied in a systematic way to both developed and developing countries, emission reductions will be inefficient.

Partial participation in an international emission reduction programme will significantly reduce its effectiveness. The growth of international trade has resulted in important links between the developed and developing countries, and the total effects of any policy undertaken in the former can only be evaluated in terms taking into account the systemic responses, including responses from the developing countries, as discussed under the heading of "general equilibrium" in Section 1.3.6 below.⁴⁴

1.3.5.1 Bankable permits

Efficiency imposes several requirements. One, just described, is that at any moment, the costs of reducing emissions should be minimized. The second is *intertemporal efficiency*: The marginal cost of reducing emissions at two points in time must be the same. If it will cost less to reduce emissions at some future date, adjusting for time discounting, option values (risk), and impacts on atmospheric concentrations, then the reduction schedule should be adjusted accordingly.

Intertemporal efficiency would be promoted by allowing banking of permits (allowing a source to use fewer permits in one year and more in another), and by the development of futures and options markets. A bankable permit system would address some equity issues between developed and developing countries, including the concern among developing countries that delays in mitigation now by the industrialized economies would leave a greater burden for the future.

1.3.5.2 Exchange/risk efficiency

When different parties to an agreement hold widely differing views about risk and the probability of loss, significant efficiency gains can result from transferring risk among them. In Section 1.3.1.2 we discussed the importance of establishing an international insurance market for those facing the threat of losses under global warming and noted the advantages of establishing a market within which countries that are less concerned about these risks can assume more of the insurance burden. Any efficient international system for addressing the problems of global climate change must include both mitigation and insurance obligations. Governments that believe they have a comparative advantage in assuming climate risks can assume a larger share of those risks, trading off other obligations and substantially reducing the overall costs of responding to climate change.

1.3.5.3 Comprehensiveness

Efficiency also requires that the cost of reducing all greenhouse emissions be minimized. This principle implies that any mitigation programme must include not only all greenhouse gases (taking into consideration their heat-trapping potentials and atmospheric lifetimes⁴⁵) but also carbon sinks.

Finally, and perhaps most controversially, it implies that mitigation strategies should focus on all elements of the Kaya identity, ensuring that the marginal cost of reductions is the same for each of the possible strategies. Thus, population control may be an element in a long-term mitigation strategy, no less than a shift in the composition of production or an increase in the energy efficiency of the economy.

1.3.6 General equilibrium

General equilibrium theory, an important element of economic research over the last century, demonstrates the advantage of looking beyond first-stage effects. It offers two important insights for climate change analysis. First, the various parts of an economic system are interrelated; perturbations to one part have ramifications for other parts, which may be quite distant. Second, when all the reverberations are taken into account, the net effect of an action may be markedly different from the initial (and intended) effect.

One implication of general equilibrium theory has already been noted: Taxes imposed on one part of the global economy may have little if any effect on global emissions; they may simply result in a relocation of economic activity. Increasingly, the world's economic system must be viewed from a global perspective. Location of economic activities is determined primarily by relative factor prices, taking into account certain specific locational advantages and specialized competencies. If, for example, the OECD countries impose carbon taxes on energy-intensive industries, those industries may relocate outside the OECD. Further, if greenhouse mitigation puts an economic drag on the developed countries, developing countries would be affected through trade.

If different countries have different obligations to reduce greenhouse emissions, different implicit tax rates will result. This will interfere with world economic efficiency – decreasing world real output – possibly with little effect on total greenhouse gas emissions. For example, the most energy-intensive activities – such as aluminum production – may well relocate to developing countries.⁴⁶

Whereas many of the energy-economy-carbon models described in subsequent chapters attempt to estimate the magnitude of such carbon “leaks” (where carbon-intensive production moves to areas in which it is least regulated), most are based on standard international trade models, in which the location of production of various goods and machines is fixed (Whalley and Wigle, 1991).⁴⁷ Thus, estimates of carbon leakages are based only on commodity substitution.⁴⁸ But in the very long run, which is the time span of interest for an analysis of global warming, leakages may well be higher, owing to the relocation of industries. No consensus now exists on the magnitude of long-run leakages.

1.3.6.1 Intertemporal substitution

General equilibrium issues also arise when production can be shifted from one period to another. For example, in a partial equilibrium analysis, a tax on gas or oil raises the price of the fuel taxed, thereby reducing its consumption, and thus associated emissions. But over the long run an exhaustible natural resource like gas or oil has, by definition, an inelastic supply (ignoring for the moment extraction costs, which, in the case of gas and oil, are small relative to the price). The general theory of incidence argues that when a commodity is in inelastic supply, a tax affects the price, but not the level of consumption. That is, *when all countries impose a tax on gas or oil, the producer price of oil falls, by an amount just equal to the tax*. The full incidence falls on producers; as a first approximation, *the level of consumption – and thus the level of emissions – remains unchanged*. Obviously, if the tax is large enough, the price will fall below the cost of extraction for some output, and supply will be reduced. Moreover, in the case of exhaustible natural resources, taxes may affect the timing of consumption of the oil and gas (Stiglitz, Dasgupta, and Heal, 1980).⁴⁹

1.4 Equity

Who will be allowed to increase their greenhouse emissions and who will pay for greenhouse gas abatement and adaptation are among the most contentious issues in climate change. Equity issues such as these have immediate implications for policy as well, because the initial allocation of emission rights and emission constraints will largely determine the distribution of costs. The Framework Convention on Climate Change explicitly directs the parties to consider the problem of equity:

The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities. Accordingly, the developed country Parties should take the lead in combating climate change and the adverse effects thereof. . . .

[Account must be taken of] the differences in their starting points and approaches, economic structures and resource bases, the need to maintain strong and sustainable economic growth, available technologies and other individual circumstances, as well as the need for equitable and appropriate contributions by each of these Parties to the global effort regarding [the Convention's] objective.⁵⁰

1.4.1 General issues

Within the limits of cost-benefit analysis, equity arises because of the principle of compensation, discussed in Section 1.3. For example, suppose it could be shown that a business-as-usual path produced higher total benefits than a path with lower greenhouse emissions. We could not conclude from this that the world as a whole would be better off. Indeed, if the losers are not compensated, and their loss is counted more heavily than the winners' gain, the world as a whole would be

worse off. Or suppose the costs of warming fall predominantly on one group or one generation, while the benefits accrue to another. (For example, some have speculated that the costs of damages from warming would fall largely on developing countries, without a compensating increase in benefits (Parikh, 1994).) Unless the gainers actually compensate the losers for their losses, cost-benefit analysis cannot conclude that the change has, on balance, been good for society. Compensation is particularly difficult if future generations bear most of the costs, because no “fund for future greenhouse victims” exists (Birdsall and Steer, 1993). Thus, some have argued that, in the absence of mechanisms to make these transfers, we should not rely on possible future transfers from gainers to losers but should instead insist that the gainers pay the costs up front. An alternative explanation addresses these equity concerns by assigning different weights, perhaps based on economic status, to changes in consumption of different individuals (Atkinson, 1970).

No consensus exists among either economists or philosophers about the appropriate ethical responses to the changes that would come with global warming. Should, for instance, owners of resources be compensated for the losses they incur as a result of mitigation actions and the consequent change in prices or values? Economists have often argued no, for several reasons. First, some wealth is not a reward for productive activity, but merely an accident. It is not because country X did something that \$200 billion worth of minerals or oil was discovered to lie beneath its territory. One position is that these random allocations of wealth have actually contributed to world inequality, and that eliminating a part of these wind-fall gains would, from the perspective of an egalitarian social welfare function, be welfare-increasing. Another view denies that government policies would be taking value from assets that by right should be there; until now, according to this view, these resources have simply been underpriced, not fully reflecting the social costs imposed by their use. In this view, actions to discourage overuse would simply rectify a previous mistake.⁵¹

Whether investors or countries should be compensated for the adverse effects on their market values remains controversial. There is, however, reasonable consensus on three general principles: First, workers in adversely affected sectors may need assistance to switch occupations (the market failure here is that workers cannot purchase insurance against these kinds of adverse shocks). Second, gradual transitions may significantly lower the absolute cost of the transition. For instance, workers leave jobs through natural attrition; if those leaving are not replaced, the industry will be scaled down, with no transition cost to any individual worker. Third, the magnitudes of the uncompensated redistributions associated with any change in policy are often correlated with the magnitude of the political opposition.

Most policy changes produce winners as well as losers. If the relative price of natural gas increases, owners of natural gas deposits may actually be better off. In economies with progressive taxation of either capital gains or consumption, some part of those gains is implicitly shared more broadly.

Virtually all policies discussed below also have different effects on different groups. Residents of very hot and very cold climates consume more energy for heating and cooling, and thus would be worse off, relative to those in more moderate climates. In some countries, city dwellers can choose less energy-intensive modes of transport than those in the countryside.

Many of these impacts will be reflected in capital costs. Thus, the value of land is likely to rise in temperate climates and to fall in extreme climates. (Similar points can be raised, of course, about the costs imposed by climate change itself.) This capitalization effect has both favourable and unfavourable implications. In the long run, residents of colder climates are likely to consume less heating fuel, but perhaps at a higher price, which would leave them on balance about where they started. Energy prices are likely to rise and land rents to fall, in an almost offsetting way. On the other hand, current owners of land would bear the full brunt of the present discounted value of all future increases in taxes (or the tax-equivalent cost of regulations designed to reduce energy utilization). As a result, unless policy changes are introduced gradually, dramatic changes in land values may occur, with possibly large effects on financial institutions and the economy as a whole. Anticipation of these policies would partially offset these effects.⁵²

National security. Climate change itself may affect the national security of many countries. At the same time, policies to reduce greenhouse emissions may affect the export earnings and therefore the national security of the energy exporting countries.

Although countries may be willing (or forced) to accept changes in national wealth as a result of changes in world prices induced by the response to the threat of global warming, countries are less likely to be willing or able to accept what they may perceive as implied threats to national security over which they have some control. Thus, a country with a large endowment of coal becomes more vulnerable if it comes to rely on imported oil or gas – supplies of which could be cut off in time of war. These countries may feel it imprudent to switch, even if private economic gains were to be had; and they are particularly unlikely to switch if the benefits take the form of an international public good.

Increasing world political stability would clearly address these concerns. But even were that successful, it would not suffice. To increase national security, policies will need to focus on increasing energy efficiency and reducing energy demand. This is an example of the necessity of allowing sufficient flexibility in the design of an international structure for greenhouse gas emissions that the particular circumstances of each country can be appropriately taken into account.

Benchmarks. The earlier discussion of equitable distribution of the burdens of responding to greenhouse gases, employing generally accepted principles of public finance, avoided the concept of benchmarks, that is, setting target emission reductions in relation to past emissions. These have played an important role in international negotiations. Indeed,

the only quantitative target in the FCCC (Article 4.2a and b) requires developed country parties to aim to return their emissions of CO₂ and other greenhouse gases not controlled by the Montreal Protocol to 1990 levels by the year 2000. Although this target suggests equitable treatment, were it to be accepted as legally binding on developed countries without further qualification, it would in fact result in unequal burdens, as it fails to take into account relative incomes and therefore imposes unequal tax rates.

But this criterion can also be criticized as inequitable in a more fundamental sense, since it pays no attention to past efforts at achieving energy efficiency, or to other circumstances that might affect the implied tax rate. For instance, a country that during the preceding ten years had made every effort to increase energy efficiency and switch consumption to less energy-intensive commodities would face the burden of reducing its emissions still further. Because the marginal cost curve for emission reductions rises steeply beyond a certain point, the implied tax rate would be considerably higher than for a country that had previously encouraged overconsumption of energy, for example, by energy subsidies. For the second country, achieving the emission targets might only require elimination of the energy subsidies, a policy with an implied negative tax rate. For a similar reason, countries with large endowments of hydroelectric power may find it relatively difficult to meet an emission target of this form.

Public finance theory has focused extensively on "second-best" policies, recognizing the difficulty of achieving first-best objectives of either economic efficiency or distributive justice. In this context, the central issue is whether alternatives to benchmarking exist. When the U.S. government recently issued tradable emission permits for sulphur dioxide, it took account of emission reductions already achieved. Benchmarking reflects information that would not be reflected in a simple criterion such as a particular emission level per unit population or GDP. Thus, a strong case can be made for including benchmarking, if not in the final allocation of permits (obligations), at least in the transition rules.

1.4.2 Intergenerational equity

Efforts to control greenhouse emissions will provide benefits primarily for our grandchildren and their descendants. We face a difficult task in estimating and judging what aspects of climate and environment they will value and how best to preserve those aspects for them. If we take aggressive action to limit climate change, they may regret that we did not use the funds instead to push ahead development in Africa, to better protect the species against the next retrovirus, or to dispose of nuclear materials safely. Chapter 4 addresses directly the most important issue in intergenerational equity: choice of an appropriate discount rate.

A similar argument applies to actions with differential impacts on different regions. If greenhouse warming turns out to be a major threat to developing countries and if the developed countries fail to reduce emissions aggressively now, the developing countries may suffer additional damage later. Alter-

natively, if the developed countries choose to embark on an aggressive control regime now, and if this cuts into their growth rates, the result will shrink export markets for developing countries and thus reduce growth there. In addition, if developed countries view their greenhouse efforts as, in effect, aid to developing economies, they may cut back on other programmes (sanitation, water, education for women, etc.) that have a more immediate impact on life expectancy, health, and well-being.

1.4.3 Within-country equity

Most discussions of equity and climate change have so far focussed on developed and developing country issues or on issues between one country and another, but issues of equity within a country are also important, and indeed play a central role in the political debates about appropriate responses to climate change. Most policy recommendations involve large within-country losses for certain groups. For instance, any policy leading to less use of coal and lower producer prices for it will lead to large losses for coal mine owners and workers.⁵³

The net efficiency gains (in reduced emissions) relative to the distributive effects may differ markedly across resources. Thus, if the price elasticity of world oil supply is small, a tax on oil will be reflected in the prices received by producers and have little effect on the cumulative consumption of oil, though it may result in some short-run substitution against coal. Policies aimed at bringing closer the date of arrival of substitutes for fossil fuels could lead to an increase in current emissions, though long-run effects on atmospheric concentrations would be positive.

1.5 Economics of Policy Actions

Earlier sections set forth a basic framework for analyzing policies related to global climate change, including a combination of mitigation, adaptation, and possibly climate engineering. Striking the appropriate balance requires taking into account the costs, benefits, and risks associated with each strategy. For instance, setting aside risk, governments should reduce emissions to the point at which a dollar of extra spending would yield a dollar of expected savings from preventing damages imposed by climate change or would save an extra dollar of expected costs of adaptation. Adding risk and sequential decision making complicates the analysis but leaves the basic principles unchanged. Because of the lasting impact of climate change and the magnitude of the resulting economic uncertainties, most policy analysis has focussed on a narrower set of questions:

- (1) What actions would improve economic efficiency (including the social costs of implementing the policy) and reduce net greenhouse gas emissions? How much could emissions be reduced by these means?
- (2) Beyond these zero-cost options, what are the least-cost methods of reducing greenhouse gas emissions? What

do the cost curves look like?⁵⁴ What are the alternative policy measures, and how do they compare?

- (3) What are the essential ingredients of an adaptation strategy, and to what extent will market forces, on their own, provide the appropriate adaptive responses?

1.5.1 Zero-cost options

A variety of inefficiencies in the energy sector – many of them government-induced – would, if eliminated, increase economic efficiency and reduce greenhouse gas emissions at the same time. How large is the reservoir of conservation opportunities? Proponents of the two major approaches to the question have debated this point for more than a decade. *Top-down models* extrapolate observed behaviour into the future. *Bottom-up models* combine cost estimates derived from engineering analyses with economic models of individual choice. Top-down models generally show significant costs to reducing greenhouse emissions in the future.⁵⁵ Bottom-up, or technology-specified models, have been used to show the existence of significant reductions in the cost of energy as new low-emission technologies are adopted. Some proponents of bottom-up models argue that emission reductions can be achieved at essentially no cost.⁵⁶

Much of the disagreement turns on empirical estimates. Economists have catalogued the unintended consequences of government regulation. Many have also identified important market failures that could give rise to inefficiencies within the private sector itself. The next two sections will examine each of these effects.

1.5.2 Policy reform

A variety of government reforms could enhance energy efficiency, including removing energy subsidies, reforming or clarifying property rights, reducing nongreenhouse gas externalities, and administrative reforms.

1.5.2.1 Removing energy subsidies

Energy subsidies induce inefficient energy use, reducing the total output of the economy as well as increasing CO₂ emissions.⁵⁷ Shah and Larsen (1991) estimated world energy subsidies in 1990 to have been \$230 billion. They calculated that their elimination would reduce global carbon emissions by 9½% in addition to improving allocative efficiency and thereby generating a welfare gain in subsidizing countries. Burniaux *et al.* (1992) obtained similar results using the GREEN model, concluding that the elimination of all existing distortions on energy markets would yield an increase in world real income of 0.7% per year in addition to cutting world emissions by 18% in 2050 (Dean, 1994). Agricultural subsidies also distort the outcome, especially by affecting the size of forests.

1.5.2.2 Property rights reform

One responsibility of governments is to define property rights and enforce contracts. Ill-defined property rights encourage overconsumption of resources. A clearer definition of prop-

erty rights could be particularly important in helping to decrease deforestation, for example, while improving economic efficiency. Uncertainties about *future* property rights may also contribute to economic inefficiency. Thus, for example, in those developing countries where large forests are owned by a few large landowners, excessive deforestation may result from the landowners' fear that their tenure will be limited.

1.5.2.3 Administrative reforms

Defining property rights and eliminating energy subsidies are two important actions governments can take to reduce greenhouse emissions. At the same time, many less sweeping reforms can improve economic efficiency and simultaneously reduce greenhouse gas emissions. For example:

Pricing of government-produced electricity. Many governments price electricity not at the market price but at the cost of production. Economists generally recommend that electricity, like any good, be priced not at its cost of production but at the competitive price. In countries with a mix of plants, this means that electricity from all sources should be priced the same – at the highest marginal cost of production.⁵⁸

Land use and other regulation. Changes in land use policy can also reduce energy consumption (especially for transportation, space heating, and air conditioning) and thus greenhouse gas emissions.

Full utilization of nonfossil fuel energy sources (taking account of other environmental impacts). When hydroelectric power generation, which does not increase greenhouse emissions, can be cost-effectively expanded without other environmental effects, it should be done.⁵⁹

1.5.2.4 Regulating nongreenhouse externalities

Many activities producing greenhouse emissions also generate pollution of other types. For example, fossil fuel combustion releases conventional air pollutants; rush hour auto use contributes to road congestion. In the presence of these spillover effects or externalities, market solutions will not properly reflect the externalities generated, leading to the overconsumption of environmental resources. Energy taxes, congestion pricing, or tradable permits can correct these market signals, resulting in lower emissions of both greenhouse gases and other pollutants. Some reforms, such as congestion pricing, also reduce the need for roads and other physical capacity.

1.5.2.5 Special problems of economies in transition

The economies in transition provide special opportunities for mitigating greenhouse emissions. In the former Soviet bloc, high energy subsidies and other price distortions affected energy usage directly, as well as indirectly through the composition of output (i.e., a bias towards heavy industrial production). Spotty environmental regulation meant that Eastern Bloc nations lacked the environmental controls common in the OECD. The capital shortage of the past decade has contributed to the problem through a general deterioration of physical capital stock.

Although these problems are largely of governments' making, the remedy is likely to rely on a combination of public and private actions: effective environmental regulation, elimi-

nation of government-caused price distortions, and an economic environment in which foreign and domestic investment can enhance the efficiency (including energy efficiency) of the economy. For example, many analysts believe that cutting methane leakage from gas pipelines will yield both high economic benefits and cost-effective reductions in greenhouse emissions (IPCC, 1990a).

1.5.2.6 Examples of policies that affect efficiency

Policies that cause individuals not to take into account the full social costs of their actions often result in greater energy use and greenhouse emissions. The National Action Plans of many countries have revealed examples of such policies and have also suggested remedies,⁶⁰ including:

Unit pricing of waste disposal to encourage recycling. The life-cycle social cost of consuming a good includes its costs of production plus disposal. Most consumers, and many businesses, pay a flat fee for trash disposal; with a flat fee, the marginal cost of throwing away an extra pound of trash is zero. By moving from flat fees to unit pricing, the actual price consumers pay to buy and dispose of a good will more closely match its full life-cycle social cost.

Pay-at-the-pump automobile insurance. In most countries, drivers pay automobile insurance yearly or monthly. Once the premium is paid, the marginal insurance cost of driving an extra mile is zero, even though driving more does increase the chance of being in an accident. As an alternative, drivers could be required to pay a portion of their insurance bill at refuelling. With pay-at-the-pump insurance, a tax would be levied on gasoline and earmarked to pay for insurance premiums. This would raise the cost of gasoline at the pump, but lower auto insurance premiums.⁶¹

Eliminating subsidies for auto travel. Many countries subsidize auto travel in various ways. In some industrialized countries, employers may provide parking to employees at no cost or lower-than-market cost, thus lowering the relative price of commuting by car relative to public transportation. A distortion arises when governments tax income spent on public transportation but not income implicit in the parking subsidy.

Eliminating subsidies that increase housing size. In some industrialized countries, home mortgage interest is tax-deductible. In all but a few countries, the implicit income on owner-occupied housing is not taxed. These tax provisions encourage individuals to consume more housing space than they otherwise would. In cold or hot climates, where more housing space requires more energy for heating and cooling, this tax treatment increases CO₂ emissions.

Eliminating subsidies for trucking. Studies suggest that virtually all road damage is caused by heavy trucks, which pay only a portion of the expense of building and maintaining the road system. Many countries thus subsidize trucking compared with rail or barge transport, probably increasing greenhouse emissions.⁶²

1.5.3 Market failures and government responses

Policies exist that would increase economic efficiency at the same time that they reduce greenhouse emissions. For exam-

ple, in some countries, fuel prices do not reflect the full social cost of fuel burning. Taxes can correct this market failure. There is less agreement about whether, *given market prices*, firms fail to take advantage of all the energy efficiency opportunities available to them. This controversy underlies the bottom-up versus top-down controversy treated at greater length in Chapter 8. Engineers have identified a host of seemingly profitable actions that would also save energy. Many economists, however, view this as evidence that the engineering analysis has omitted characteristics important to consumers.

The substantial differences in practices both within and between countries suggest scope for significantly increasing energy efficiency. Moreover, even best practices within a country may not put it at the technological frontier. In deciding whether to adopt a new production process, businesses look only at the private costs and benefits. Many technologists, however, conclude that, even considering private costs only, firms should be undertaking many energy efficiency improvements. This section attempts to reconcile the different schools of thought by reference to information-based market imperfections as well as the criteria by which businesses make decisions.

Information dissemination. Acquiring information is costly. Moreover, providing and disseminating information has many features of a public good (Stiglitz, 1988). In the absence of government intervention, there will be too little production and dissemination of information. This is particularly true for information with widely dispersed impacts, as opposed to information about, for example, the production of certain chemicals, which is primarily of value to a few companies.⁶³

Moreover, both theory and evidence support the view that markets, on their own, do not provide an efficient level of disclosure of information (see, *inter alia*, Stiglitz, 1975a; Grossman and Stiglitz, 1981). Indeed, some evidence indicates that markets may try to obfuscate relevant information.⁶⁴ This provides the rationale for government provision of information, or laws that in many countries require disclosure of interest rates and other consumer-relevant information, including appliance energy consumption.

Bureaucratic structure and limited scope of attention. In recent years, economic and organizational theory⁶⁵ has emphasized that large organizations are not, in general, run by owners; that the managers, even with the best-designed incentives, do not in general maximize the firm's market value; and that among the principal scarce factors within an organization are time and attention. How managers direct their attention has much to do with what the firm does.⁶⁶ The information services and disclosure requirements noted above, as well as a number of other government programmes focusing on energy efficiency in consumer products, electric lights, and motors, help focus management attention on energy efficiency. The marginal managerial time required to make efficient energy decisions may be small, and focussing attention on this issue – when information is being freely provided through government and other sources – may thus yield *private* returns well beyond these slight marginal costs.

Returns to scale and system effects (network externalities). Some technologies might be economically attractive at a large scale of production but not on the much smaller scale on which they might initially be adopted. Other technologies exhibit dynamic scale economies: Unit cost falls over time as a function of the cumulative output of firms or industries. Technology “networks” may also affect diffusion rates. For example, cars and trucks powered by electricity, natural gas, methanol, or other alternative energy sources, require a refuelling infrastructure, which itself competes for resources with the conventional fuel infrastructure already in place.⁶⁷

Building codes can be justified both in terms of these effects on network externalities and in terms of information failures. Consumers often have limited information concerning the construction of their houses, and obtaining the information after the house is completed is often difficult. Even were they to be provided with construction details, they would have difficulty interpreting the implications.

Capital market imperfections. A major explanation of the difference between best-practice and actual-practice technology is that bottom-up models often compute cost-effectiveness using a discount rate substantially lower than the cost of capital calculated by firms.⁶⁸ Studies of implicit discount rates consistently show that households and firms use discount rates substantially above the market rate for long-term government bonds. Two explanations have been offered:

- (1) *Risk:* Interest rates facing firms and households reflect the risk premium that lenders require to compensate them for the probability of default. Firms often use discount rates that include a risk premium to reflect the riskiness of projects.
- (2) *Capital constraints:* Individuals and firms often face rationing in capital markets, both for credit and equity. Recent research has provided a rationale for this rationing based on the fact that information is imperfect and costly.⁶⁹

These capital market problems have one important implication: Models analyzing best-practice, cost-effective technologies using discount rates lower than those typically employed by firms will overestimate the rate of dissemination of these technologies and underestimate the perceived costs (to the firms and households adopting these technologies) of mitigation strategies.

But these capital market problems raise three other questions: (1) Are firms rational in using such high discount rates? (2) Does the use of such high discount rates imply a market failure? (3) If so, will government intervention improve on the market outcome?

Economists emphasize that an analysis of the costs and benefits of a project must separate four issues: timing, risk, capital constraints, and information. Discount rates are only to be used for timing. Risk should be treated by converting costs and benefits into certainty equivalents, then discounting costs and benefits for each year at the relevant discount rate.⁷⁰ Higher risks should not result in higher discount rates.⁷¹ Similarly, capital constraints should be reflected in the shadow price of capital, not in the discount rate.⁷² Because of limited

information (and a version of the “winners’ curse”⁷³) firms often require threshold rates of return significantly greater than the market rate of interest. In doing so, they may confuse time and information risk; that is, the rules of thumb firms use to evaluate investments may sometimes lead to market inefficiencies, including some perhaps in the area of energy-efficient technologies.

Even were firms to follow the economists’ guidelines, in the presence of capital constraints, market outcomes would not, in general, be socially efficient (i.e., they are not constrained to be Pareto optimal). There may be significant discrepancies between social and private returns on investment (even apart from the externalities associated with greenhouse gases or technological diffusion). This provides part of the rationale for possible government interventions in capital markets.⁷⁴ Though these capital market imperfections imply that there is no presumption that market allocations are efficient, there is no consensus that they lead to significant underinvestment in energy-efficient technologies in particular.⁷⁵

1.5.3.1 Revising national accounts

Some have suggested revising the conventional systems of national accounts to incorporate full social pricing of resources. An early contribution suggested a new measure of economic welfare based on consumption that increases quality of life (Nordhaus and Tobin, 1973). These authors and others recognized that national income accounting, widely adopted after World War II, measures aggregate income and expenditure flows but does not incorporate environmental costs and benefits.

Many researchers have noted deficiencies in standard national income accounts. First, national income accounts do not, in general, provide an adequate measure of welfare; second, they do not provide the correct information for making policies relevant to sustainable development. Sustainable development is concerned with society’s resources; an economy is growing when its resource base (capital stock combined with natural resources) is growing. GDP does not, and is not intended to be, a measure of resource availability. Firms have two sets of accounts – cash flow (income) statements and balance sheet statements. GDP is a statement of the former type.

Standard accounting procedures require that firms, in an attempt to present an accurate account of “true income,” take account of depreciation. GDP measures gross output; it does not take into account depreciation, either of natural or physical capital stocks. The reason is simply that it is hard to get accurate measures of depreciation. Net national product, however, does consider depreciation, the change in capital stock. And it is this account that should be most subject to criticism, since it accounts for changes in the physical capital stock but not in other capital assets, in particular, environmental assets and natural resources.

Conventional national income accounting does not fully report three categories of resource expenditures: (a) defensive expenditures, either for pollution prevention before the fact or for cleanup after the fact (although these expenditures are not separately reported, they are counted in GDP); (b) consumption of environmental goods (such as exhaustible resources);⁷⁶

and (c) conflicting uses of environmental services (such as the atmosphere, used by producers as an input into production and by households as a consumption good).

One proposal would include in GDP the effect of changes in quality of the environment. In Eastern Europe and the former Soviet Union, steady increases in reported postwar GDP masked the effects of decades of environmental degradation; for part of that period, environment-adjusted GDP almost certainly declined.⁷⁷

However, important conceptual problems in defining levels and changes of environmental assets, complicate the task of modifying national accounts. First, the stock of natural resources has no obvious definition. Although most geologists would agree on the size of coal stocks – their location is known and their *in situ* value can be estimated – this cannot be said for oil or minerals.⁷⁸ Second, environmental assets, such as air quality, present another set of problems, because no market prices exist to value the asset.

Four approaches are commonly used to calculate changes in the natural environment (Peskin and Lutz, 1990):

- (1) The environmental expenditure approach, used recently in the United States, which subtracts pollution abatement expenditures from GDP;
- (2) The physical accounting approach, used in Norway and France, which establishes satellite accounts using physical units of measurement to account for flows and stocks of resources;
- (3) The depreciation approach, which adjusts gross and net product by subtracting the value of natural resource depletion (Repetto, 1989; El Serafy, 1989); and
- (4) The comprehensive approach, which uses both physical measures and value (United Nations Statistical Office 1992).

Another measure of broad-based welfare, although it does not include environmental amenities, is the UN's human development index or HDI (UNDP, 1992). The HDI gives a composite measure of human development by combining three key indicators: longevity (measured by life expectancy at birth), education (measured by adult literacy and mean years of schooling), and income (real GDP per capita adjusted for purchasing power). Although the HDI is not directly related to global environmental issues, both global warming and abatement policies may affect it.⁷⁹

1.5.4 Innovation

Standard competitive analysis argues that, *given all required information and technology*, market economies produce efficient outcomes. But recent economic analyses have shown that, in general, market economies need not result in the efficient allocation of resources either to information production and dissemination or to innovation. The first of these issues was discussed earlier. The second is more complex.

In the absence of intellectual property rights, firms would have less incentive to innovate. With standard patent terms, firms are not able to appropriate all the returns from their innovative activity. Setting the optimal patent life involves bal-

ancing off the inefficiencies resulting from the exercise of monopoly power during the duration of the patent (static inefficiencies) with the increased incentives for innovation.⁸⁰ Largely because innovators seldom appropriate all the returns from their innovations, there is a general consensus that markets provide insufficient incentives for research and development, and the greater the unrewarded spillovers, the greater the undersupply of innovation.⁸¹ The fact that spillovers are likely to be greater at more basic levels of research suggests a role for government in subsidizing basic and near-basic research. In the same way, the high cost of establishing intellectual property rights impedes the transfer of technology to developing countries.

Still, there is a general consensus among economists that the patent system provides a better basis for financing applied research than do government grants, largely because of the difficulties government has in picking those innovations most likely to produce high returns. Consequently, it should be asked if market failure because of insufficient innovation is more likely than market failure for other reasons. In other words, are there any special grounds for arguing for government research and development subsidies, provided the government has corrected energy prices to reflect the externalities generated? Obviously, in the absence of such corrections, market incentives to provide energy-saving innovations will be distorted, just as market incentives to adopt energy-saving technologies are reduced.⁸² (Tradable permits have effects similar to those of corrective taxes: They encourage firms to place a higher value on new technologies that reduce emissions because reductions will require them to purchase fewer permits.)

Innovation is important, because it provides perhaps the best opportunity for low-cost methods of reducing emissions. Several studies have confirmed the impact of accelerated deployment of advanced energy technologies on the future rate and timing of anthropogenic climate change.⁸³

1.5.5 Carbon taxes and tradable permits

Economic efficiency requires all agents in the economy to pay the full marginal social costs of their actions. But firms and households are not charged for the additional warming potential they add to the atmosphere, and so do not pay the full social costs they impose. Two economic instruments can correct this market failure: carbon taxes and tradable permits. (Note on terminology: More detailed treatments, as in Chapter 11, often reserve the term "emission permits" for domestic instruments and "emission quotas" for international instruments. This section treats the issue of tradable emission rights in a general way, most often using the term "permits"; whether the meaning is domestic or international should be clear from the context.)

Implementing either one of these instruments could raise issues of national sovereignty, because to be effective either carbon taxes or permits would require the creation of institutions with the authority to allocate, administer, and enforce agreements. Although these issues lie outside the immediate concern of economics, they are relevant to any discussion of practical implementation.

A tradable permit scheme involves a determination of the total level of permits and a distribution of the initial allocation, with emission levels for any firm limited to the number of permits held. The initial distribution may be made by an auction or allocation according to benchmarks (e.g., per capita emissions as of a given date), or by historical emission levels ("grandfathering"). Alternatively, emission rights could be grandfathered in at current levels and gradually shifted over to a per capita allocation as of a given date.

Once permits are distributed among the regulated entities, a market is set up, allowing companies to buy and sell permits according to their plants' planned emissions. The cost of production then includes not only the costs of conventional inputs, but also the costs of additional permits to offset additional emissions. Plants whose cost of mitigation is low will find it relatively easier to abate pollution rather than to buy permits. Plants with higher costs of mitigation will have a greater preference for buying permits than for abating pollution. The price of the permits, which are artificially created scarce resources, is determined by the market. With the use of tradable permits, companies have an incentive to improve the efficiency of their production and thereby reduce their emission levels, as they can sell excess permits on the market and generate revenue.⁸⁴

Although permits thus create a marginal cost of production related to the marginal emissions, carbon taxes impose a tax directly on the marginal emissions. Both systems thus force producers and households to face the true social costs of their actions.⁸⁵ In principle, either could be adjusted to achieve the level of emissions desired, although adjustments of this sort may be difficult in practice.

The initial allocation of permits will largely determine the distribution of costs of abatement (Chapter 3 discusses these issues of equity at greater length) and at the same time influence the growth path of participants' economies. For example, an allocation based on population at a given date would provide an incentive for population control.⁸⁶

Imposing carbon taxes can have large distributive consequences. A system of grants can largely offset these distributive consequences, but such offsetting grants might well not be made. Providing tradable permits equal to existing levels of emissions seemingly makes no firm or household a loser. But granting permits in that way effectively represents a grant of money (such permits have monetary value) in a way that may not accord well with standard ethical principles. For instance, by embarking on an ambitious programme to reduce emissions, a firm may qualify for *fewer* permits than it would otherwise. Not only does this violate ordinary notions of fairness, but anticipation of granting permits in this way would, accordingly, have strong adverse effects on emissions.⁸⁷

Although presenting a political impediment to its introduction, the fact that a tax has large distributive consequences is not necessarily an argument against it. Some argue that those who failed to pay the full social costs of their actions earlier are not therefore entitled to special allotments now.

Once it is recognized that the distribution of permits across countries will inevitably be decided by some principle other

than current levels of emissions, then it becomes clear that both taxes and tradable permits will have distributive consequences. An agreement among countries to impose uniform corrective taxes, with each country retaining its own revenue, would have few consequences for redistribution between countries, and the burden of the tax would, as noted earlier, likely be progressive.

Governments in the developed countries might decide to use some of the revenues so generated to encourage activities that benefit less developed countries (such as research and development directed at technology appropriate for developing economies) or to provide other forms of assistance. Decisions about such uses could be made bilaterally or collectively. In contrast, decisions about how tradable permits would be allocated across countries would have to be made multilaterally. Arriving at a formula for distributing these property rights may be far more difficult than arriving at a tax rate and a procedure for its revision, as any such formula may entail substantial redistribution.

1.5.5.1 *A double dividend?*

Many measures that reduce emissions of greenhouse gases also yield other environmental or economic benefits, such as reductions in emissions of other pollutants and energy savings. These are called secondary benefits or double dividends. Some analysts argue that using carbon tax revenues to reduce existing distortionary taxes is an economic double dividend.

Revenues from carbon taxes may allow a reduction in distortionary taxes elsewhere in the economy. If the (compensated) elasticity of demand of labour is relatively high, and the revenues from the carbon tax are used to reduce taxes on labour income, then there would be a double dividend from the carbon tax in the reduced deadweight loss from the labour tax, which would otherwise be significant.

At least three objections have been raised to this idea. First, conceptually, rationalizing the tax system by reducing the most distortionary taxes is certainly a worthy goal but is not equivalent to imposing a carbon tax. Distortions can be reduced without a carbon tax, and a carbon tax could be imposed without reducing the existing distortions. Second, empirically, if the (compensated) labour supply elasticity is relatively low, then the deadweight loss from the labour tax is low, and the commensurate welfare gain is reduced. Third, politically, if carbon tax revenues are used to offset the existing deficit rather than to reduce taxes on labour and capital, then the carbon tax acts more like an ordinary tax increase, increasing distortions from taxation to pay for budget items with a lower return than the extra burden imposed. The gains to total welfare (reductions in deadweight loss) depend on the welfare losses associated with these other distortionary taxes, as well as the cross-elasticities of demand between carbon and other taxed commodities.⁸⁸

Even though carbon taxes may have a positive effect on economic welfare, they can at the same time have a negative effect on *measured* economic growth, since those measures typically do not include the value of environmental degradation. Researchers differ on the size of the loss. The wide

spread in the numerical results, however, should not obscure agreement among researchers on a number of important points. All models used in the major comparison studies to date have projected, first, that intervention would be required to achieve the emission targets; second, that the size of the required tax increases with the stringency of the carbon limit; and third, that the size of the appropriate carbon tax varies over time, even for the same emission or concentration target.⁸⁹

1.5.5.2 Energy taxes

Energy taxes as a means of controlling greenhouse emissions must be viewed as "second-best" taxes, in that they do not directly tax the externality, greenhouse emissions. Whereas carbon taxes directly penalize the externality-generating activity, less targeted alternatives, such as energy taxes, may be politically more acceptable. Carbon taxes reduce emissions, first directly, by moving up the demand curve; second indirectly, by encouraging consumers to switch to less carbon-intensive energy sources. On the other hand, energy taxes work through the first path by reducing total energy consumption. But to the extent that certain kinds of energy, like hydroelectric, have, at least in the short run, a relatively inelastic supply, there will be a major impact on oil, gas, and coal; and to the extent that oil and gas supplies are best described by a model of an exhaustible natural resource, with relatively low extraction costs, most of the supply reduction will occur in coal. Thus, indirectly, there will be a considerable amount of switching, through the indirect effects.

1.5.5.3 Tradable permit markets

In order for systems of emission permits to achieve reductions in emissions efficiently, there needs to be a market for emissions *across international boundaries*. There is some debate about the role of government or international organizations in establishing a market for such emissions. Some believe that there are private incentives for the establishment of markets; others contend that government can play a key market facilitation role through establishing centralized clearinghouses for information or even providing for permit banking (storage) or brokerage (trading) to facilitate trades between private parties. These services would prove especially useful in the more complex international context.

1.5.5.4 Combining taxes with tradable permits

Although carbon taxes and tradable permits are typically presented as alternatives, policymakers may prefer to combine them. The major disadvantage is the additional administrative cost. The advantage is more subtle: The market value of tradable permits is reduced as taxes increase. With an optimal carbon tax, and with a tradable permit supply set equal to the optimally chosen level of emissions, the price of a permit should be zero. More generally, the greater the tax, the less the value of a permit (for a fixed supply of permits), and thus, the less the distributive consequences of alternative rules for allocating the initial endowments of permits. Another possible

combination would utilize permits for large sources and a tax (set to equal the permit price) on small sources.

1.5.5.5 Intertemporal patterns of taxation

If the target is the long-run atmospheric concentrations of greenhouse gases, then climate change damages will be approximately the same for emissions in any particular year, although the optimal carbon tax must be adjusted for differences in costs, discounting, and risk.⁹⁰ The focus on concentrations also implies that early reductions are more valuable than later reductions.

For exhaustible natural resources such as oil, economic efficiency requires that those deposits with the lowest cost of extraction be extracted first. Hotelling (1931) argued that competitive equilibrium implies that rents (price minus costs of extraction) must rise at the rate of interest. The price of the backstop technology (an energy source assumed to be available in unlimited quantities at a certain price after a certain date, such as electricity from solar photovoltaic cells) determines the set of resources to be ultimately exploited, namely, all resources for which the cost of extraction is less than the price implied by the backstop technology's price. Thus, it is the tax on oil or gas at the date of switching to the backstop technology that determines the ultimate amount of oil and gas that will be extracted, and thus the total burden of CO₂ placed on the atmosphere by oil and gas. If that were the only matter of concern, one could simply announce a commitment to impose such a tax sometime in the future when relevant backstop technologies become available and competitive. That announcement would, if believed, have an immediate effect on current prices.

1.5.6 Regulatory approaches

Regulation of greenhouse emissions may take many forms, including fuel restrictions, technology standards, and various economic incentives. Chapter 11 discusses these options in detail. Economists have long argued for the use of economic incentives for environmental management, although governments have so far relied on traditional regulations almost exclusively, as traditional approaches have been more acceptable to the public and industry.

Proponents of the traditional approaches often claim that these approaches "force" technology (i.e., stimulate technological innovation or refinement), with less redistribution than forcing technology through taxes. Thus, if automobile makers are required to attain a certain mileage standard, they will meet the standard; on the other hand, gasoline taxes might have to rise significantly to reduce fuel consumption by the same amount. Evidence for the claim of technology forcing, however, is equivocal. In several cases in which industry failed to meet the applicable standards, regulators withdrew the standard in the face of unacceptably high economic costs. The apparent advantage of technology forcing – one large instrument of coercion instead of the subtle and continuous incentives provided by market forces – is often in fact a disadvantage.

There are other disadvantages to the traditional approach as well. First, traditional regulations do not in general result in economic efficiency, since those in one sector face implicit or explicit incentives at the margin that differ from those in other sectors. Second, traditional regulations fail to account for offsetting private responses that may neutralize the regulation's intended effects and even cause environmental harm. Third, traditional regulations provide no incentives for exceeding the given target, even when doing so might result in little additional cost.⁹¹

Traditional regulations that focus on inputs and technology rather than outputs have the further disadvantage of not directing research toward meeting performance objectives at least cost. For instance, when stack gas scrubbers are required, research will be directed at producing scrubbers at least cost, rather than reducing emissions at least cost. Hence, a dynamic inefficiency is added to the obvious static inefficiencies. Finally, because of the nature of the regulatory process, traditional regulatory designs are more likely to be captured by special interest groups.⁹²

It should be kept in mind that government policies to address external effects (market imperfections) are likely to generate their own external effects, in part because of the difficulty in identifying the gainers and losers from changes in policy. Thus, the likely cost of "market failure" must be compared to the likely costs imposed by governments' attempts to remedy the problem.

1.6 Sustainable Development

The concept of sustainable development was formulated about 1980 as a response to the apparent conflict between environmental concerns and the need for economic growth, especially in developing countries. At the time, preserving biodiversity and maintaining environmental quality seemed incompatible with a five- or tenfold increase in world output, as would be necessary if per capita incomes of the developing countries were eventually to approach those enjoyed by the developed countries now. The sustainable development debate rekindled interest in the question of resource scarcity, originally addressed in the economics literature by Malthus (1798) and revived in the policy arena with the publication of *The Limits to Growth* (Meadows and Meadows, 1972). Recently, the field of "ecological economics" has extended this approach (Howarth and Norgaard, 1992).

A variety of definitions of sustainable development have been proposed. The Brundtland Commission offered this interpretation (World Commission on Environment and Development, 1987):

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Although the Commission clearly had in mind environmental considerations, its report did not spell out exactly what sustainable development included.

1.6.1 The economic concept of sustainable development

Although sustainable development began as an ethical principle, it is at the same time an economic concept, focussing on two issues: (1) intertemporal equity and (2) capital accumulation and substitutability.

Intertemporal equity. Robert Solow's definition of sustainable development (Solow, 1992), which focusses on intertemporal equity, has enjoyed wide currency among economists. Sustainable development, he argues, requires that future generations be able to be at least as well off as current generations. The central implication is that any environmental degradation should be offset by increases in capital stock sufficient to ensure future generations at least the same standard of living. Sustainable development does not preclude the use of exhaustible natural resources but requires that any use be appropriately offset.

In practice, sustainability as defined by Solow provides few constraints on growth paths for the developed countries, so long as steady increases in productivity continue. Technical change alone, without further capital accumulation, may well sustain future living standards and offset any effects of environmental degradation. To see this with a numerical example, note that even if estimates of adaptation costs are taken to be 1-3% of GDP should significant warming occur, and if even moderate rates of technical progress of 1-1.5% per annum continue to occur, then future generations 45 to 70 years from now will have twice the income of the current generation. Even with no discounting, it would be hard on this account alone to justify the sacrifice of further consumption by this generation in order to enhance the standard of living of the future generation.

Capital accumulation and substitutability. To what extent can technology, skills, and capital equipment substitute for a decline in exhaustible resource stocks or a decline in per capita environmental amenities? Solow's definition, in common with much economic theory to date, implicitly assumes that substitutes exist or could be found for all resources. Pearce (1989, 1991) argued that if substitution possibilities are high, as most evidence from economic history indicates, then no single resource is indispensable, and intertemporal equity stands as the only crucial issue. If, on the other hand, human and natural capital are complements or only partial substitutes for each other (e.g., if, because of the irreversibility of extinction,⁹³ capital accumulation is only a partial substitute for biodiversity), then different classes of assets must be treated differently, and some assets are to be preserved at all costs.

Pearce *et al.* (1994) distinguished between strong and weak sustainability. Weak sustainability requires that any depletion of natural capital be offset by increases in human-produced capital – the Solow criterion – or by the substitution of other forms of natural capital, such as renewable assets in place of nonrenewable assets. Strong sustainability requires that some natural capital, being irreplaceable, must be preserved.⁹⁴ It has been argued that there are no close substitutes for the atmosphere and the climate it produces, implying no

substitution possibilities and hence the need to preserve the atmosphere.

1.6.2 Implications of sustainable development for developing countries

In many developing countries, Solow's definition would not be viewed as acceptable, since it seems to place no weight on their aspirations for growth and development. Developing countries have also implicitly criticized the debate over substitutability for the same reason: If some natural assets must be preserved at any cost, then there may be no trade-off with development. Tariq Osman Hyder of Pakistan, a leading spokesman for the G-77 group of developing nations, has emphasized the importance of economic growth in achieving sustainable development:

None of these linked [development] issues can be resolved unless and until there is broad-based development in the South. Only such broad-based development can provide the foundation of international security. The Northern approach is to attack the symptoms, with a residual emphasis on poverty eradication. But the international community must insist on addressing the underlying causes for concern. Development, environmental protection, peace, and security are indivisible. (Hyder, 1992)

Similarly, the G-77 and China emphasized the need for economic growth in the following statement on sustainable development and the environment introduced during the INC-2 negotiations in 1991:

Protection of the global climate against human-induced change should proceed in an integrated manner with economic development in light of the specific conditions of each country, without prejudice to the socioeconomic development of developing countries. Measures to guard against climate change should be integrated into national development programmes, taking into account that environmental standards valid for developed countries may have inappropriate and unwarranted social and economic costs in developing countries. (Hyder, 1992)

Endnotes

1. Some analysts believe that the justification for costly and more restrictive actions rests on intangible costs (Nordhaus, 1993). Intangible refers to the difficulty of measuring; intangible costs are related to such factors as migration, comfort, health, leisure activities, urban infrastructure, and air pollution (Fankhauser, 1994; Cline, 1992). A warmer climate would improve human comfort in cold areas, and in the winter generally, while decreasing comfort in warm areas. Mearns *et al.* (1984) calculate a threefold increase in heat waves for a 1.7°C rise in U.S. mean temperature. It is not yet clear whether net comfort averaged over the globe will rise or fall for a given rise in temperature. Chapter 6 covers these issues in more detail.
2. Both the natural rate of species loss and the human contribution to the process are difficult to estimate (U.S. EPA, 1989). Predicting the effect of climate change on species distribution is more difficult

still. The magnitude and even the sign of these intangibles remains in dispute, for uncertainty about the duration and types of environmental changes that would be caused by climate change makes the long-term projection of species change highly complex. Population pressures have added to pressure on ecosystems, particularly in the Third World. Climate change may exacerbate these damages, particularly in Africa, where environmental degradation has been particularly pronounced during the last fifteen years (UN, 1989).

3. For greater warming – such as might be experienced over the next two centuries, or which could occur sooner if modest near-term warming triggers the release of large amounts of carbon from the biosphere and oceans to the atmosphere – the probability of large losses increases. These losses refer to global losses, which represent an aggregation of individual losses. Impacts will differ across individuals, groups, and regions. For some, the probability of large losses will be high over the next century, despite the expectation that aggregate global losses will be small.

4. Recent ice core data from Greenland point to the occurrence of earlier temperature rises of several degrees within a few decades (IPCC, 1995). Reasons for these sudden changes are still not understood, but might have come from changes in deep ocean currents. The other side of this debate holds that on the whole the biosphere is homeostatic or self-correcting. This “Gaia hypothesis” compares the biosphere to a living being: Once moved away from equilibrium, self-correcting forces naturally move it back to equilibrium (Lovelock, 1979). The two hypotheses are not necessarily inconsistent. Within a range of variation, homeostatic properties could dominate, even if stability were not guaranteed outside that range.

5. A warmer climate might also increase climate variability, though climatologists cannot say with assurance whether climate will become more or less variable daily and seasonally. The normal variability of existing climate also makes it difficult to detect any warming that might be occurring. The “signal-to-noise” problem makes it possible for observers to mistakenly consider a normal extreme event as evidence of a trend or to fail to see a trend in a noisy data series. Because of the signal-to-noise problem, the scientific community is unable to indicate confidently, for example, whether the extremely warm years of the 1980s are evidence of climate change or not (IPCC, 1992; Solow, 1990).

6. Countries make century-long choices implicitly, for example, when they choose population policies, policies affecting long-term capital formation and productivity growth, or policies to protect environmental assets.

7. Bargaining theory has contributed some basic principles, however, such as the importance of threat points (i.e., the outcome in the absence of an agreement).

8. Although the global warming potential (GWP) measure, endorsed by the IPCC, is useful in formulating comprehensive approaches to greenhouse mitigation policies (Stewart and Wiener, 1990), some analysts have recently criticized it on the grounds that GWP implicitly makes the opportunity costs of an increment in radiative forcing equal for all periods in the future (Schmalensee, 1993). If all greenhouse gases had the same rate of decay, then this problem would not arise.

9. Aerosols have very short lifetimes, so their effects are far more regional than those from longer-lived greenhouse gases. It may not be possible to develop an analogue of global warming potential for aerosols.

10. Forests cannot be expanded indefinitely, however. Thus, increased carbon sequestration is not a permanent solution to increasing greenhouse gas emissions.

11. Advances in cost-benefit analysis have allowed the introduction of risk and equity issues in a systematic way.

12. Knight's often-quoted distinction (Knight, 1921) separates risk, for which the probabilities of different outcomes are known, from uncertainty, in which either the probabilities are unknown or some potential outcomes are not specified.

13. This transfer of risk is made easier by dividing the risk into small parts, so that any individual faces only a small risk and thus requires only a small risk premium in compensation.

14. This conclusion assumes decreasing absolute risk aversion (about which there is a general consensus). Even if developing countries were adversely affected, so long as the adverse economic effects were proportionately smaller, then, assuming decreasing relative risk aversion (about which there is less consensus), the developed countries would be in a position to insure the undeveloped.

Insurance contracts may also be created because of differences in judgments concerning the probability of the insured event occurring. This suggests the potential of an important principle to be invoked in future international negotiations or agreements: Countries that believe that the risks of climate change are low, and are therefore seemingly unwilling to take strong actions to mitigate these risks, ought to be willing to provide insurance against climate change at low cost, since it has, from their perspective, an actuarially low value (Chichilnisky and Heal, 1993), although enforcement issues may complicate the problem.

Insurance markets, if appropriately designed, have one further advantage: They encourage actions that diminish the potential size of any loss, because insurance firms have an interest in minimizing the cost of losses. Some of the losses associated with climate change can be easily avoided or reduced (e.g., by making ocean-front houses more durable to reduce vulnerability to storm damage). In designing insurance for climate change risks, either the insurance should be based on exogenous events (e.g., not on the dollar losses incurred, but on the rise in sea level), or the insurance companies should be given broad discretion to require the insured to undertake actions to mitigate losses.

15. Chapter 6 provides estimates of expected regional damage.

16. In the absence of such requirements, moral hazard problems arise. It may be desirable to focus government intervention not on the primary insurance market but on the reinsurance market. See recent U.S. government analyses of failures in insurance markets for natural disasters and the design of appropriate responses to these.

17. Computer modellers participating in the Energy Modeling Forum (EMF) examined an "accelerated R&D" scenario in which the cost of nonelectric backstop falls from \$100 to \$50 per barrel of oil equivalent, and the cost of the electric backstop falls from 75 to 50 mills per kWh. The four models used were remarkably consistent in their estimates of economy-wide costs, reporting GDP losses falling by 65% for the 20% emission reduction scenario (EMF, 1993).

18. Weitzman *et al.* (1981), cited in Lind (1994), make these points in formulating a sequential decision strategy for developing synthetic fuels.

19. Manne and Richels (1992), Nordhaus (1993), and Peck and Teisberg (1993) all report a high value for better scientific information on

climate change, including the cost and timing of new supply and conservation strategies.

20. Richels and Edmonds (1993) provide a demonstration of this proposition; they calculate relatively low costs for stabilizing CO₂ concentrations if flexibility in timing is allowed, compared to capping and stabilizing emissions to achieve the same atmospheric concentration.

21. Alternatively, the Kaya identity may be written

$$\text{Growth rate of CO}_2 \text{ emissions} = \text{growth rate of output} - \text{decline in energy intensity per unit output} - \text{emissions per unit of energy use}$$

That is, CO₂ emissions will not rise as long as output grows no faster than the combined decline in energy intensity per unit of production and CO₂ emissions per unit of energy use. This formulation applies most usefully to the developed countries.

22. Chapter 8, Estimating the Costs of Mitigating Greenhouse Gases, treats the important issue of inertia and technology.

23. Note that energy-efficient development paths for developing countries have been proposed (Goldemberg *et al.*, 1988).

24. That is, for conventional exhaustible resources, there is a stock, *S*. Welfare depends on flows out of the stock each year:

$$U(S_1 - S_0, S_2 - S_1, \dots, S_{t+1} - S_t, \dots)$$

where *U* is utility or welfare, and *S_t* is the stock at the end of period *t*.

In the case of climate change, welfare depends *directly* only on the stock of carbon in the atmosphere, though indirectly also on emissions, through the consumption of goods.

$$U(S_0, C_1(S_1 - S_0), S_1, C_2(S_2 - S_1), \dots, S_t, C_t(S_{t+1} - S_t), \dots)$$

25. Even when the flow exceeds the long-run sustainable level, it will not be optimal to reduce the flow instantaneously, unless there are zero costs of adjustment. For the atmosphere, a sustainable stock of greenhouse gases means stable concentrations. Current emissions are estimated to be at about twice the level consistent with stable concentrations.

26. Postponing action may lead to some irreversible damages, such as the flooding of low-lying states.

27. As noted, this is a simplification. Recent literature in resource economics often treats fossil fuels as depletable rather than exhaustible; that is, price affects incentives for exploration, and some marginal wells would not be drilled if oil prices fell too low. It is also a simplification to treat coal reserves as inexhaustible. With the more realistic assumptions of a steeply rising supply curve for oil and gas reserves (over the next century or two) and a rather flat supply curve for coal, the results quoted still hold.

28. Energy economic models often use the assumption that alternative sources of energy will become available at some future date from nonfossil (noncarbon-emitting) sources. The means to supply this energy is often called *backstop technology*. The modeller must specify the quantity, cost, and date of availability of the backstop technology.

29. For analyses of market and optimal responses to uncertainty about the arrival of backstop technologies, see Dasgupta, Gilbert, and Stiglitz (1979) and Dasgupta and Stiglitz (1981).

30. For counterexamples to the received wisdom, see Coase (1960).

31. Formally, if A measures the quality of the atmosphere, then each individual's or country's welfare, U^i , is a function of its own consumption, C^i , and the shared public good, A : $U^i(C^i, A)$. This does not mean that value changes in A are the same for all individuals and countries; that is $(\partial U^i / \partial C^i) / (\partial U^i / \partial A)$ may differ in magnitude, and even in sign.

32. Although there may also be trade-offs. Reductions in gases that contribute most to local pollution may sometimes be achieved at the expense of increased emissions of greenhouse gases.

33. This kind of optimization problem was first studied by Edgeworth (1881). The importance of incentive effects for the analysis of distributional issues was first emphasized by Mirrlees (1971). There are, obviously, important incentive effects: If the less developed countries were able to classify any expenditure that had some effect on mitigation as a mitigation expenditure, with the cost borne by the developed countries, they would have an incentive to undertake excess expenditures of this type. The GEF (Global Environmental Facility) directly addresses this issue by providing funds only for incremental costs, that is, those costs that go beyond what would have been the efficient level of expenditures if the public good benefits of greenhouse gas mitigation were ignored.

34. The importance of the assumption that bargaining or transaction costs are absent (and perfect information is present) has only gradually come to be recognized. See Stiglitz (1988) for an elementary textbook treatment.

35. For instance, it makes no difference whether smokers or non-smokers are given the property rights to air. Rather, it is whether smokers value smoking more or less than nonsmokers value clean air that will determine whether smoking occurs. How property rights are assigned *does* make an important difference for the distribution of welfare. Coase's conclusion that outcomes are unrelated to the initial assignment of property rights obviously ignores potentially important income effects.

A slight extension of this perspective says that social scientists should simply *describe* the outcome of the bargaining process by which property rights are assigned. Beginning with the important work of Nash (1955), a variety of bargaining theories has been developed, most of which emphasize the importance of "threat points" – the outcomes which arise in the absence of a bargaining agreement – to the determination of the eventual outcome. In this case, the fact that the net losses of many developed countries may be limited relative to those of many of the less developed countries suggests a bargaining solution in which much more of the costs of mitigation are borne by the less developed countries than under the "social welfare function" allocations described earlier.

36. In the case of small taxes, these are "compensated" taxes and have no welfare effect, though they have a substitution effect, and therefore do reduce pollution.

37. The loss in welfare (ignoring the benefits from reduced greenhouse gas warming) are the Harberger triangles, and can thus be shown to be proportional to the product of the elasticity of demand for energy and the share of energy in national output. Since poorer countries are likely to have less access to alternatives that increase the elasticity of demand, and since the share of energy is larger in richer countries, the burden of the tax is progressive.

38. The *polluter-pays principle* endorsed by the OECD is exclusively prospective.

39. Many have challenged the ethical basis for assigning responsibility based on past damages. Using either an egalitarian social welfare function approach or a Rawlsian "behind the veil of ignorance" analysis (Rawls 1971) leads to the rejection of the polluter-pays principle. Since at the time the relevant actions are taken, the polluter is not cognizant of the effects, such fees have no incentive effects, but rather appear as random taxes, lowering each person's expected utility, and in particular the expected utility of the worst-off individual.

There is a further ethical issue: It is generally difficult to ascertain who actually benefits from escaping the obligation of paying for the pollution. It need not be the individual, firm, or country actually engaging in the pollution-generating activity. In competitive markets, when firms are not charged the full social costs of production, product prices will fall, giving consumers a substantial fraction of the benefits.

40. Manne and Richels (1992) show that, under the IPCC emission scenarios, even the most drastic controls on emissions from developed countries would be insufficient to stabilize greenhouse gas concentrations without some means of controlling emissions from developing countries.

41. Public goods exist when property rights are not or cannot be clearly assigned. The atmosphere is an international public good because assigning property rights to the atmosphere is difficult for one nation acting alone, and particularly difficult when many sovereign states must agree among themselves. Tradable greenhouse emission permits, discussed below, attempt to resolve the problem by explicitly assigning property rights to greenhouse emissions.

42. Coase's discussion of externalities (1960), emphasized the separability of efficiency and equity issues. Though there have been several important qualifications to Coase's conjecture, emphasizing the importance of public goods, imperfect information, and transaction costs, the basic insight still remains applicable here.

43. Chapter 7 discusses this issue at greater length.

44. These concerns are not just theoretical possibilities, as the following two examples illustrate. Assume that the developed countries impose high energy taxes, but the developing countries fail to do so. Energy-intensive industries, such as aluminum, migrate from the developed to the developing countries. But energy efficiency in the developing countries is much less than in the industrialized countries, so the total energy used to produce a tonne of aluminum could increase substantially. Although economic efficiency would call for locating energy intensive industries where energy efficiency is greatest, a system of partial controls would result in energy-intensive industries being located where energy efficiency is lowest. Similarly, the reduced energy consumption by the developed countries will result in lower *producer* prices of oil and gas, leading to increased consumption of energy in the developing world, partially offsetting any energy conservation induced in the industrialized countries.

45. The precise manner in which this should be done is a technical matter, treated in the literature on Global Warming Potential (see, e.g., IPCC, 1990a, 1995). To the extent that there are large differences in atmospheric lifetimes, then the relative weighting of different greenhouse gases should change over time, since the "shadow price" associated with effects on relative concentrations at different dates will differ.

46. Similarly, if the developed countries restrict forest cutting, the price of lumber may rise, inducing the developing countries to cut

down more of their own trees. Thus, total global carbon sequestration may not increase. Furthermore, if hardwood forests in the less developed countries are the least desirable ones to cut down from an ecological or economic perspective, as some researchers have concluded, then environmental and economic efficiency will decrease if these forests are exploited more intensively (Edmonds and Reilly, 1983).

47. Only a few models take into account international capital flows. Thus, most models do not address issues of industry relocation (McKibben and Wilcoxon, 1992). It is also doubtful whether computed general equilibrium models can realistically represent capital relocation from one country to another. Chapter 11 provides a more complete discussion of leakages.

48. In the case of production of highly substitutable commodities, carbon leakage will be much greater.

49. Whether taxes, in fact, have this effect depends in part on the shape of the demand curves. With intertemporal separability in demand curves, constant elasticity, and no backstop technology, a constant ad valorem tax has no effect on the pattern of consumption.

Coal presents markedly different issues, not so much because of its greater emissions per unit energy, but because of its higher cost of extraction-to-price ratio. Lowering producer prices may result in less coal being consumed, provided alternative energy sources become available. Thus, taxes on coal are likely to have significant general equilibrium as well as partial equilibrium effects; the increase in the price of coal will lead to a substitution of gas and oil. If alternative energy sources are not available, such policies will only affect the intertemporal timing of coal consumption (given the much more limited resources of gas and oil). But even that might be of some value in reducing long-run greenhouse gas emissions, as the ability to extract energy from coal may increase significantly over time. Analyzing the optimal intertemporal structure of taxes to minimize long-run ambient levels of greenhouse gases, taking into account both intertemporal substitution and substitution across energy sources, is a complicated technical issue that to date has not been adequately analyzed.

50. United Nations Conference on Environment and Development, Framework Convention on Climate Change, May 9, 1992.

51. The most difficult problem is posed by investors who invested in these resources under a previous regime (where these resources were not taxed). Do they have any special claim to compensation for a "change in regime." Changes in demands and supplies occur for virtually all resources and are an inevitable part of the risks in investing. Most economists would argue that arbitrary and capricious changes in policies contribute to business uncertainty, and therefore have an adverse effect on economic growth, but reasoned changes in policies in response to changes in information are an inevitable part of business risk.

52. For example, some electric utilities in the U.S. are already making decisions in anticipation of some future policies to limit greenhouse emissions.

53. These issues also arise among countries. Countries with large coal deposits will find the value of their natural wealth eroded and, quite naturally, will be less enthusiastic about international agreements that reduce coal use or lower producer prices.

54. Studies show variation in GDP losses across models. For example, it is estimated that stabilizing emissions at their 1990 levels would reduce U.S. GDP by 0.2% to 0.8% in the year 2010 – roughly

a \$20 billion to \$80 billion loss for that year. Estimates of the costs of reducing emissions by 20% below 1990 levels in the year 2010 range from 0.9% to 1.7% of GDP. Aggregated models (top-down) have generally reported higher costs, whereas disaggregated models (bottom-up) have shown lower costs. Chapter 9 contains a more complete discussion.

These GDP losses occur when carbon taxes lead to investments that are more expensive than those that would take place in the absence of the taxes. The higher the carbon taxes, the greater the investment in price-induced conservation and the greater the extent of fuel switching toward less carbon-intensive substitutes.

The overall impact of a carbon tax will depend not only on the size of the tax but also on the uses to which the revenues are put. In the standard Energy Modeling Forum (EMF) scenarios, it was assumed that tax revenues would be redistributed in a neutral manner (i.e., without affecting the marginal tax rates). There are, of course, numerous ways in which tax revenues can be used. These include reducing budget deficits; reducing marginal rates of income, payroll, corporate, or other taxes; granting tax incentives to preferred activities; or increasing the level of government expenditures. The costs of the tax will vary widely depending on how the revenues are recycled. 55. Top-down models estimate that for developing countries there exist low-cost options for reducing emissions in the near term, but eventually costs would exceed 1% to 2% of GDP (EMF, 1993). For economies in transition, because of historical inefficiencies and energy subsidies, there exist large opportunities to reduce emissions at little or no cost. For developing countries, problems of informal economies make hard estimates difficult, but the cost of stabilizing emissions would likely be large enough to cut into economic growth.

56. Recent comparisons indicate that the most important differences between top-down and bottom-up models arise from differences in input parameters rather than from differences in model structure.

57. Government institutions and regulations often hinder the efficient use of energy. Developing countries are least able to absorb the costs of these inefficiencies. Thus, although some developing countries argue that they cannot afford to reduce greenhouse emissions, or cannot eliminate the subsidies to poor people implicit in below-market energy prices, the same countries often have the most to gain from reforming government-caused inefficiencies. At least in the short run, international agreements committing countries to eliminate at least the most egregious of these practices might go a long way to addressing the problem of emission reductions.

58. This may also be a problem with electricity generated by the private sector, as regulation has historically set price equal to average cost, rather than allowing it to match the competitive price. In many countries, the increase of competitive pressures has moved electricity prices closer to the marginal cost of production.

59. Further examples include:

Eliminating regulations impeding efficient energy utilization. Many, perhaps most, countries have a host of regulations that increase energy use as they impede economic efficiency. For instance, the U.S. has had a policy of restricting oil exports from Alaska. Whatever the merits of that policy, it has forced Japan to import oil from Indonesia and Saudi Arabia. World oil transportation costs have thus been greatly increased at the expense of the American economy. Another example of government reform, included in the U.S. Action Plan (Clinton and Gore, 1993), encourages efforts to expand and im-

prove natural gas markets through continued regulatory reform. These reform efforts include guidelines to allow greater natural gas use in the summer in coal- and oil-fired power plants.

Other regulation. Unintended effects of many tax, expenditure, and other policies have contributed further to inefficiencies in land use. Among the unfortunate effects of the U.S. Superfund programme for the management of hazardous wastes, for example, has been the creation of large unoccupied holes in the centres of major cities.

60. In actual practice, some of these proposals would likely present practical obstacles, including the cost of implementation.

61. Pay-at-the-pump insurance also has several potential drawbacks. For example, most such proposals fail to link the factors that most influence insurance rates (driver history, vehicle location, vehicle repair costs) with actual insurance payments.

62. Consider the following thought experiment: Compare an optimally designed road system that only carries cars with an optimally designed road system that also carries trucks. The incremental cost of carrying trucks is, in most countries, much larger than the proportionate share of the cost they bear in fuel taxes and other fees.

63. For example, in many countries, governments have taken an active role in the dissemination of information to the agriculture sector. These programmes are in some measure responsible for the large increase in agricultural productivity in countries with agricultural extension services.

64. This is because those who would be at a competitive disadvantage under "true" disclosure have an incentive to add "noise" and because there are strong market forces for product differentiation. In markets with homogeneous commodities, profits will be driven to zero (in Bertrand competition), even with a limited number of suppliers. For a discussion of these and related issues, see Salop (1977), Salop and Stiglitz (1977, 1982), and Stiglitz (1988).

65. The standard reference in the organizational literature is March and Simon (1958). Economic theories emphasizing the nonvalue maximizing behaviour of managers include those of Baumol (1959) and Marris (1964). The principal agent literature (Ross, 1973; Stiglitz, 1974) provided the informational microfoundations for understanding the divergences of interests. See Stiglitz (1988). A more recent overview is provided by Stiglitz (1991) and the symposium in the *Journal of Economic Perspectives*, Spring 1991.

66. The facts that time is a scarce commodity and that decision making in large organizations is decentralized do not in themselves constitute a market failure; they do not prove that resources are not efficiently allocated, given the real constraints facing society, which include time. However, Greenwald and Stiglitz (1984, 1988) have established a very general theorem showing that when information is imperfect and costly, market equilibrium is, in general, not Pareto efficient. Thus, there is no presumption concerning the efficiency of the market economy, even in the absence of the kinds of externality and public goods problems that are associated with greenhouse gases. For a more extended discussion, see Stiglitz (1994).

Recent advances in the economics of information have provided sounder microfoundations for these theories of the firm. And indeed, the importance of the limitations on the availability of information, and the consequent importance of attention-directing efforts, applies to individuals as well as to organizations. Some studies have suggested that the limited success of the special tax provisions in the U.S. designed to encourage savings (IRA accounts) was primarily

due to the competitive efforts of banks to recruit these accounts and the attention that savings got as a result.

67. Network externalities are manifested in other ways. Builders fail to install energy-efficient light bulbs, because customers dislike them and stores do not carry replacements; and stores do not carry them because the demand for them is too low.

When there are important network externalities, market equilibria are frequently inefficient. The economy might, for instance, get "stuck" in the wrong equilibrium. Government action can, in these instances, "force" the economy to move from one equilibrium to another.

68. This is not the only explanation of differences between bottom-up and top-down models. There are several other features of market behaviour that bottom-up models often ignore.

(a) *Hidden costs:* Consumers value a range of attributes difficult to include in an engineering model. For example, auto buyers value not only initial costs and fuel economy (which computer models can easily calculate) but also performance, safety, and durability, which they typically do not.

(b) *Divergence between laboratory and in-use performance:* Especially for new technologies, actual energy use often differs significantly from energy use calculated in the laboratory. It is the latter on which purchasers focus.

(c) *Variation across individual consumers:* Engineering models generally assume an average consumer, but actual consumers may display a wide range of characteristics and usage patterns. Except when demand functions are linear in the relevant variables, the consumption of the "average" individual is not equal to the average consumption, and what is optimal for the average person may not be optimal for a significant fraction of the population.

69. For a survey, see Jaffee and Stiglitz (1990). The basic theory of credit rationing was developed in Stiglitz and Weiss (1981), and the theory of credit rationing is further developed in Greenwald *et al.* (1984) and Myers and Maljuf (1984).

70. This generally accepted methodology is, for instance, reflected in the guidelines issued by the Office of Management and Budget in the U.S. for the evaluation of projects and regulations. The applied literature does not address the question of whether this procedure is appropriate in the presence of certain types of time and risk nonseparabilities.

71. Though if the variance of the net benefits is increasing over time in a particular manner, the differences in the two methodologies may not be large.

72. Again, under certain restrictive conditions, where the shadow value of a capital constraint is changing systematically over time, the differences in the two methodologies may not be great.

73. See Wilson (1977). The "winner's curse" describes the tendency for the winner of an auction to fail to realize a competitive return; that is, in retrospect, to have paid too much. Though the original discussion of winner's curse focussed on bidding in auctions, it has subsequently come to be applied to a range of other market phenomena.

74. For a discussion of the role of the state in capital markets, see Stiglitz (1994).

75. In some industrialized countries, energy-efficient home mortgage lending may help correct the problem. Lenders generally set criteria for the maximum loan amount based on the borrowers' ability to repay, which, in turn, depends on income and wealth. The fact

that a particular expenditure would enhance efficiency and reduce utility bills is not given special attention. Energy-efficient mortgages provide funds to households to make energy efficiency-enhancing investments that are intended to pay for themselves by reducing utility bills by an amount equal to or greater than the interest payments. With capital constraints, builders may have an incentive to trade off initial capital costs for higher maintenance costs (lower energy efficiency). Building codes specifying minimal levels of energy efficiency and full disclosure of expected life-cycle energy costs may help address these market distortions.

76. A country that rapidly depletes its natural resources may show a high rate of growth under conventional income accounting, but a lower rate of growth when resource depletion is taken into account. Repetto (1989, 1991) calculated resource-adjusted GDP for several countries that were rapidly harvesting their stocks of hardwoods and other resources, arguing that conventional measures sharply overstated GDP.

77. Daley and Cobb (1989) have even claimed that U.S. per capita GDP, when adjusted for environmental damage, was stagnant between 1950 and 1986. This assertion is hard to reconcile with the steady improvement in most measures of environmental quality since 1970, when measurement standards were established.

78. Analysts now use two methods to estimate stocks. The first assumes a fixed stock of a natural resource such as oil. Consumption of oil then depletes the stock by the amount of consumption. The second begins by treating discovered reserves as the asset. Thus, additions to reserves increase the asset, while consumption reduces it. If in any given year, new discoveries match resource utilization, then according to this method no net depletion has occurred.

79. A number of difficult conceptual problems face the analyst defining levels and changes in levels of these assets.

First, how should the "stock" of natural resources be defined? Coal poses perhaps the easiest situation. The location of coal reserves is known. Costs of extraction are high, so the rents (the value of coal *in situ*) are low. The depletion can be measured not by the coal used times the market price, but the coal used times the *in situ* value. But for oil and other minerals, information about where reserves are located is vital. Two models have been proposed. One sees the world as having a fixed stock of natural resources (say oil). When one uses oil, one is depleting this stock. Thus, to calculate the value of depletion, one does not need to know the entire stock; the flow (the amount of oil consumed) provides an accurate measure of the change in stock.

The alternative model looks at the size of discovered reserves. Reserves are treated as the asset. Additions to reserves thus are viewed as increasing the resource base. If, in any given year, new discoveries match resource utilization, then there is no net depletion. This is the approach being taken by the U.S. Department of Commerce. This accounting framework would be correct if there were an infinite supply of the resource (reflected in zero rents). The essential "capital" good is information about where the resource is located.

Environmental assets – such as air quality – present another set of problems, because there are no market prices to value the asset. Dynamic optimization problems of the kind described earlier can be used to calculate shadow prices. How sensitive these shadow prices are to specific assumptions remains to be investigated.

Accounting systems do not, however, have to aggregate all information together. Just as information about longevity and other indi-

cators of well-being (see below) serve to complement information from national income accounts concerning standards of living, so too can information about *physical* environmental measures be used to complement information from the extended national income accounts.

80. There is some concern that excessively broad and long patents may actually impede innovation. When technological progress occurs by building on previous innovations, later innovators require the permission of earlier innovators to realize the returns on their innovation. Although advocates of broad patent coverage argue that the parties always arrive at efficient bargaining solutions, critics point out that the outcomes of bargaining models with incomplete information often entail large inefficiencies.

81. Matters are more complicated, since the patent does not reward the innovator with his marginal contribution – the increase in the present discounted value of benefits as a result of the innovation occurring earlier than it otherwise would have occurred. For a fuller discussion, see Stiglitz (1994) and Dasgupta and Stiglitz (1980).

82. If less developed countries fail to implement fully a set of corrective taxes or tradable permits, or if less developed countries fail to adopt and effectively enforce intellectual property rights, there will be insufficient incentives to produce energy- and emission-saving innovations, particularly those appropriate for the level of technological knowledge, human capital, and factor prices in those countries. If less developed countries do take these actions, there is concern that they will result in higher prices for innovations, and thus the pace of adoption will be retarded. An effective form of aid, targeted to reducing greenhouse gas emissions, might take the form of subsidies directed at producing appropriate energy-saving and emission-reducing technologies for LDCs.

83. Edmonds *et al.* (1994) have studied the importance of available advanced energy technologies such as those proposed by Johannson, *et al.* (1993). Edmonds *et al.* use the Edmonds-Reilly-Barnes model for energy-related greenhouse gas emissions; the MAGICC model for atmospheric composition, climate response, and sea level rise; the IPCC scenario IS92a (IPCC, 1992) as the reference base case, and five alternative energy scenarios that are far more advanced than today's energy supply and transformation technologies. The five energy scenarios are:

- advanced fossil fuel technologies
- advanced liquefied hydrogen fuel cells
- advanced hydrogen fuel cells without liquefied hydrogen
- low-cost biomass
- accelerated rate of exogenous end-use energy intensity improvement

Combined, the energy technologies reduce annual emissions from fossil fuel use to levels that stabilize atmospheric concentrations below 550 ppmv (i.e., double the concentration prior to the Industrial Revolution). The tax rate used, which was assumed to apply globally, was the marginal cost of stabilizing fossil fuel carbon emissions in the reference case. With values reflected for only carbon dioxide emission reductions, the estimated cost of global emission reductions grew from approximately \$35 (U.S.) billion in 2005 to \$230 (U.S.) billion per year in the year 2095. With advanced fossil fuels, low-cost solar electric power, low-cost fuel cell vehicles, the present discounted value of adding low-cost biomass fuel to the energy tech-

nology bundle is almost half a trillion dollars (U.S.). The present discounted value of the advanced energy technologies taken together is \$1.8 trillion (U.S.).

The introduction of advanced biomass energy production technology was found to play a key role in reducing emissions. Biomass energy at \$2.00/GJ, growing to become the core energy supply technology by 2050, could significantly reduce emissions. This possibility highlights the potential role of technology development and deployment relative to that of fiscal and regulatory intervention.

These results should be viewed as illustrative rather than predictive. In this analysis, the gains from introduction and deployment of advanced energy technologies depend on the sequence of technologies evaluated in the study.

84. The literature has identified three types of permit systems. The ambient permit system (APS) works on the basis of permits defined according to exposure at the receptor points. Each polluter, then, may face quite complex markets – different permit markets according to different receptor points, and hence different prices. The simpler emission permit system (EPS) issues permits on the basis of source emissions and ignores what effects those emissions have on the receptor points. Within a given region or zone, the polluter would have only one market to deal with and one price. Finally, there is the pollution offset (PO) system, wherein the permits are defined in terms of emissions and trade takes place within a defined zone. However, the standard has to be met at all receptor points. The exchange value of the permits is then determined by the effects of the pollutants at the receptor points. The PO system thus combines characteristics of the EPS and the APS (Pearce and Turner, 1990). These distinctions are of limited relevance for greenhouse gases, where what is of concern is global emission levels. The specific location of the emissions is of no concern.

85. The choice between taxes and tradable permits depends on the objectives of the policymaker and the nature of the uncertainty about the marginal cost and marginal benefit curves for carbon emission reductions (Weitzman, 1974). Theory tells us that if the nature of the curves is known with very little certainty, but the marginal cost curve is known to be relatively steeper (i.e., a change in the level of pollution allowed brings about a greater change in the marginal costs of mitigation than in the marginal benefits) then taxes should be the policy of choice. This is because, in this case, an erroneous estimation of the optimal tax rate will lead to a relatively small deviation from the optimal pollution level. On the other hand, an erroneous estimation of the optimal level of total emissions in a permit scheme will lead to a relatively large deviation from the optimal cost of the permits.

If the marginal benefit curve is known to be relatively steeper than the marginal cost curve, however, tradable permits are the better option. Here, an erroneous estimation of the optimal tax rate will lead to a relatively large deviation from the optimal level of emissions, whereas an erroneous estimation of the optimal level of emissions in a permit strategy will lead to a relatively small deviation from the optimal cost of the permits.

In the case of greenhouse gas emissions, the time horizon for adjustment is sufficiently long that many of these uncertainties become less important. If the tax rate initially chosen yields too high a level of emissions in one year, it can be increased, and the net impact of the erroneous initial estimate on global warming (or the total cost of achieving a given level of atmospheric concentration) will be negli-

gible. In any case, as the earlier discussion of sequential decision making has emphasized, there is likely to be a need for continued revisions in either tax rates or permit levels.

Still, there is some argument that the required adjustments under a permit scheme may be less burdensome (Tietenberg, 1992). For instance, if the authority feels that the old standard needs some tightening it may enter the market itself and buy some of the permits, holding them out of the market.

There must be effective, competitive markets in tradable permits if such schemes are to achieve efficient outcomes. There are transaction costs of running such schemes, just as there are transaction costs associated with collecting tax revenues. Whether transaction costs give one system a decided advantage over the other is not clear. There seems to be no compelling reason to believe that good markets in tradable permits would not develop.

86. It is possible to design allocations of trading permits that (a) on average, impose no net burden on developing countries (thus conforming to the ability to pay principle); (b) provide those economies that are growing faster per capita with commensurately greater permits, thus imposing no net drag on economic growth, provided the economy exhibits an increase in fuel efficiency at least equal to the average of fast-growing, less-developed countries; and (c) rewards those economies that are able to reduce greenhouse gas emissions faster than benchmark rates, either through greater control of population growth, larger increases in energy efficiency, or switching from higher- to lower-carbon fuels.

The extent to which individual circumstances of countries should be taken into account in setting benchmarks remains a question for international negotiations. To the extent that high emissions are due to natural endowments (e.g., the availability of coal rather than natural gas as a source of energy), a persuasive case can be made for benchmarks to reflect initial emission levels. To the extent that high emissions are due to inappropriate energy pricing policies, the case that benchmarks should reflect initial emission levels is far more tenuous.

87. Similarly, some developing countries have asked, should the developed countries be given higher levels of permits, simply because they have, in the past, been the chief source of greenhouse gases?

88. Standard tradable permit schemes essentially take the revenue from a carbon tax and distribute it to current user emitters, rather than using the revenue to reduce other taxes. An alternative to these standard schemes is for the government to auction off the tradable permits.

If taxing carbon leads to reduced labour supply or reduced savings, then government revenues from wage or capital taxes may be reduced, more than offsetting the direct revenue gain from the carbon tax. Cross-elasticities of this magnitude are unlikely, though any such cross-elasticity will reduce the net gain from the carbon tax. The magnitude of the double dividend has been the subject of some dispute, with Goulder (1994) and Repetto *et al.* (1992) taking opposite views.

89. Two main studies provide insights into the root of the variance in estimates of the economic effects of carbon taxes: the Energy Modeling Forum Study-12 and the OECD comparison project. In each case, sophisticated sensitivity analyses were run by standardizing key economic assumptions and using these in conjunction with common reference-case scenarios of reductions. The magnitude of the effect on economic growth in these studies depends both on

assumptions concerning the effect of carbon taxes on savings and labour supply, and the induced investment to offset the higher energy prices. If higher energy prices do not lead to much capital substitution, and if the cross-elasticity with savings and labour is low, then the likely effect on economic growth will be small.

The OECD model comparison project was conducted to compare economy-wide estimates of the effects of carbon taxes. Time horizons as well as the key economic assumptions on growth, population, and resource prices, and the reduction scenarios for six global models were standardized. The global models compared were the GREEN model, the IEA model, and four North American models (the Edmonds-Reilly Model (ERM), the Global 2100 model of Manne and Richels (MR), Rutherford's Carbon Rights Trade Model (CRTM), and the Whalley-Wigle model) (Dean, 1994).

Because of differing assumptions about several key considerations, the models showed significant variation in tax rates and costs for the same amount of emission reduction. Several factors explain the differences between model results. The most important factors are:

- the degree of substitution between fuels – the ease with which producers and consumers can switch from high-carbon-content fuels to low-carbon-content fuels
- expectations about future energy prices and taxes
- the speed of emission reduction
- the way in which revenue is recycled
- the treatment of the removal of energy subsidies
- assumptions regarding backstop technology and a host of other technical and economic factors

Because of the varying approaches to these questions, the range of estimated tax rates and costs is quite wide. For a 45% reduction in baseline emissions by 2020, the required tax would be in the range of \$150–325 per tonne of carbon and the cost might be in the range of 1.5–2.9% of world GDP. A 70% reduction in baseline emissions by 2050 could require a tax of between \$230 and \$880 per tonne and a loss in world GDP of 2.4–3.8% (Dean, 1994).

The required carbon taxes and associated costs vary significantly across regions in all of the models. This indicates that the same proportional reductions in emissions across all regions would give rise to very different costs in different regions and would thus be globally inefficient – with great potential for savings in the global cost of reducing emissions through the use of emission trading between countries or regions or a global carbon tax.

Three insights emerging from the OECD study (Dean, 1994) are:

- Small amounts of emission reduction can probably be achieved with low taxes;
- Large reductions can only be achieved at high tax rates (i.e., marginal reduction costs rise with emission reductions);
- Carbon-free backstop technologies are likely to slow the rise of the carbon tax, or halt it altogether, if they are available at constant marginal cost.

The Energy Modeling Forum-12 (Impact of Carbon Emission Control Strategies) examined the cost of reducing CO₂ emissions (EMF, 1993). A diverse group of economic models, employing common assumptions for selected numerical inputs, were used to analyze

a standardized set of emission reduction scenarios. In all, fourteen top-down models participated in the study.

The EMF model comparison provides the most comprehensive application of top-down methodologies to date. The study addresses a wide range of policy questions. How large are emissions likely to grow in the absence of controls? How much market intervention will be required to meet alternative targets? What will be the price tag? In exploring economic costs, the modellers were asked to examine the impacts of timing, research and development, and revenue recycling.

The EMF exercise provides a wealth of useful information for policymaking. Although the focus was primarily on the U.S., many of the insights are applicable to developed countries in general.

In selecting parameters for standardization, the EMF study focussed on what were felt to be the most influential determinants of mitigation costs. These included GDP, population, the fossil fuel resource base, and the cost and availability of long-term supply options. In addition, although the EMF models differed considerably in their technology representation, the study attempted to impose uniformity with regard to world oil prices, the oil and gas resource base, and the cost of backstop technologies. For its reference case, EMF adopted the average of the 1990 IPCC high and low economic growth cases (IPCC, 1990c). To be consistent with the IPCC scenarios, the study also adopted the population growth projections of Zachariah and Vu (1988).

The modellers generally used taxes based on the carbon content of the fossil fuels to achieve a prescribed emission reduction. The magnitude of the tax provided a rough estimate of the degree of market intervention that would be required to achieve the carbon emission target. Estimates ranged from \$20 to \$140 per tonne for the carbon taxes required to hold emissions at 1990 levels in 2010. Estimates of the carbon taxes required to reduce emissions by 20% below 1990 levels in 2010 ranged from \$50 to \$330 per tonne.

Two parameters are particularly important in explaining the differences in tax projections: the price elasticity of energy demand and the speed with which the capital stock adjusts to higher energy prices. Neither was controlled in the EMF experiments. Those models using lower price elasticities required higher taxes to achieve the same emission goal. Those models that assumed greater malleability of capital required lower taxes.

90. Rapid capital stock retirement may add to the cost of immediate CO₂ reductions. Also, reductions may be cheaper later because of technical changes in the intervening years.

91. Indeed, the "ratchet effect," a commonly observed phenomenon in command and control economies (Stiglitz, 1975b; Weitzman, 1978), leads firms to do no more than just satisfy the target.

92. Two examples from the experience of the United States Clean Air Act: (1) the expensive and evidently counterproductive requirement in the 1977 amendments that coal-burning power plants install stack-gas scrubbers even if they burn low-sulphur Western coal has been attributed to an unusual alliance between environmental activists and Eastern U.S. high-sulphur coal interests; (2) the mandates for ethanol in the motor fuels market are generally attributed to the political power of the corn and ethanol interests.

93. It has been argued that new species and varieties produced by genetic engineering may be able to more than offset the loss in genetic variability from climate impacts, particularly because of the increasing capacity to direct those mutations toward socially desirable objectives.

94. Other views represented in the debate on sustainable development but not generally accepted in the economics profession include those of Daly (1991) and Daly and Cobb (1989), and those of the new field of ecological economics (Costanza, 1991).

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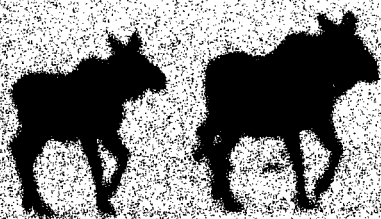
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