THE ECONOMICS OF
GLOBAL CLIMATE CHANGE

by Jonathan M. Harris
and Anne-Marie Codur

This reading is based on Chapter 18 from:
Environmental and Natural Resource Economics: A Contemporary Approach
(Houghton Mifflin, 2002)

Portions of this reading also appear in
Microeconomics and the Environment
by Jonathan M. Harris and Anne-Marie Codur

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Tufts University Global Development and Environment Institute
Cabot Center, Tufts University
Medford, MA 02155
http://ase.tufts.edu/gdae
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1. CAUSES AND CONSEQUENCES OF CLIMATE CHANGE

Concern has grown in recent years over the issue of global climate change1. In terms of economic analysis, greenhouse gas emissions, which cause planetary warming, represent both environmental externalities and overuse of a common property resource.

The atmosphere is a global commons into which individuals and firms can release pollution in the shape of gases and particulates. Global pollution creates a “public bad” born by everyone -- a negative externality with a wide impact. In many countries, environmental protection laws limit the release of local and regional air pollutants. In economic terminology, the negative externalities associated with local and regional pollutants have to some degree been internalized.

Few controls exist for carbon dioxide (CO₂), the major greenhouse gas, which has no short-term damaging effects at ground level. Atmospheric accumulations of carbon dioxide and other greenhouse gases, however, will have significant effects on world weather, although is uncertainty about the probable scale and timing of these effects (See Box 1).

If indeed the effects of climate change are likely to be severe, it is in everyone’s interest to lower their emissions for the common good. But where no agreement or rules on emissions exist, no individual firm, city, or nation will choose to bear the economic brunt of being the first to reduce its emissions. In this situation, only a strong international agreement binding nations to act for the common good can prevent serious environmental consequences.

Because CO₂ and other greenhouse gases continuously accumulate in the atmosphere, stabilizing or “freezing” emissions will not solve the problem. This is a case of a stock pollutant: only major reductions in emissions levels will prevent ever-increasing atmospheric accumulations. The development of national and international policies to combat global climate change is a huge challenge, involving many scientific, economic, and social issues.

1 The problem, frequently called global warming, is more accurately referred to as global climate change. A basic warming effect will produce complex effects on climate patterns -- with warming in some areas, cooling in others, and increased climate variability.
BOX 1: WHAT IS THE GREENHOUSE EFFECT?

The sun’s rays travel through a greenhouse’s glass to warm the air inside, but the glass acts as a barrier to the escape of heat. Thus plants which require warm weather can be grown in cold climates. The global greenhouse effect, through which the earth’s atmosphere acts like the glass in a greenhouse, was first described by French scientist Jean Baptiste Fourier in 1824.

Clouds, water vapor, and the natural greenhouse gases carbon dioxide (CO2), methane, nitrous oxide and ozone allow inbound solar radiation to pass through, but serve as a barrier to outgoing infrared heat. This creates the natural greenhouse effect, which makes the planet suitable for life. Without it, the average surface temperature on the planet would average around -18° C (0ºF), instead of approximately 15°C (60º F).

The possibility of an enhanced or man-made greenhouse effect was introduced one hundred years ago by the Swedish scientist Svante Arrhenius. Arrhenius hypothesized that the increased burning of coal would lead to an increased concentration of carbon dioxide in the atmosphere and warm the earth. Since Arrhenius’ time, greenhouse gas emissions have grown dramatically. Carbon dioxide concentrations in the atmosphere has increased by 25% over pre-industrial levels. In addition to increased burning of fossil fuels such as coal, oil and natural gas, man-made chemical substances such as chlorofluorocarbons (CFCs) as well as methane and nitrous oxide emissions from agriculture and industry contribute to the greenhouse effect.

In 1988, the United Nations Environment Programme and the World Meteorological Organization together established the Intergovernmental Panel on Climate Change (IPCC) to provide an authoritative international statement of scientific opinion on climate change. With respect to human-caused greenhouse effect, the IPCC concluded that “there has been a real, but irregular, increase of global surface temperature since the late nineteenth century” amounting to 0.5°C on average.

Current emissions trends will lead to a doubling of greenhouse gas concentration over pre-industrial levels by around 2050. Using general circulation models - large mathematical models of the atmosphere - scientists can simulate the effect of increased greenhouse gas concentrations. The IPCC projects a global average temperature increase of 1 to 6 degrees Celsius, or 2 to 10 degrees Fahrenheit, which would have significant impact on climate throughout the world.

Trends and Projections for Temperature Change

Despite two global conferences dealing with the issue, the 1992 United Nations Conference on Environment and Development (UNCED) at Rio de Janeiro and a 1997 meeting in Kyoto, Japan - as well as follow-up negotiating sessions, progress on combating global climate change has been slow. Global emissions of greenhouse gases continue to rise (see Figure 1).

**FIGURE 1**

**CARBON EMISSIONS DUE TO FOSSIL FUEL CONSUMPTION, 1860-1995**

![Graph showing carbon emissions due to fossil fuel consumption, 1860-1995.](http://cdiac.esd.ornl.gov/)

Increasing accumulations of greenhouse gases have caused the earth’s surface temperature to rise perceptibly. Although some warming may be a natural trend, the Intergovernmental Panel on Climate Change (IPCC) has determined that human-caused impact on the atmosphere has “contributed substantially to the observed warming over the last 50 years.”

Temperatures have now reached levels unprecedented in the last thousand years (See Figure 2).

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The IPCC scientists project that continued emissions of greenhouse gases will further increase average temperatures between 1 and 6 degrees Celsius (about 2 to 10 degrees Fahrenheit) over the next century (Figure 3). This steady rise in earth’s average temperature will have many significant effects on climate. For example, a rise in sea levels is likely as polar ice caps and glaciers melt. This will have serious effects on islands and low-lying coastal areas (see Box 2).
The onset of climate change poses a choice between preventative and adaptive strategies. For example, the only way to stop rising sea levels would be to prevent the climate change itself. It might be possible to build dikes and sea walls to hold back the higher waters. Those who live close to the sea – including whole island nations, which could lose most of their territory to sea level rise -- are not likely to endorse this mitigation strategy. But to carry out a strategy of prevention, most of the world’s countries will have to be convinced to participate. Is it in their interest to do so? To answer this question, we have to find a way of evaluating the effects of climate change.
BOX 2: PACIFIC ISLANDS DISAPPEAR AS OCEANS RISE

Two islands in the Pacific Ocean nation of Kiribati - Tebua Tarawa and Abanuea - have disappeared as a result of rising sea level. And others are nearly gone, both in Kiribati and in the neighboring island nation of Tuvalu. So far the seas have completely engulfed only uninhabited, relatively small islands, but the crisis is growing all along the shores of the world's atolls.

Populated islands are already suffering. The main islands of Kiribati, Tuvalu and the Marshall Islands (also in the Pacific) have suffered severe floods as high tides demolish sea walls, bridges and roads and swamp homes and plantations. Almost the entire coastline of the 29 atolls of the Marshall Islands is eroding. Second World War graves on its main Majuro atoll are being washed away, roads and sub-soils have been swept into the sea and the airport has been flooded several times despite being supposedly protected by a high sea wall.

The people of Tuvalu are finding it difficult to grow their crops because the rising seas are poisoning the soil with salt. In both Kiribati and the Marshall Islands families are desperately trying to keep the waves at bay by dumping trucks, cars and other old machinery in the sea and surrounding them with rocks.

The story is much the same in the Maldives. The Indian Ocean is sweeping away the beaches of one-third of its 200 inhabited islands. "Sea-level rise is not a fashionable scientific hypothesis," says President Gayoom. "It is a fact."

The seas are rising partly because global warming is melting glaciers and nibbling away at the polar ice caps, but mainly because the oceans expand as their water gets warmer. Scientists' best estimate is that these processes will raise sea levels by about 1.5 feet over the next century, quite enough to destroy several island nations.

The higher the seas rise, the more often storms will sweep the waves across the narrow atolls carrying away the land - and storms are expected to increase as the world warms up. And many islands will become uninhabitable long before they physically disappear, as salt from the sea contaminates the underground freshwater supplies on which they depend.

2. ECONOMIC ANALYSIS OF CLIMATE CHANGE

Scientists have modeled the effects of a projected doubling of accumulated carbon dioxide in the earth’s atmosphere. Some of the predicted effects are:

- Loss of land area, including beaches and wetlands, to sea-level rise
- Loss of species and forest area
- Disruption of water supplies to cities and agriculture
- Increased costs of air conditioning
- Health damage and deaths from heat waves and spread of tropical diseases
- Loss of agricultural output due to drought

Some beneficial outcomes might include:

- Increased agricultural production in cold climates
- Lower heating costs

In addition to these effects, there are some other, less predictable but possibly more damaging effects including:

- Disruption of weather patterns, with increased frequency of hurricanes and other extreme weather events.
- Sudden major climate changes, such as a shift in the Atlantic Gulf Stream, which could change the climate of Europe to that of Alaska.
- Positive feedback effects, such as an increased release of carbon dioxide from warming arctic tundra, which would speed up global warming.

How can we evaluate such major possible impacts? In attempting to respond to this question, economists have employed the tool of cost-benefit analysis. Others have criticized this approach as attempting to put a monetary valuation on issues that have great social, political, and ecological implications, which go far beyond money value. But many economists feel that since there are clearly costs associated with taking action against global climate change, it is essential to seek some way to balance costs and benefits. We will examine economists’ efforts to place the issue in a cost-benefit context, then return to the debate over whether this effort is appropriate, and what policies should be implemented.

We can place greenhouse policies in context by first considering first a business-as-

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3 A feedback effect occurs when an original change in a system causes further changes that either reinforce the original change (positive feedback) or counteract it (negative feedback).
usual scenario in which no action is taken to limit greenhouse gas emissions. According to World Bank projections, global energy use will have nearly doubled by 2030, with the greatest growth coming from developing nations\(^4\). The resulting dramatic increase in carbon emissions is shown in Figure 4.

**FIGURE 4: PROJECTED CARBON EMISSIONS THROUGH 2020, BUSINESS AS USUAL SCENARIO**


Today, the developed nations are responsible for most carbon emissions, but the largest projected increase in emissions will be in the presently developing nations. By 2020 developing nations will at least equal developed nations in emissions. But note that even with this large increase, per-capita emissions levels will remain much lower in developing nations (Figure 5). With expected population and economic growth, emissions increases in the developing world are unavoidable. Thus to reduce global emissions, there must be significant policy action by developed nations, as well as eventual limits on developing nation emissions.

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Cost-Benefit Studies of Global Climate Change

In performing a cost-benefit analysis, we must weigh the consequences of allowing this uncontrolled emissions scenario to proceed versus the costs of policy action to prevent it. We can do this by estimating the damages from uncontrolled global climate change. Strong policy action to prevent climate change will bring benefits equal to the value of these damages\(^5\). Then we must compare these to benefits to the costs of taking action. Various economic studies have attempted to estimate these benefits and costs. The results of one such study for the U.S. economy are shown in Table 1.

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\(^5\) These benefits of preventing damage can also be referred to as *avoided costs*. 

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<table>
<thead>
<tr>
<th></th>
<th>2xCO₂ ( +2.5 degrees C)</th>
<th>Very-long-term warming</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(+10 degrees C)</td>
</tr>
<tr>
<td>Agriculture</td>
<td>17.5</td>
<td>95.0</td>
</tr>
<tr>
<td>Forest loss</td>
<td>3.3</td>
<td>7.0</td>
</tr>
<tr>
<td>Species loss</td>
<td>4.0+D</td>
<td>16.0+D’</td>
</tr>
<tr>
<td>Sea-level rise</td>
<td></td>
<td>35.0</td>
</tr>
<tr>
<td>Building dikes, levees</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Wetlands loss</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td>Drylands loss</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Electricity requirements</td>
<td>11.2</td>
<td>64.1</td>
</tr>
<tr>
<td>Nonelectric heating</td>
<td>-1.3</td>
<td>-4.0</td>
</tr>
<tr>
<td>Human amenity</td>
<td>Xa</td>
<td>Ya</td>
</tr>
<tr>
<td>Human life</td>
<td>5.8</td>
<td>33.0</td>
</tr>
<tr>
<td>Human morbidity</td>
<td>Xm</td>
<td>Ym</td>
</tr>
<tr>
<td>Migration</td>
<td>0.5</td>
<td>2.8</td>
</tr>
<tr>
<td>Hurricanes</td>
<td>0.8</td>
<td>6.4</td>
</tr>
<tr>
<td>Construction</td>
<td>+/- Xc</td>
<td>+/- Yc</td>
</tr>
<tr>
<td>Leisure activities</td>
<td>1.7</td>
<td>4.0</td>
</tr>
<tr>
<td>Water supply</td>
<td>7.0</td>
<td>56.0</td>
</tr>
<tr>
<td>Urban infrastructure</td>
<td>0.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Air pollution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tropospheric ozone</td>
<td>3.5</td>
<td>19.8</td>
</tr>
<tr>
<td>Other</td>
<td>Xo</td>
<td>Yo</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>61.1+Xa+Xm+Xo+D +/- Xc</td>
<td>335.7+Ya+Ym+Yo+D +/- Yc</td>
</tr>
</tbody>
</table>


The study is based on an estimated doubling of CO₂ over pre-industrial levels. When the monetized costs are added up, the total annual U.S. damages are estimated at approximately $60 billion (1990 dollars). This is about 1% of U.S. GNP. Although different economic studies come up with different estimates, most of them are in the range of 1-2% GNP. Cost estimates for larger temperature change over the longer term rise to around 5% of GNP (Table 1, column 2).
Note, however, that there are also some “Xs”, “Ys” and “Ds” in the totals -- unknown quantities that cannot easily be measured. The value of species loss, for example, is difficult to estimate in dollar terms: the estimates used here show a cost of at least $4 billion in the short term and $16 billion in the long term, with an additional unknown cost D.

Other monetized estimates could also be challenged on the grounds that they fail to capture the full value of potential losses. For example, oceanfront land is more than just real estate. Beaches and coastal wetlands have great social, cultural, and ecological value. The market value of these lands fails to capture the full scope of the damage society will suffer if they are lost.

In addition, these estimates omit the possibility of the much more catastrophic consequences that could result if weather disruption is much worse than anticipated. A single hurricane, for example, can cause over $10 billion in damage, in addition to loss of life. For example, in November 1998, a severe hurricane caused massive devastation and the loss of over 7000 lives in Central America. If climate changes cause severe hurricanes to become much more frequent, the estimate here of less than one billion annual losses could be much too low. Another of the “X” values – human morbidity or losses from disease – could well be enormous if tropical diseases extend their range significantly due to warmer weather conditions.

Clearly, these damage estimates are not precise, and are open to many criticisms. But suppose we decide to accept them – at least as a rough estimate. We must then weigh the estimated benefits of policies to prevent climate change against the costs of such policies. To estimate these costs, economists use models that show how economic output is produced from factor inputs such as labor, capital, and resources.

To lower carbon emissions, we must cut back the use of fossil fuels, substituting other energy sources that may be more expensive. In general, economic models predict that this substitution would reduce GNP growth. One major study showed GNP losses ranging from 1 to 3 percent of GNP for most countries, with higher potential long-term losses for coal-dependent developing nations such as China.

If both costs and benefits of an aggressive carbon abatement policy are both in the range of 1-3% GNP, how can we decide what to do? Much depends on our evaluation of future costs and benefits. The costs of taking action must be born today or in the near future. The benefits of taking action (the avoided costs of damages) are further in the future. How can we decide today how to balance these future costs and benefits?

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3. ANALYZING LONG-TERM ENVIRONMENTAL EFFECTS

Economists evaluate future costs and benefits by the use of a **discount rate**. The problems and implicit value judgments associated with discounting add to the uncertainties that we have already noted in valuing costs and benefits. This suggests that we should consider some alternative approaches - including techniques that incorporate ecological as well as economic costs and benefits.

Two major economic studies dealing with benefit/cost analysis of climate change have come to very different conclusions about policy. According to a study by William Nordhaus, the **economic optimum** would be a small reduction in greenhouse gas emissions below the business-as-usual emissions growth shown in Figure 4. This would require few changes in the carbon-based energy path typical of current economic development.

In contrast, a study by William Cline recommends “a worldwide program of aggressive action to limit global warming” including cutting back carbon emissions well below present levels, and then freezing them at this lower level, with no future increase. What explains the dramatic difference between these two benefit/cost analyses?

The two studies used similar economic methodologies to assess benefits and costs. The main differences were that the Cline study considered long-term effects and used a low discount rate (1.5%) to balance present and future costs. Thus even though costs of aggressive action appeared higher than benefits for several decades, the high potential long-term damages sway the balance in favor of aggressive action today.

The present value (PV) of a long-term stream of benefits or costs depends on the discount rate. A high discount rate will lead to a low present valuation for benefits that are mainly in the longer-term, and a high present valuation for short-term costs. On the other hand, a low discount rate will lead to a higher present valuation for longer-term benefits. The estimated net present value of an aggressive abatement policy will thus be much higher if we choose a low discount rate.

While both the Cline and Nordhaus studies used standard economic methodology, Cline’s approach gives greater weight to long-term ecological effects. These effects are

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significant both for their monetary and non-monetary effects. In the long term, damage done to the environment by global climate change will have significant negative effects on the economy too. Thus these long-term effects have a high monetary value, as shown in Figure 6. But the use of a standard discount rate of in the 5-10% range has the effect of reducing the present value of significant future damages to relative insignificance.

An ecologically oriented economist would argue that the fundamental issue is the stability of the physical and ecological systems that serve as a climate-control mechanism for the planet. This means that climate stabilization should be the goal, rather than economic optimization of costs and benefits. Stabilizing greenhouse gas emissions is not sufficient, since at the current rate of emissions carbon dioxide and other greenhouse gases will continue to accumulate in the atmosphere. Stabilizing the accumulations of greenhouse gases will require a significant cut below present emission levels.

Any measure taken to prevent global climate change will have economic effects on GDP, consumption, and employment, which explains the reluctance of governments to take drastic measures to reduce significantly emissions of CO₂. But these effects may not necessarily be negative.

A comprehensive review of economic models of climate change policy shows that the economic outcomes predicted for carbon reduction policies are very much dependent on the modeling assumptions that are used. The predicted effects of stabilizing emissions at 1990 levels range from a 2 percent decrease to a 2 percent increase in GDP. The outcomes depend on a range of assumptions including:

- The efficiency or inefficiency of economic responses to energy price signals.
- The availability of non-carbon “backstop” energy technologies.
- Whether or not nations can trade least-cost options for carbon reduction.
- Whether or not revenues from taxes on carbon-based fuels are used to lower other taxes.
- Whether or not external benefits of carbon reduction, including reduction in ground-level air pollution, are taken into account.

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Thus policies for emissions reduction could range from a minimalist approach of slightly reducing the rate of increase in emissions to a dramatic CO₂ emissions reduction of 40 or 50%. Most economists who have analyzed the problem agree that action is necessary (see Box 3), but there is a wide scope of opinion on how drastic this action should be, and how soon it should occur. The nations of the world have acknowledged the problem, and are negotiating over plans to achieve emissions reductions. The scope of the reductions now being discussed, however, falls well short of what would be required for climate stabilization.

Whatever the outcome of these negotiations, any serious effort to reduce carbon emissions will require the kinds of economic policies to deal with negative externalities. We will now turn to an analysis of some possible policies.
**BOX 3: ECONOMISTS’ STATEMENT ON CLIMATE CHANGE**

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.

Note: The above statement has been endorsed by more than 2,500 economists, including eight Nobel Laureates)

Source: Redefining Progress, San Francisco, California ([http://www.rprogress.org](http://www.rprogress.org)).
4. POLICY RESPONSES TO CLIMATE CHANGE

Two types of measures can be used to address climate change; preventative measures tend to lower or mitigate the greenhouse effect, and adaptive measures deal with the consequences of the greenhouse effect and trying to minimize their impact.

Preventative measures include:

- Reducing emissions of greenhouse gases, either by reducing the level of economic activities which are responsible for it or by shifting to more energy-efficient technologies which would allow the same level of economic activity at a lower level of CO₂ emissions.
- Enhancing greenhouse gas sinks. Forests recycle CO₂ into oxygen; preserving forested areas and expanding reforestation have a significant effect on net CO₂ emissions.

Adaptive measures include the following:

- Construction of dikes and seawalls to protection against rising sea level and extreme weather events such as floods and hurricanes.
- Shifting cultivation patterns in agriculture to adapt to changed weather conditions in different areas.

An economic approach suggests that we should apply cost-effectiveness analysis in considering such policies. This differs from cost-benefit analysis in having a more modest goal: rather than attempting to decide whether or not a policy should be implemented, cost-effectiveness analysis asks what is the most efficient way to reach a policy goal.

In general, economists favor approaches that work through market mechanisms to achieve their goals. Market-oriented approaches are considered to be cost-effective – rather than attempting to control market actors directly, they shift incentives so that individuals and firms will change their behavior to take account of external costs and benefits. We have already mentioned the examples of pollution taxes and transferable, or tradable, permits. Both of these are potentially useful tools for greenhouse gas reduction. Other relevant economic policies include measures to create incentives for the adoption of renewable energy sources and energy-efficient technology.

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10 Carbon sinks are areas where excess carbon may be stored. Natural sinks include the oceans and forests. Human intervention can either reduce or expand these sinks through forest management and agricultural practices.
Policy Tools: Carbon Taxes

The release of greenhouse gases in the atmosphere is a clear example of a negative externality that imposes significant costs on a global scale. In the language of economic theory, the market for carbon-based fuels such as coal, oil, and natural gas takes into account only private costs and benefits, which leads to a market equilibrium that does not correspond to the social optimum.

A standard economic remedy for internalizing external costs is a per-unit tax on the pollutant. In this case, what is called for is a carbon tax, levied exclusively on carbon-based fossil fuels. Such a tax will raise the price of carbon-based energy sources, and so give consumers incentives to conserve energy and to shift demand to alternative sources (Figure 7). Demand may also shift from carbon-based fuels with a higher proportion of carbon, such as coal, to those with relatively lower carbon content, such as natural gas.

“Carbon taxes would appear to consumers as energy price increases. But since taxes would be levied on primary energy, which represents only one part of the cost of delivered energy (such as gasoline or electricity) and more important, since one fuel can in many cases be substituted for another, overall price increases may not be jolting. Consumers can respond to new prices by reducing energy use and buying fewer carbon-intensive products (those that require great amounts of carbon-based fuels to produce). In addition, some of these savings could be used to buy other less carbon-intensive goods and services.

“Clearly, a carbon tax creates an incentive for producers and consumers to avoid paying the tax by reducing their use of carbon-intensive fuels. Contrary to other taxed items and activities, this avoidance has social benefits – reduced energy use and reduced CO$_2$ emissions. Thus, declining tax revenues over time indicate policy success – just the opposite of what happens when tax policy seeks to maintain steady or increasing revenues.”

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Consider Table 2, which shows the impact different levels of carbon tax will have on the prices of coal, oil and gas. A $10/ton carbon tax, for example, raises the price of a barrel of oil by $1.30, which is about 3 cents a gallon. Will this affect people’s driving or home heating habits very much? Probably not – we would expect a high elasticity of demand for gasoline or heating oil, since these commonalities are viewed as necessities.

**TABLE 2: ALTERNATIVE TAXES ON FOSSIL FUELS**

<table>
<thead>
<tr>
<th></th>
<th>Coal</th>
<th>Oil</th>
<th>Natural Gas</th>
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<tbody>
<tr>
<td><strong>Unit of measure</strong></td>
<td>ton</td>
<td>barrel</td>
<td>ccf (hundred cubic feet)</td>
</tr>
<tr>
<td><strong>Tons of carbon per unit of fuel</strong></td>
<td>.605</td>
<td>.130</td>
<td>.016</td>
</tr>
<tr>
<td><strong>Average mine-mouth or wellhead price, 1989</strong></td>
<td>$23.02</td>
<td>$17.70</td>
<td>$1.78</td>
</tr>
</tbody>
</table>

**Carbon tax:**

<table>
<thead>
<tr>
<th>Absolute tax:</th>
<th>$/ton</th>
<th>$/barrel</th>
<th>$/ccf</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10/ton of carbon</td>
<td>$6.34</td>
<td>$1.30</td>
<td>$0.016</td>
</tr>
<tr>
<td>$100/ton of carbon</td>
<td>$63.4</td>
<td>$13.00</td>
<td>$0.16</td>
</tr>
</tbody>
</table>

**Tax as % of price:**

<table>
<thead>
<tr>
<th></th>
<th>$10/ton of carbon</th>
<th>$100/ton of carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>26%</td>
<td>260%</td>
<td></td>
</tr>
<tr>
<td>8%</td>
<td>80%</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7 shows a cross-country relationship between gasoline prices and per capita use. Notice that the pattern of this relationship is similar to a demand curve: higher prices are associated with lower consumption, lower prices with higher consumption. The relationship shown here is not exactly the same as a demand curve – since we are looking at data from different countries, the assumption of “other things equal”, which is needed to construct a demand curve, doesn’t hold.

People in the United States, for example, may drive more partly because travel distances (especially in the U.S. West) are greater than in many European countries. But there does seem to be a clear price/consumption relationship. The data shown here suggest that it would take a fairly big price hike – in the range of $0.50- $1.00 per gallon or more – to affect fuel use substantially.

**FIGURE 7: GASOLINE PRICE VERSUS USE IN INDUSTRIAL COUNTRIES, 1994**
(Circled area represents price/consumption range typical of most West European countries)

A much larger tax would be needed to promote a major shift away from fossil fuels. According to most studies, stabilizing global CO₂ emissions would require a carbon tax in the range of $200/ton.¹² This would more than double the price of oil and quadruple the price of coal. That would certainly affect consumption patterns. In addition, the long-term elasticity of demand would be significantly greater, as higher prices for carbon-based fuels promoted development of alternative technologies.

But would such a tax ever be politically feasible? Especially in the United States, high taxes on gasoline and other fuels would face much opposition, especially if people saw it as infringing on their freedom to drive. Note that in Figure 7 the U.S. has by far the lowest price and the highest consumption per person.

But let’s note two things about the proposal for substantial carbon taxes:

# First, revenue recycling could redirect the revenue from such taxes to lower other taxes. Much of the political opposition to high energy taxes comes from the perception that they would be an *extra* tax – on top of the income, property, and social security taxes that people already pay. If a carbon tax was matched, for example, with a substantial cut in income and social security taxes, it might be more politically acceptable. The idea of increasing taxes on economic “bads” such as pollution and reducing taxes on things we want to encourage, such as labor and capital investment, is fully consistent with principles of economic efficiency.¹³ Rather than a net tax increase, this would be **revenue-neutral tax shift** - the total amount which citizens pay to the government in taxes is unchanged.

# Second, if such a tax shift did take place, individuals or businesses whose operations were more energy-efficient would actually save money. The higher cost of energy would also create a powerful incentive for energy-saving technological innovation. Economic adaptation would be easier if the higher carbon taxes (and lower income and capital taxes) were phased-in over time.

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¹³ To encourage higher investment, carbon tax revenues could be used to lower capital gains or corporate taxes.
Policy Tools: Tradable Permits

As we have seen, one alternative to a pollution tax is a system of tradable pollution permits. In the international negotiations over greenhouse gas reduction, the United States has advocated the implementation of a tradable permit system for carbon emissions. Such a system would work as follows:

# Each nation would be allocated a certain permissible level of carbon emissions. The total number of carbon permits issued would be equal to the desired goal. For example, if global emissions of carbon are 6 billion tons and the goal is to reduce this by 1 billion, permits for 5 billion tons of emissions would be issued.

# Permit allocation would meet agreed-on targets for national or regional reductions. For example, under the Kyoto agreement of 1997, the U.S. agreed to set a goal of cutting its greenhouse emissions 7% below 1990 levels by 2008-2012. Japan agreed to a 6% cut, and Europe to an 8% cut.

# Nations could then trade permits among themselves. For example, if the U.S. failed to meet its target, but Europe exceeded its target, the U.S. could purchase permits from Europe.

# The permits might also be tradable among firms, with countries setting targets for major industrial sectors, and allocating permits accordingly. Firms could then trade among themselves, or internationally.

# Nations and firms could also receive credit for reductions that they help to finance in other countries. For example, U.S. firms could get credit for installing efficient electric generating equipment in China, replacing highly polluting coal plants.

From an economic point of view, the advantage of a tradable permit system is that it would encourage the least-cost carbon reduction options to be implemented. Depending on the allocation of permits, it might also mean that developing nations could transform permits into a new export commodity by choosing a non-carbon path for their energy development. They would then be able to sell permits to industrialized nations who were having trouble meeting their reduction requirements.

The stumbling block to an international tradable permit system is obtaining agreement on the targets. Developing nations have resisted any limitations on their emissions – which are currently much lower per capita than those of industrialized nations -- until the developed nations show significant progress in reducing theirs. But some developed nations, such as the U.S. and Australia, are reluctant to implement a reduction policy until developing nations have agreed to some commitments (see Box 4).
The December 1997 Kyoto Conference, held under the auspices of the United Nations, produced an agreement on greenhouse gas reduction called the Kyoto Protocol. Whereas the previous Framework Convention on Climate Change (FCCC), agreed to at the Rio Conference on Environment and Development in 1992, was entirely voluntary, the Kyoto protocol is intended to be binding on its signatory nations. Industrialized countries accepted goals for emissions reduction over a fifteen-year period. Developing countries would not accept specific emissions limits, arguing that developed nations must first live up to their responsibility to cut their much greater per capita emissions.

Under the Kyoto Protocol, the **Clean Development Mechanism** allows cooperative projects, such as construction of highly efficient power plants in developing countries, where an industrialized country can receive emissions reduction credit for aid given to a developing country. Another cooperative or **joint implementation** mechanism is sink enhancement, where common efforts between industrialized countries and developing countries could promote forest conservation and reforestation.

These mechanisms do not add up to a global tradable permit system. Limited trading may be possible between nations that have agreed to specific emissions limits. But for a global emission trading system to work, all nations would have to agree to emissions caps— which would require breaking the deadlock between developed and developing nations.

In meetings at The Hague in November 2000, climate change negotiations between the United States and the European Union broke down over two contentious points: whether to give countries emissions credits for **carbon sinks** such as forests, and the limits to be placed on the so-called flexibility mechanisms.

US emissions have increased by 12 percent since 1990, and are projected to increase further by 2010. Drastic policy changes would be needed for the United States to meet its Kyoto obligation of a 7 percent cut below 1990 levels by 2010.

In the negotiations at The Hague, the United States took the position that all of the carbon held in its existing forest and farm land should be counted towards its commitment. This would allow domestic industry to continue to emit at nearly the same levels seen today, and it represents nearly half of the original United States commitment (Figure 8). A compromise proposal agreed to by Britain would allow counting a portion of forested area. This plan was also rejected by the EU as a whole.

Disagreement also arose over how countries will meet their obligations after counting the appropriate sinks. The three principal “flexibility mechanisms” are: emissions trading, joint implementation, and the clean development mechanism. All of these would allow an industrial nation to finance emission reductions in other countries and apply them to its own Kyoto commitment.

The European Union sought to limit the amount of any country’s commitment that
can be satisfied through “flexibility,” while the United States wanted no limits. This has important implications for actual domestic emission reductions. If unlimited flexibility is allowed, all required reductions could theoretically occur without any change in domestic emissions. According to the United States negotiators, increased flexibility would help achieve the ultimate goal of reducing global greenhouse gas emissions. But European nations argued that unlimited flexibility would allow the United States to avoid taking any serious measures to reduce its own carbon emissions.

In 2001, the Bush administration rejected the Kyoto agreement, arguing that negotiations had failed, and a new approach was necessary. They sought to emphasize voluntary rather than mandatory carbon limits. This dealt a serious blow to efforts to control global greenhouse gas emissions. Some observers argued, however, that the Kyoto process had already failed, and that a fresh start was needed in any case. As the 2008-20012 target dates grow closer, it seems clear that the original Kyoto targets will remain unmet, but it is unclear what will replace them.

FIGURE 8
UNITED STATES GREENHOUSE GAS EMISSIONS, 1990-2010

To demonstrate the economic impacts of a tradable carbon permit system, we can use the analytical concept of **marginal net benefit**. Figure 9 shows the marginal net benefit of carbon emissions to producers and consumers.\(^{14}\) The emissions level \(Q_E\) will result if there are no limits on emissions – this is the market equilibrium, where consumers and producers maximize total net benefits, without taking into account environmental externalities.

Under a permit system, \(Q^*\) represents the total number of permits issued. The equilibrium permit price will then be \(P^*\), reflecting the marginal net benefit of carbon emissions at \(Q^*\). It is advantageous for emitters who gain benefits greater than \(P^*\) from their emissions to purchase permits, while those with emissions benefits less than \(P^*\) will do better to reduce emissions and sell any excess permits.

Figure 10 shows how this system affects carbon reduction strategies. Three possibilities are shown. Replacement of plants using existing carbon-emitting technologies is possible, but will tend to have high marginal costs. Reducing emissions through greater energy efficiency has lower marginal costs, as does carbon storage through forest area expansion. The permit price \(P^*\) will govern the relative levels of implementation of each of these strategies.

Nations and corporations who are subject to the trading scheme can decide for themselves how much of each control strategy to implement, and will naturally favor the least-cost methods. This will probably involve a combination of different approaches. Suppose one nation undertakes extensive reforestation. They are then likely to have excess permits, which they can sell to a nation with few low-cost reduction options. The net effect will be the worldwide implementation of the least-cost reduction techniques.

This system combines the advantages of economic efficiency with a guaranteed result – reduction to overall emissions level \(Q^*\). The problem, of course, is to achieve agreement on the initial allocation of permits. There may also be measurement problems, and issues such as whether to count only commercial carbon emissions, or to include emissions changes resulting from land use patterns.

\(^{14}\) The marginal net benefit curve is derived from the demand and supply curve (in this case for carbon-based fuels), showing the marginal benefits of the product minus the marginal costs of the supply.
FIGURE 9
DETERMINATION OF CARBON PERMIT PRICE

$\text{MNB}_C = \text{Marginal net benefits of carbon emissions}$

$Q_E = \text{Quantity of carbon emissions without permit system}$

$Q^* = \text{Quantity of carbon permits issued}$

$P^* = \text{Equilibrium price of carbon permit}$
FIGURE 10
CARBON REDUCTION WITH A PERMIT SYSTEM

\[ MC_A = \text{Marginal costs of carbon reduction by plant replacement} \]

\[ MC_B = \text{Marginal costs of carbon reduction by increased energy efficiency} \]

\[ MC_C = \text{Marginal costs of carbon reduction by forest area expansion} \]

\[ P^* = \text{Equilibrium price of carbon permit} \]

\[ q_a = \text{Units of carbon reduced by plant replacement} \]

\[ q_b = \text{Units of carbon reduced by increased energy efficiency} \]

\[ q_c = \text{Units of carbon reduced by forest area expansion} \]
Policy Tools: Subsidies, Standards, R&D, and Technology Transfer

Although political problems may prevent the adoption of sweeping carbon taxes or transferable permit systems, there are a variety of other policy measures which have potential to lower carbon emissions. These include:

# Shifting subsidies from carbon-based to noncarbon-based fuels. Many countries currently provide direct or indirect subsidies to fossil fuels. The elimination of these subsidies would alter the competitive balance in favor of alternative fuel sources. If these subsidy expenditures were redirected to renewable sources, especially in the form of tax rebates for investment, it could promote a boom in investment in solar, photovoltaics, fuel cells, biomass and wind power -- all technologies which are currently at the margin of competitiveness in various areas.

# The use of efficiency standards to require utilities and major manufacturers to increase efficiency and renewable content in power sources. A normal coal-fired generating plant achieves about 35% efficiency, while a high-efficiency gas-fired co-generation facility achieves from 75% to 90% efficiency. Current automobile fuel-efficiency standards do not exceed 27.5 miles per gallon, while efficiencies of up to 50 miles per gallon are achievable with proven technology. Tightening standards over time for plants, buildings, vehicles, and appliances would hasten the turnover of existing, energy-inefficient capital stock.

# Research and development (R&D) expenditures directed toward the commercialization of alternative technologies. Both government R&D programs and favorable tax treatment of corporate R&D for alternative energy can speed commercialization. The existence of a non-carbon “backstop” technology significantly reduces the economic cost of measures such as carbon taxes, and if the backstop became fully competitive with fossil fuels carbon taxes would be unnecessary.

# Technology transfer to developing nations. The bulk of projected growth in carbon emissions will come in the developing world. Many energy development projects are now funded by agencies such as the World Bank and regional development banks. To the extent that these funds can be directed towards non-carbon energy systems, supplemented by other funds dedicated specifically towards alternative energy development, it will be economically feasible for developing nations to turn away from fossil-fuel intensive paths, achieving significant local environmental benefits at the same time.
The future course of energy and global climate change policy will undoubtedly be affected by further scientific evidence regarding the impact of atmospheric carbon dioxide accumulation. Political barriers which prevent significant policy action may eventually be overcome. Some combination of the policies discussed in this chapter will certainly be centrally relevant to energy policies for the next half-century and beyond.

5. SUMMARY

Climate change, arising from the greenhouse effect of heat-trapping gases, is a global problem. All nations are involved in both its causes and consequences. Currently developed nations are the largest emitters of greenhouse gases, but emissions by developing nations will grow considerably in coming decades.

The most recent scientific evidence indicates that effects during the twenty-first century may range from a global temperature increase of 1ºC (2ºF) to as much as 6ºC (10ºF). In addition to simply warming the planet, other predicted effects include disruption of weather patterns and possible sudden major climate shifts.

Economic analysis of climate change can be attempted through analysis of costs and benefits. The benefits in this case are the damages potentially averted through action to prevent climate change; the costs are the economic costs of shifting away from fossil fuel dependence, as well as other economic implications of greenhouse gas reduction.

Cost-benefit studies have estimated both costs and benefits in the range of several percent of GDP. However, the relative evaluation of costs and benefits depends heavily on the discount rate selected. Since damages tend to get worse with time, the use of a high discount rate leads to a lower evaluation of the benefits of avoiding climate change. In addition, some effects such as species loss and effects on life and health are difficult to measure in monetary terms. Also, depending on the assumptions used in economic models, the GDP impacts of policies to avoid climate change could range from a 2% decrease to a 2% increase in GDP.

Policies to respond to global climate change could be preventive or adaptive. One of the most widely discussed policies is a carbon tax, which would fall most heavily on fuels causing the highest carbon emissions. The revenues from such a tax could be recycled to lower taxes elsewhere in the economy. Another policy option is tradable carbon emissions
permits, which could be bought and sold by firms or nations, depending on their level of carbon emissions. Both these policies have the advantage of economic efficiency, but it has been difficult to obtain the political support necessary to implement them.

Other possible policy measures include shifting subsidies away from fossil fuels and towards renewable energy, strengthening energy efficiency standards, and increasing research and development on alternative energy technologies.

The international negotiation process on climate change has led to some pledges for emissions reduction, but progress has stalled due to disagreements on the assignment of responsibility for cuts. The original targets for greenhouse gas reduction will probably not be met, and new approaches are needed to devise a global response to the problem.
KEY TERMS AND CONCEPTS

avoided costs
business as usual
carbon sinks
carbon tax
Clean Development Mechanism
climate stabilization
common property resource
cost-benefit analysis
cost-effectiveness analysis
dISCOUNTING.
discounting.
edconomic optimum
efficiency standards
elasticity of demand
energy-efficient technology
environmental externalities
externalities/external costs and benefits
global climate change
global commons
global warming
greenhouse effect
internalizing externalities
joint implementation
local and regional air pollutants
marginal net benefit
pollution taxes
preventive and adaptive measures
renewable energy sources
research and development (R&D)
revenue-neutral tax shift
revenue recycling
social optimum
stock pollutant
subsidies
technology transfer
transferable (tradable) pollution permits
REFERENCES


DISCUSSION QUESTIONS

1. Do you consider cost-benefit a useful means of addressing the problem of climate change? How can we adequately value things like the melting of arctic ice caps and inundation of island nations? What is the appropriate role of economic analysis in dealing with questions that affect global ecosystems and future generations?

2. Which policies to address climate change would be most effective? How can we decide which combination of policies to use? What kinds of policies would be especially recommended by economists? What are the main barriers to effective policy implementation?

3. The process for formulating and implementing international agreements on climate change policy has been plagued with disagreements and deadlocks. What are the main reasons for the difficulty in agreeing on specific policy actions? From an economic point of view, what kinds of incentives might be useful to induce nations to enter and carry out agreements? What kinds of “win-win” policies might be devised to overcome negotiating barriers?
EXERCISES

1. Suppose that under the terms of an international agreement, U.S. CO₂ emissions are to be reduced by 200 million tons, and those of Brazil by 50 million tons.

Here are the policy options that the U.S. and Brazil have to reduce their emissions:

USA:

<table>
<thead>
<tr>
<th>Policy options</th>
<th>Total emissions reduction (million tons carbon)</th>
<th>Cost ($ billion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Efficient machinery</td>
<td>60</td>
<td>12</td>
</tr>
<tr>
<td>B: reforestation</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>C: Replace coal fueled power plants</td>
<td>120</td>
<td>30</td>
</tr>
</tbody>
</table>

Brazil:

<table>
<thead>
<tr>
<th>Policy options</th>
<th>Total emissions reduction (million tons carbon)</th>
<th>Cost ($ billion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Efficient machinery</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>B: Protection of Amazon forest</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>C: Replace coal fueled power plants</td>
<td>40</td>
<td>8</td>
</tr>
</tbody>
</table>

a) What are the most efficient policies for the U.S. and Brazil to use in meeting their targets? What will be the cost to each nation if they must operate independently?

b) Suppose a market of transferable permits allows the U.S. and Brazil to trade permits to emit CO₂. Who has an interest in buying permits? Who has an interest in selling permits? What agreement can be reached between the U.S. and Brazil so that they can meet the overall emissions reduction target of 250 at the least cost? Can you estimate a range for the price of a permit to emit one ton of carbon? (Hint: calculate the average cost per unit for each reduction policy.)
2. Suppose that the annual consumption of an average American household is 2000 gallons of oil in heating and transportation and 2000 ccf (hundred cubic feet) of gas in cooking. Using the figures given in Table 2 on the effects of a carbon tax, calculate how much an average American household would pay per year with an added tax of $10 per ton of carbon. (One barrel of oil contains 42 gallons.)

Figuring 100 million households in the United States, what would be the revenue to the U.S. Treasury of such a carbon tax? What would be the national revenue of a tax of $100 per ton of carbon? (Consider the issue of possible changes in consumption.) How might the government use such revenues? What would the impact be on the average family?
WEB LINKS

1. [http://www.epa.gov/globalwarming/](http://www.epa.gov/globalwarming/) The global warming web site of the U.S. Environmental Protection Agency. The site provides links to information on the causes, impact, and trends related to global climate change.

2. [http://ipcc.ch/](http://ipcc.ch/) The web site for the Intergovernmental Panel on Climate Change, a United Nations-sponsored agency “to assess the scientific, technical, and socioeconomic information relevant for the understanding of the risk of human-induced climate change.” Their web site includes assessment reports detailing the relationships between human actions and global climate change.

3. [http://wri.org/climate/](http://wri.org/climate/) World Resource Institute’s web site on climate and atmosphere. The site includes several articles and case studies, including research on Clean Development Mechanisms.
