CHAPTER 13

Global Climate Change: Policy Responses

CHAPTER 13 FOCUS QUESTIONS

• What are the possible policy responses to global climate change?
• What does economic theory suggest about appropriate policy response?
• What climate policies have been proposed and implemented at local, national, and global levels?

adaptive measures/adaptive strategies actions designed to reduce the magnitude or risk of damages from global climate change.

preventive measures/preventive strategies actions designed to reduce the extent of climate change by reducing projected emissions of greenhouse gases.

13.1 ADAPTATION AND MITIGATION

As discussed in Chapter 12, the scientific evidence regarding the seriousness of global climate change supports policy action. Economic analyses of climate change have generally recommended policy changes, although with considerable variability. The Stern Review on the Economics of Climate Change, in particular, calls for “an urgent global response.”

Recent economic analyses of climate change have placed greater emphasis on insurance against catastrophic risks and the need to adapt to inevitable climate change impacts.

Policy responses to climate change can be broadly classified into two categories: adaptive measures to deal with the consequences of climate change and mitigation, or preventive measures intended to lower the magnitude or timing of climate change. Adaptive measures include:

• Construction of dikes and seawalls to protect against rising seas and extreme weather events such as floods and hurricanes.
• Shifting cultivation patterns in agriculture to adapt to changing weather conditions.
• Creating institutions that can mobilize the needed human, material, and financial resources to respond to climate-related disasters.

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Mitigation measures include:

- Reducing emissions of greenhouse gases by meeting energy demands from sources with lower greenhouse gas emissions (e.g., switching from coal to wind energy for electricity).
- Reducing greenhouse gas emissions by increasing energy efficiency (e.g., demand-side management, as discussed in Chapter 11).
- Enhancing natural carbon sinks. Carbon sinks are areas where carbon may be stored; natural sinks include soils and forests. Human intervention can either reduce or expand these sinks through forest management and agricultural practices. Forests recycle carbon dioxide (CO$_2$) into oxygen; preserving forested areas and expanding reforestation can have a significant effect on net CO$_2$ emissions. Soils are also vast carbon repositories, with three times more carbon stored in soils than in the atmosphere. Restoring degraded soils could capture large quantities of CO$_2$.

**carbon sinks** portions of the ecosystem with the ability to absorb certain quantities of carbon dioxide, including forests and oceans.

**cost-benefit analysis** (CBA) a tool for policy analysis that attempts to monetize all the costs and benefits of a proposed action to determine the net benefit.

**cost-effectiveness analysis** a policy tool that determines the least-cost approach for achieving a given goal.

**pollution tax(es)** a per-unit tax based on the level of pollution.

**transferable (tradable) permits** tradable permits that allow a firm to emit a certain quantity of a pollutant.

Economic analysis can provide policy guidance for nearly any particular preventive or adaptive measure. **Cost-benefit analysis**, discussed in Chapters 7 and 12, can present a basis for evaluating whether a policy should be implemented. However, as discussed in Chapter 12, economists disagree about the appropriate assumptions and methodologies for cost-benefit analyses of climate change. A less controversial conclusion from economic theory is that we should apply **cost-effectiveness analysis** in considering which policies to adopt. The use of cost-effectiveness analysis avoids many of the complications associated with cost-benefit analysis. While cost-benefit analysis attempts to offer a basis for deciding upon policy goals, cost-effectiveness analysis accepts a goal as given by society and uses economic techniques to determine the most efficient way to reach that goal.

In general, economists usually favor approaches that work through market mechanisms to achieve their goals. Early in the climate change debate, in 1997, a statement by leading economists endorsed market-based policies to slow climate change (see Box 13.1). Market-oriented approaches are considered cost effective; rather than attempting to control market actors directly, they shift incentives so that individuals and firms will change their behavior to take external costs and benefits into account. Examples of market-based policy tools include **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.

Most of this chapter focuses on mitigation policies, but it is becoming increasingly evident that mitigation policies need to be supplemented with adaption policies. Climate change is already occurring, and even if significant mitigation policies are implemented in the
immediate future, warming and sea-level rise will continue well into the future, even for centuries. The urgency and ability to institute adaptive measures varies across the world. It is the world’s poor who face the greatest need to adapt but also most lack the necessary resources.

[Climate change’s] adverse impacts will be most striking in the developing nations because of their geographical and climatic conditions, their high dependence on natural resources, and their limited capacity to adapt to a changing climate. Within these countries, the poorest, who have the least resources and the least capacity to adapt, are the most vulnerable. Projected changes in the incidence, frequency, intensity, and duration of climate extremes (for example, heat waves, heavy precipitation, and drought), as well as more gradual changes in the average climate, will notably threaten their livelihoods—further increasing inequities between the developing and developed worlds.

### BOX 13.1 ECONOMISTS’ STATEMENT ON CLIMATE CHANGE

In 1997, more than 2,500 economists, including eight Nobel laureates, signed the following public statement calling for serious steps to deal with the risks of global 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.


The Intergovernmental Panel on Climate Change (IPCC) has identified adaptation needs by major sectors, as shown in Table 13.1. Some of the most critical areas for adaptation include water, agriculture, and human health. Climate change is expected to increase precipitation in some areas, mainly the higher latitudes including Alaska, Canada, and Russia, but decrease it in other areas, including Central America, North Africa, and southern Europe. A reduction in water runoff from snowmelt and glaciers could threaten the water supplies of more than a billion people in areas such as India and parts of South America. Providing safe drinking water in these regions may require building new dams for water storage, increasing the efficiency of water use, and other adaptation strategies.

Changing precipitation and temperature patterns have significant implications for...
agriculture. With moderate warming, crop yields are expected to increase in some colder regions, including parts of North America, but overall the impacts on agriculture are expected to be negative, and increasingly so with greater warming. In the US, climate change has worsened and lengthened the episodes of droughts in the Western States, notably California, which, as a result, has already forced farmers to adapt to less water-intensive crops, replacing orange groves and avocado trees with other tree crops such as pomegranates or cactus-like dragonfruit. Agricultural impacts are expected to be the most severe in Africa and Asia. More research is necessary to develop crops that can grow under anticipated drier weather conditions. Agriculture may need to be abandoned in some areas but expanded in others.

Table 13.1 Climate Change Adaptation Needs, by Sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>Adaptation strategies</th>
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</thead>
<tbody>
<tr>
<td>Water</td>
<td>Expand water storage and desalination</td>
</tr>
<tr>
<td></td>
<td>Improve watershed and reservoir management</td>
</tr>
<tr>
<td></td>
<td>Increase water-use and irrigation efficiency and water re-use</td>
</tr>
<tr>
<td></td>
<td>Urban and rural flood management</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Adjust planting dates and crop locations</td>
</tr>
<tr>
<td></td>
<td>Develop crop varieties adapted to drought, higher temperatures</td>
</tr>
<tr>
<td></td>
<td>Improved land management to deal with floods/droughts</td>
</tr>
<tr>
<td></td>
<td>Strengthen indigenous/traditional knowledge and practice</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Relocate vulnerable communities</td>
</tr>
<tr>
<td></td>
<td>Build and strengthen seawalls and other barriers</td>
</tr>
<tr>
<td></td>
<td>Create and restore wetlands for flood control</td>
</tr>
<tr>
<td></td>
<td>Dune reinforcement</td>
</tr>
<tr>
<td>Human health</td>
<td>Health plans for extreme heat</td>
</tr>
<tr>
<td></td>
<td>Increase tracking, early-warning systems for heat-related diseases</td>
</tr>
<tr>
<td></td>
<td>Address threats to safe drinking water supplies</td>
</tr>
<tr>
<td></td>
<td>Extend basic public health services</td>
</tr>
<tr>
<td>Transport</td>
<td>Relocation or adapt transport infrastructure</td>
</tr>
<tr>
<td></td>
<td>New design standards to cope with climate change</td>
</tr>
<tr>
<td>Energy</td>
<td>Strengthen distribution infrastructure</td>
</tr>
<tr>
<td></td>
<td>Address increased demand for cooling</td>
</tr>
<tr>
<td></td>
<td>Increase efficiency, increase use of renewables</td>
</tr>
<tr>
<td>Ecosystems</td>
<td>Reduce other ecosystem stresses and human use pressures</td>
</tr>
<tr>
<td></td>
<td>Improve scientific understanding, enhanced monitoring</td>
</tr>
<tr>
<td></td>
<td>Reduce deforestation, increase reforestation</td>
</tr>
<tr>
<td></td>
<td>Increase mangrove, coral reef, and seagrass protection</td>
</tr>
</tbody>
</table>

Source: IPCC, 2007; IPCC, 2014b.

The impacts of climate change on human health are already occurring. The World Health Organization (WHO) has estimated that more than 140,000 people per year are already dying as a direct result of climate change, primarily in Africa and Southeast Asia. The WHO estimates that after 2030, climate change will result in 250,000 additional deaths per years,
caused by malnutrition, malaria, diarrhea, and heat stress. The WHO estimates direct damage costs to health at between US$ 2–4 billion per year by 2030. WHO policy recommendations include strengthening public health systems, including increased education, disease surveillance, vaccination, and preparedness.7

Various estimates exist for the cost of appropriate adaptation measures. The United Nations Environment Program (UNEP) estimates that the cost of adaptation for developing nations could rise to between $140 and $300 billion per year by 2030, and between $280 and $500 billion per year by 2050. These sums significantly exceed the $100 billion per year pledged by developed nations in the 2015 Paris Agreement. UNEP warns that there will be a significant finance gap, “likely to grow substantially over the coming decades, unless significant progress is made to secure new, additional and innovative financing for adaptation”. Adaptation costs are already two to three times higher than current international public funding for adaptation.8

13.2 CLIMATE CHANGE MITIGATION: ECONOMIC POLICY OPTIONS

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 current 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. From a social perspective, the market price for fossil fuels is too low and the quantity consumed too high, as discussed in Chapter 11.

| **carbon tax** | a per-unit tax on goods and services based on the quantity of carbon dioxide emitted during the production or consumption process. |
| **social cost of carbon** | an estimate of the financial cost of carbon emissions per unit, including both present and future costs. |

**Carbon Taxes**

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 on carbon-based fossil fuels in proportion to the amount of carbon associated with their production and use. Such a tax will raise the price of carbon-based energy sources and so give consumers incentives to conserve energy overall (which would reduce their tax burden), as well as shifting their demand to alternative sources of energy that produce lower carbon emissions (and are thus taxed at lower rates). In economic terms, the level of such a tax should be based on the **social cost of carbon** – an estimate of the financial impact on society of carbon emissions. The U.S. Environmental Protection Agency estimates the social cost of carbon, based on varying assumptions, as being between $11 and $212, with a median range around $50.9 (As noted in Chapter 12, a major reason for differing estimates is assumptions regarding discount rates and risk/uncertainty).

Table 13.2 shows the impact that different levels of a carbon tax would have on the prices of coal, oil, and natural gas. The tax here is given in dollars per ton of CO₂ (see Box 13.2 for a discussion of the difference between a tax on carbon and a tax on CO₂). Based on energy content, measured in British Thermal Units (Btus), coal is the most carbon-intensive fossil fuel, while natural gas produces the lowest carbon emissions per Btu (Figure 13.1). Calculating the impact of a carbon tax relative to the standard commercial units for each fuel

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source, we see that a carbon tax of $50/ton of CO₂, for example, raises the price of a gallon of gasoline by about 44 cents, or 20%, based on 2016 prices (Figure 13.2). A tax of $100/ton of CO₂ equates to an increase in gasoline prices of about 88 cents per gallon. The impact of a carbon tax would be even greater for coal prices—a tax of $50/ton of CO₂ would increase coal prices by 262%. And a $100/ton tax would raise coal prices by a factor of five. For natural gas, the percent impact is about the same as for gasoline. For natural gas, although its carbon content is lower than that of gasoline, its low price (as of 2016) means that the percentage impact on price is about the same as for gasoline.

Table 13.2 Alternative Carbon Taxes on Fossil Fuels

<table>
<thead>
<tr>
<th>Impact of Carbon Price on Retail Price of Gasoline</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>kg CO₂ per gallon</td>
<td>8.89</td>
</tr>
<tr>
<td>tonnes CO₂ per gallon</td>
<td>0.00889</td>
</tr>
<tr>
<td>$/gal., $50/tonne tax</td>
<td>$0.45</td>
</tr>
<tr>
<td>$/gal., $100/tonne tax</td>
<td>$0.88</td>
</tr>
<tr>
<td>Retail price (2016) per gallon</td>
<td>$2.20</td>
</tr>
<tr>
<td>% increase, $50/tonne tax</td>
<td>20.2</td>
</tr>
<tr>
<td>% increase, $100/tonne tax</td>
<td>40.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impact of Carbon Price on Retail Price of Coal</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>kg CO₂ per short ton</td>
<td>2100</td>
</tr>
<tr>
<td>tonnes CO₂ per short ton</td>
<td>2.1</td>
</tr>
<tr>
<td>$/short ton, $50/tonne tax</td>
<td>$105</td>
</tr>
<tr>
<td>$/short ton, $100/tonne tax</td>
<td>$210</td>
</tr>
<tr>
<td>Retail price (2016) per short ton</td>
<td>$40</td>
</tr>
<tr>
<td>% increase, $50/tonne tax</td>
<td>262.5</td>
</tr>
<tr>
<td>% increase, $100/tonne tax</td>
<td>525.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impact of Carbon Price on Retail Price of Natural Gas</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>kg CO₂ per 1000 cu. ft.</td>
<td>53.12</td>
</tr>
<tr>
<td>tonnes CO₂ per 1000 cu. ft.</td>
<td>0.05312</td>
</tr>
<tr>
<td>$/1000 cu. ft., $50/tonne tax</td>
<td>$2.66</td>
</tr>
<tr>
<td>$/1000 cu. ft., $100/tonne tax</td>
<td>$5.31</td>
</tr>
<tr>
<td>Retail price (2016)</td>
<td>$12</td>
</tr>
<tr>
<td>% increase from $50/tonne tax =</td>
<td>22.1</td>
</tr>
<tr>
<td>% increase from $100/tonne tax =</td>
<td>44.2</td>
</tr>
</tbody>
</table>

Source: Carbon emissions calculated from carbon coefficients and thermal conversion factors available from the U.S. Department of Energy. All price data from the U.S. Energy Information Administration.
**BOX 13.2 CARBON TAX CONVERSIONS**

A common point of confusion is that a carbon tax can be expressed as either a tax per unit of carbon or per unit of carbon dioxide. When comparing different carbon tax proposals we need to be careful that we are expressing each tax in the same units. Say, for example, that an economist proposes a tax of $100 per ton of carbon, while another economist proposes a tax of $35 per ton of carbon dioxide. Which one is proposing the larger tax?

To convert between the two units, we first note the relative molecular weights of carbon and carbon dioxide (CO2). Carbon has a molecular weight of 12, while CO2 has a molecular weight of 44. So if we want to convert a tax of $100 per ton of carbon into a tax per ton of CO2, we would multiply the tax by 12/44, or 0.2727:

\[ \$100 \times 0.2727 = \$27.27 \]

So a tax of $100 per ton of carbon is equivalent to a tax of about $27 per ton of CO2. If we wanted instead to convert the tax of $35 per ton of CO2, we would multiply by the inverse ratio of 44/12, or 3.6667:

\[ \$35 \times 3.6667 = \$128.33 \]

So a tax of $35 per ton of CO2 is equivalent to a tax of about $128 per ton of carbon. Using either comparison, we can conclude that a tax of $35 per ton of CO2 is larger than a tax of $100 per ton of carbon.

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**Figure 13.1 Carbon Content of Fuels**

![Carbon Content of Fuels](chart)

*Source:* Calculated from U.S. Department of Energy data.
Will these tax amounts affect people’s driving or home heating habits very much, or impact industry’s use of fuels? This depends on the elasticity of demand for these fuels. As noted earlier (see Chapter 3 Appendix), elasticity of demand is defined as:

\[
\text{Elasticity of demand} = \frac{\text{Percent change in quantity demanded}}{\text{percent change in price}}
\]

Economists have measured the elasticity of demand for different fossil fuels, particularly gasoline. (Elasticity of demand is generally negative, since a positive percent change in price causes a negative percent change in quantity demanded.) Studies indicate that in the short term (about one year or less) elasticity estimates ranged from \(-0.03\) to \(-0.25\). This means that a 10 percent increase in the price of gasoline would be expected to decrease gasoline demand in the short term by about \(-0.3\) to \(-2.5\) percent.

In the long term (about five years or so) people are more responsive to gasoline price increases, as they have time to purchase different vehicles and adjust their driving habits. The average long-term elasticity of demand for motor fuels, based on fifty-one estimates, is \(-0.64\). According to Table 13.2, a tax of $50 per ton of CO\(_2\) would increase the price of gasoline by about 20 percent, adding 44 cents per gallon to the price of gasoline based on 2016 prices. A long-term elasticity of \(-0.64\) suggests that after people have time to fully adjust to this price change, the demand for gasoline should decline by about 13 percent.

Figure 13.3 shows a cross-country relationship between gasoline prices and per capita consumption. (Since the cost of producing a gallon of gasoline varies little across countries, variations in the price of a gallon in different countries is almost solely a function of differences in taxes.) Note that this relationship is similar to that of a demand curve: Higher prices are associated with lower consumption, and lower prices with higher consumption.

The relationship shown here, however, 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, does not hold. Differences in demand may, for example, be in part a function of differences in income levels rather than prices. Also, people in the United States may drive more partly because travel distances (especially in the western
United States) are greater than in many European countries, and public transportation options fewer. 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.

Would a large gasoline tax increase, or a broad-based carbon tax, ever be politically feasible? Especially in the United States, high taxes on gasoline and other fuels would face much opposition. As Figure 13.3 shows, the United States has by far the highest gasoline consumption per person and the lowest prices outside the Middle East. But let us note two things about the proposal for substantial carbon taxes:

**Figure 13.3 Gasoline Price Versus Consumption in Industrial Countries, 2012**

![Graph showing gasoline price versus consumption in industrial countries, 2012.](image)


*Note: Shaded area represents price/consumption range typical of West European countries.*

- **Revenue-neutral tax shift** policies that are designed to balance tax increases on certain products or activities with a reduction in other taxes, such as a reduction in income taxes that offsets a carbon-based tax.

- First, revenue recycling could redirect the revenue from carbon and other environmental 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 were matched, for example, with a substantial cut in income or social security taxes, it might be more politically acceptable.

- The idea of increasing taxes on economic “bads,” such as pollution, while reducing taxes on things we want to encourage, such as labor and capital investment, is fully consistent with principles of economic efficiency. Rather than a net tax increase, this would be **revenue-neutral tax shift**—the total amount that citizens pay to the government in taxes is essentially unchanged. Some of the tax revenues could also be used to provide relief for low-income people to offset the burden of higher energy...
costs.

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

** Tradable Permits**

| cap and trade | a tradable permit system for pollution emissions |

An alternative to a carbon tax is a system of tradable carbon permits, also called **cap-and-trade**. A carbon trading scheme can be implemented at the state or national level, or could include multiple countries. A national permit system could work as follows, as discussed in Chapter 8:

- Each emitting firm would be allocated a specific permissible level of carbon emissions. The total number of carbon permits issued would equal the desired national goal. For example, if carbon emissions for a particular country are currently 40 million tons and the policy goal is to reduce this by 10 percent (4 million tons), then permits would be issued to emit only 36 million tons. Over time, the goal could be increased, with the result that fewer permits would be issued in future periods.

- Permits are allocated to individual carbon-emitting sources. Including all carbon sources (e.g., all motor vehicles) in a trading scheme is generally not practical. It is most effective to implement permits as far upstream in the production process as possible to simplify the administration of the program and cover the most emissions. (“upstream” here denotes an early stage in the production process, as discussed in Chapter 3 regarding a pollution tax). Permits could be allocated to the largest carbon emitters, such as power companies and manufacturing plants, or even further upstream to the suppliers through which carbon fuels enter the production process—oil producers and importers, coal mines, and natural gas drillers.

- These permits could initially be allocated for free on the basis of past emissions or auctioned to the highest bidders. As discussed in Chapter 8, the effectiveness of the trading system should be the same regardless of how the permits are allocated. However, there is a significant difference in the distribution of costs and benefits: Giving permits out for free essentially amounts to a windfall gain for polluters, while auctioning permits imposes real costs upon firms and generates public revenues.

- Firms are able to trade permits freely among themselves. Firms whose emissions exceed the number of permits they hold must purchase additional permits or else face penalties. Meanwhile firms that are able to reduce their emissions below their allowance at low cost will seek to sell their permits for a profit. A permit price will be determined through market supply and demand. It may also be possible for environmental groups or other organizations to purchase permits and retire them—thus reducing overall emissions.

- In an international system, countries and firms could also receive credit for financing carbon reduction efforts in other countries. For example, a German firm could get...
credit for installing efficient renewable electric generating equipment in China, replacing highly polluting coal plants.

A tradable permit system encourages the least-cost carbon reduction options to be implemented, as rational firms will implement those emission-reduction actions that are cheaper than the market permit price. As discussed in Chapter 8, tradable permit systems have been successful in reducing sulfur and nitrogen oxide emissions at low cost. Depending on the allocation of permits in an international scheme, it might also mean that developing countries 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 countries that were having trouble meeting their reduction requirements. Farmers and foresters could also get carbon credits for using methods that store carbon in soils or preserve forests.

While the government sets the number of permits available, the permit price is determined by market forces. In this case, the supply curve is fixed, or vertical, at the number of permits allocated, as shown in Figure 13.4. The supply of permits is set at \( Q_0 \). The demand curve for permits represents firms’ willingness to pay for them. Their maximum willingness to pay for permits is equal to the potential profits they can earn by emitting carbon.

**Figure 13.4 Determination of Carbon Permit Price**

![Graph showing the determination of carbon permit price](image)

*Note: WTP = Willingness to pay.*

Assume that the permits will be auctioned off one by one to the highest bidders (a process known as a sequential auction). Figure 13.4 shows that the willingness to pay for the first permit would be quite high, as a particular firm stands to make a relatively large profit by being allowed to emit one unit of carbon. For the second permit, firms that failed to obtain the first permit would be expected to simply repeat their bids. The firm that successfully bid for the first permit could also bid for the second permit, but would be expected to bid a lower amount assuming their marginal profits are declining (i.e., their supply curve slopes upward, as is normal).

Regardless of whether the same firm wins the bid for the second permit, or a new firm,
the selling price for the second permit would be lower. This process would continue, with all successive permits selling for lower prices, until the last permit is auctioned off. The selling price of this permit, represented by $P^*$ in the graph, is the market-clearing permit price. We can also interpret $P^*$ as the marginal benefit, or profit, associated with the right to emit the $Q_0$ unit of carbon.

While permits could theoretically sell for different prices in a sequential auction, tradable permit markets are normally set up so that all permits sell for the market-clearing price. This is the case for the acid rain program in the United States, which has operated since 1995 and is widely considered to be a successful emissions trading program, as discussed in Chapter 8, Box 8.2. In that program, all parties interested in purchasing permits make their bids, indicating how many permits they are willing to purchase at what price. Whoever bids the highest gets the number of permits that were requested. Then the second-highest bidders get the number of permits they applied for, and so on until all permits are allocated. The selling price of all permits is the winning bid for the very last permit available. This would be $P^*$ in Figure 13.4. All bidders who bid below this price do not receive any permits.

Another important point is that each firm can choose to reduce its carbon emissions in a cost-effective manner. Firms have various options for reducing their carbon emissions. Figure 13.5 shows an example in which a firm has three carbon reduction strategies: replacing older manufacturing plants, investing in energy efficiency, and funding forest expansion to increase carbon storage in biomass. In each case, the graph shows the marginal costs of reducing carbon emissions through that strategy. These marginal costs generally rise as more units of carbon are reduced, but they may be higher and increase more rapidly for some options than others.

**Figure 13.5 Carbon Reduction Options with a Permit System**

![Diagram showing carbon reduction options with a permit system](Image)

*Note: Marginal costs shown here are hypothetical.*

In this example, replacement of manufacturing plants using existing carbon-emitting technologies is possible but will tend to have high marginal costs—as shown in the first graph in Figure 13.5. Reducing emissions through greater energy efficiency has lower marginal costs, as seen in the middle graph. Finally, carbon storage through forest area expansion has the lowest marginal costs. The permit price $P^*$ (as determined in Figure 13.4) will govern the relative levels of implementation of each of these strategies. Firms will find it profitable to reduce emissions using a particular strategy so long as the costs of that option are lower than the cost of purchasing a permit. The analysis indicates that forest
expansion would be used for the largest share of the reduction ($Q_{FE}$), but plant replacement and energy efficiency would also contribute shares ($Q_{PR}$ and $Q_{EE}$) at the market equilibrium. Firms (and countries if the program is international) that participate in such a trading scheme can thus 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. In an international program, suppose that one country undertakes extensive reforestation. It is then likely to have excess permits, which it can sell to a country 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 in overall emissions to the desired level. The major problem, of course, is achieving agreement on the initial number of permits, and deciding whether the permits will be allocated freely or auctioned off. There may also be measurement problems and issues such as whether to count only commercial carbon emissions or to include emissions changes that result from land use changes such as those associated with agriculture and forestry. Including agriculture and forestry has the advantage of broadening the scheme to include many more, reduction strategies, possibly at significantly lower cost, but it may be more difficult to get an accurate measure of carbon storage and release from land use change.

**Carbon Taxes or Cap and Trade?**

There is a lively debate regarding which economic approach should be used to reduce carbon emissions. Carbon taxes and a cap-and-trade approach have important similarities but also important differences.

As discussed in Chapter 8, both pollution taxes and cap-and-trade can, in theory, achieve a given level of pollution reduction at the least overall cost. Both approaches will also result in the same level of price increases to final consumers, and both create a strong incentive for technological innovation. Both approaches can raise the same amount of government revenue, assuming all permits are auctioned off, and can be implemented upstream in production processes to cover the same proportion of total emissions.

Yet the two policies have several important differences. Some of the advantages of a carbon tax include:

- In general, a carbon tax is considered simpler to understand and more transparent than a cap-and-trade approach. Cap-and-trade systems can be complex and require new bureaucratic institutions to operate.
- As we saw in Chapter 8, with technological change that lowers the cost of carbon reduction, a carbon tax will automatically further reduce carbon emissions. In a cap-and-trade program, technological change will instead reduce the price of permits, probably resulting in some firms actually emitting more carbon.
- A carbon tax could probably be implemented more quickly. Given the need to address climate change as soon as possible, it may be inadvisable to spend years working out the details and implementation of a cap-and-trade program.
- Perhaps the most important advantage of a carbon tax is that it provides greater price predictability. If businesses and households know what future taxes will be on fossil fuels and other greenhouse gas–emitting products, they can invest accordingly. For example, whether a business invests in an energy efficient heating and cooling system depends on its expectations of future fuel prices. In a cap-and-trade system, permit prices could vary considerably, leading to **price volatility** that makes planning
difficult. A carbon tax, by contrast, provides a degree of price stability, especially if carbon tax levels are published years into the future.

**price volatility** rapid and frequent changes in price, leading to market instability.

The advantages of a cap-and-trade system include:

- Even though a cap-and-trade system ultimately results in the same level of price increases to consumers and businesses, it avoids the negative connotations of a “tax.” So a cap-and-trade system often generates less political opposition than a carbon tax.
- Some businesses favor cap-and-trade because they believe that they can successfully lobby governments for free permits, rather than having to purchase them at auction. Distributing permits for free in the early stages of a cap-and-trade program can make it more politically acceptable to businesses.
- The greatest advantage of a cap-and-trade approach is that emissions are known with certainty because the government sets the number of available permits. Since the policy goal is ultimately to reduce carbon emissions, a cap-and-trade approach does this directly while a carbon tax does it indirectly through price increases. Using a cap-and-trade approach, we can achieve a specific emissions path simply by setting the number of permits. In a carbon tax system, achieving a specific emissions target may require numerous adjustments to the tax rates, which may be politically very difficult.

The choice of instrument—carbon tax or cap-and-trade—mainly depends on whether policy makers are more concerned with price uncertainty or emissions uncertainty. (Recall the discussion on price versus quantity instruments in Chapter 8). If you take the perspective that price certainty is important because it allows for better long-term planning, then a carbon tax is preferable. If you believe that the relevant policy goal is to reduce carbon emissions by a specified amount with certainty, then a cap-and-trade approach is preferable, although it may lead to some price volatility. Another practical difference appears to be that carbon tax revenues are more often refunded to taxpayers or used in general government spending, while cap-and-trade auction revenues are more often used to support such “green” investments as renewable energy, energy efficiency, and forest conservation.12

**Other Policy Tools: Subsidies, Standards, R&D, and Technology Transfer**

Political hurdles may prevent the adoption of sweeping carbon taxes or transferable permit systems. Fortunately, a variety of other policy measures have the potential to lower carbon emissions. Even with implementation of a widespread carbon tax or cap-and-trade system, supplemental policies may still be necessary to reduce carbon emissions sufficiently to keep warming within acceptable levels. These policies are generally not considered to be sufficient by themselves, but they may be important components of a comprehensive approach. To some extent these policies are already being implemented in various countries. These policies include:

- *Shifting subsidies from carbon-based to non-carbon-based fuels.* Many countries currently provide direct or indirect subsidies to fossil fuels, as discussed in Chapter 11. 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 renewables.

- **The use of efficiency standards** for machinery and appliances, and fuel-economy standards or requirements for low-carbon fuels. By imposing standards that require greater energy efficiency or lower carbon use, technologies and practices can be altered in favor of a low-carbon path.

- **Research and development (R&D) expenditures promoting 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 non-carbon “backstop” technologies significantly reduces the economic cost of measures such as carbon taxes, and if the backstop were to become fully competitive with fossil fuels, carbon taxes would be unnecessary.

- **Technology transfer to developing countries.** 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 toward non-carbon energy systems, supplemented by other funds dedicated specifically to alternative energy development, it will be economically feasible for developing countries to turn away from fossil-fuel intensive paths, achieving significant local environmental benefits at the same time.

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**efficiency standards** regulations that mandate efficiency criteria for goods, such as fuel economy standards for automobiles.

**technology transfer** the process of sharing technological information or equipment, particularly among countries.

## 13.3 Climate Change: The Technical Challenge

Meeting the climate change challenge requires both behavioral change and technological change. Economic policy instruments such as carbon taxes, cap and trade, and subsidies use incentives to motivate changes in behavior. For example, a carbon tax that raises the price of gasoline will create incentives to drive less or buy a more fuel-efficient vehicle. But we can also look at climate change from a technical perspective rather than a behavioral perspective. Economic policies can create powerful incentives for technological changes. Because of higher gas prices as a result of a carbon tax, the increased demand for high-efficiency vehicles would motivate automobile companies to direct more of their investments to hybrid and electric vehicles.

It is worthwhile to consider what needs to be done in response to climate change from a technical perspective—not just to gain a greater understanding of the issues but to also gain some insights for appropriate policies. We now summarize two well-known analyses of the technical aspects of carbon mitigation.

**Climate Stabilization Wedges**

Some proposals for carbon mitigation require significant technological advancement, such as the widespread use of artificial photosynthesis, carbon capture and storage, or nuclear fusion. The future cost and technical feasibility of these technologies remain uncertain. Ideally, we could reduce carbon emissions sufficiently using existing technologies or those reasonably expected to be available in the near future. One way of summarizing the potential for scaling up existing technologies is the “carbon wedge” concept proposed by physical scientists Stephen Pacala and Robert Socolow.13
They present the climate challenge as shown in Figure 13.6. Under a business as usual (BAU) scenario, carbon emissions are expected to approximately double during the fifty years from 2010 to 2060, from about 9 billion tons of carbon per year to 18 billion tons. Pacala and Socolow identify specific policies that would each effectively reduce total emissions by 1 billion tons per year by 2060. Each of these actions produces a climate stabilization wedge that moves emission down from the BAU scenario. Thus if nine of these wedges were implemented, carbon emissions would remain steady over the next fifty years, even as population expands and economies grow.

**Climate stabilization wedge** a concept in which specific mitigation actions are presented to reduce projected global greenhouse gas emissions by one gigaton each (one gigaton reduction equals one wedge).

![Figure 13.6 Climate Stabilization Wedges](image)

*Source: Pacala and Socolow, 2004; Socolow and Pacala, 2006; Socolow, 2011*

The proposed policies are broadly divided into three categories: increased energy efficiency, energy supply-side shifts, and carbon storage. Possible policies include:

- Double fuel efficiency of 2 billion cars from 30 to 60 miles per gallon (mpg).
- Decrease the number of car miles traveled globally by half.
- Use best-efficiency practices in all residential and commercial buildings.
- Produce current coal-based electricity with twice today’s efficiency.
- Replace 1,400 coal electricity plants with natural gas-powered facilities.
- Capture and store emissions from 800 coal electricity plants.
- Add double the current global nuclear capacity, displacing coal plants.
- Add 2 million 1-Megawatt wind turbines (about 5 times 2015 capacity). Add 2,000 Gigawatts of photovoltaic power (about 11 times 2015 capacity).
- Use 40,000 square kilometers of solar panels (or 4 million wind turbines) to produce hydrogen for fuel cell cars.
- Eliminate tropical deforestation.
- Adopt conservation tillage in all agricultural soils worldwide.14
All of these policies would need to be implemented on a global, rather than national, scale. Also, as indicated by Figure 12.11 in the previous chapter, keeping emissions constant over the next fifty years will not be sufficient to keep warming to acceptable levels. Thus more than nine “wedges” will be required to stabilize atmospheric accumulations of carbon. The wedges concept, though, does indicate significant potential from existing technologies:

None of the options is a pipe dream or an unproven idea. Today, one can buy electricity from a wind turbine, PV array, gas turbine, or nuclear power plant. One can buy hydrogen produced with the chemistry of carbon capture, biofuel to power one’s car, and hundreds of devices that improve energy efficiency. One can visit tropical forests where clear-cutting has ceased, farms practicing conservation tillage, and facilities that inject carbon into geologic reservoirs. Every one of these options is already implemented at an industrial scale and could be scaled up further over 50 years to provide at least one wedge.\footnote{15}

Significant policy changes will be needed to implement these wedges on a global scale. Most important, Pacala and Socolow note the need for carbon to be properly priced, with a suggested price of $100–$200 per ton of carbon ($27–$55 per ton of CO\textsubscript{2}). This would equate to about 25 cents per gallon of gasoline.

They also address the path of carbon emissions for developing and developed countries. If members of the Organization for Economic Cooperation and Development (OECD) were to reduce their emissions by 60 percent over the next fifty years, emissions could theoretically grow by 60 percent in the non-OECD countries over the same time period, allowing them space for economic development while keeping total emissions stable. Yet even with this allocation, per capita emissions would still be twice as high in the OECD countries as in the developing countries. And, as noted in Chapter 12, stabilizing emissions will not be sufficient to avert the worst impacts of climate change—significant overall global reduction will be needed.

**Greenhouse Gas Abatement Cost Curves**

The climate stabilization wedges analysis does not address the costs of each wedge. Obviously some wedges would be cheaper than others to implement. Depending on the social cost of carbon emissions, some wedges may not provide net benefits to society. For a more complete economic analysis, we also need to consider costs.

Another well-known analysis, by McKinsey & Company, estimates both the costs and the potential carbon reduction of more than 200 greenhouse gas mitigation, or abatement, options on a global scale. The various options are arranged in order of cost, from lowest cost to highest. The economic logic is that it makes sense to implement actions that reduce carbon at the lowest per-unit costs first and then proceed to more costly actions. The results of their analysis are presented in Figure 13.7. The costs are estimated in euros, but the analysis covers worldwide reduction possibilities.\footnote{16}

This figure takes a little explanation. The y-axis indicates the cost range for each abatement option, measured in euros per ton of CO\textsubscript{2} reduction per year (or an amount equivalent to one ton of CO\textsubscript{2} for reductions in other gases such as methane). The thickness of the bar represents the amount of CO\textsubscript{2} emissions that can be avoided by each action. The cost of policies such as building insulation, increased efficiency, and waste recycling is in the negative range. This means that these policies would actually save money, regardless of their effect on CO\textsubscript{2} emissions. So even if we did not care about climate change and the environment, it would make sense to insulate buildings, increase appliance and recycle wastes, solely on long-term financial grounds.
The x-axis tells us the cumulative reduction in CO$_2$ equivalent emissions, relative to a BAU scenario, if we were to implement all the actions to the left. So if we were to implement all negative-cost options including improving efficiency of air-conditioning, lighting systems, and water heating, total CO$_2$ equivalent reduction would be about 10 billion tons (Gt) per year, all while saving money!

Moving farther to the right, actions are identified that do entail positive costs. In other words, for all these other actions it does cost us money to reduce CO$_2$ emissions. Figure 13.7 shows all actions that reduce CO$_2$ emissions for a cost of less than €60 per t, including expanding wind and solar energy, expanding nuclear energy, improved forest management and reforestation, and implementing carbon capture and storage (CCS). (“Low penetration” wind is defined as expanding wind energy to provide as much as 10 percent of electricity supplies, while “high penetration” expands wind energy further, at slightly higher cost.)

If all these actions were implemented, total CO$_2$-equivalent reduction would be 38 billion tons/year. Total global CO$_2$ equivalent emissions, including all greenhouse gases and emissions from land use change, are currently about 50 billion tons per year, projected to rise to about 70 Gt by 2030. Thus instead of emitting 70 Gt/year in 2030, we would be emitting only 32 Gt—a decrease of 18 Gt below current levels. Further reduction could be achieved at slightly higher cost, especially by more extensive expansion of wind and solar energy. (This analysis does not take into account likely cost reductions for renewable energy.) The total cost of implementing all options in Figure 13.7, considering that some options actually save money, is estimated to be less than 1 percent of global GDP in 2030. The report notes that delaying action by just ten years makes keeping warming under 2°C extremely difficult.

Policy recommendations to achieve the reductions represented in Figure 13.7 include:

- Establish strict technical standards for efficiency of buildings and vehicles.

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• Establish stable long-term incentives for power producers and industrial companies to invest in and deploy efficient technologies.
• Provide government support for emerging efficiency and renewable energy technologies, through economic incentives and other policies.
• Ensure efficient management of forests and agriculture, particularly in developing countries.\(^\text{17}\)

Again we see that instituting a carbon price is a part of a broader policy approach. A carbon tax or cap-and-trade program would create an incentive for the actions in Figure 13.7, but it does not guarantee that they will occur. In theory, we should already be using all the negative-cost options even in the absence of a carbon price, yet we are not. Standards and mandates can be an effective complement to a carbon price to ensure that cost-efficient actions are implemented. Potential policies could include efficiency standards for appliances, lighting, and building insulation.

How reliable is this abatement cost curve analysis? The McKinsey study has been subject to criticism both for underestimating and overestimating some costs. Also, some actions that are technically feasible, like reducing emissions from agricultural and forestry practices, may be difficult to achieve in practice due to political and institutional barriers.\(^\text{18}\) Nonetheless, abatement costs curves such as those presented in the McKinsey study illustrate the basic principle that many low-cost or no-cost actions could be taken to reduce carbon emissions. Emissions growth is therefore not inevitable; substantial emissions reduction below current levels can be achieved at modest economic cost.

13.4 CLIMATE CHANGE POLICY IN PRACTICE

Climate change is an international environmental issue. In economic theory terms, as we noted in Chapter 12, climate change is a public good issue, requiring global collaboration to achieve effective results. Since the United Nations Framework Convention on Climate Change (UNFCCC) was first established in 1992, there have been extensive international discussions, known as “Conferences of the Parties” or COPs, aimed at reaching a global agreement on emissions reduction (See Table13.3).

The first comprehensive international agreement on climate change was the Kyoto Protocol, adopted at the third COP in 1997, which has now expired. Under the Kyoto treaty, industrial countries agreed to emission reduction targets by 2008–2012 compared to their baseline emissions, set to 1990 levels. For example, the United States agreed to a 7 percent reduction, France to an 8 percent reduction, and Japan to a 6 percent reduction. The average target was a cut of around 5% relative to 1990 levels. Developing countries such as China and India were not bound to emissions targets under the treaty, an omission that the United States and some other countries protested. Under President George W. Bush, the U.S. refused to ratify the Kyoto Protocol. But despite the U.S. withdrawal, the Kyoto Protocol entered into force in early 2005.

The results of the Kyoto Protocol were mixed. Some nations, such as Canada and the U.S., increased rather than reduced emissions; Canada withdrew from the Protocol, and the U.S. never entered it. Some European countries met or exceeded their targets, while others fell short. Russia and most East European countries considerably exceeded their targets, not as a result of deliberate policy but rather as a byproduct of communism’s economic collapse in the early 1990s. The overall Kyoto target was technically achieved, but only as a result of this significant drop in Russian and Eastern European emissions.
Table 13.3 Important Events in International Climate Change Negotiations

<table>
<thead>
<tr>
<th>Year, Location</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992, Rio de Janeiro</td>
<td>UN Framework Convention on Climate Change (UNFCCC). Countries agree to reduce emissions with “common but differentiated responsibilities.”</td>
</tr>
<tr>
<td>1995, Berlin</td>
<td>The first annual Conference of the Parties to the framework, known as a COP. U.S. agrees to exempt developing countries from binding obligations.</td>
</tr>
<tr>
<td>1997, Kyoto</td>
<td>At the third Conference of the Parties (COP-3) the Kyoto Protocol is approved, mandating developed countries to cut greenhouse gas emissions relative to baseline emissions by 2008-2012 period.</td>
</tr>
<tr>
<td>2001, Bonn</td>
<td>(COP-6) reaches agreement on terms for compliance and financing. Bush administration rejects the Kyoto Protocol; U.S. is only an observer at the talks.</td>
</tr>
<tr>
<td>2009, Copenhagen</td>
<td>COP-15 fails to produce a binding post-Kyoto agreement, but declares the importance of limiting warming to under 2°C. Developed countries pledge $100 billion in climate aid to developing countries.</td>
</tr>
<tr>
<td>2011, Durban</td>
<td>(COP-17) participating countries agreed to adopt a universal legal agreement on climate change as soon as possible, and no later than 2015, to take effect by 2020.</td>
</tr>
<tr>
<td>2015, Paris</td>
<td>COP-21 195 nations sign the Paris Agreement, providing for worldwide voluntary actions (INDC’s) by individual countries.</td>
</tr>
</tbody>
</table>

In addition, we need to consider the effects of trade (discussed further in Chapter 21). In the Kyoto framework, emissions released during production of goods were assigned to the country where production takes place, rather than where goods are consumed. Therefore the “outsourcing” of carbon emissions through imports from developing countries, especially China, was not included in official accounting. Considering the full country carbon footprint taking trade into account, the progress made under Kyoto was very limited, with Europe’s savings reduced to just 1% from 1990 to 2008, and the developed world as a whole seeing its emissions rise by 7% in the same period (25% for the US, when trade is included). Moreover, Kyoto placed no restrictions on emissions from developing countries, meaning that overall global emissions continued to grow during the Kyoto period, as shown in Figure 12.1 in the previous chapter.19

But if the Kyoto protocol was a failure in its inability to slow down global emissions, it nevertheless provided an important first step in global climate diplomacy, and from the failures of Kyoto and its aftermath, countries learned lessons that proved useful in the later phases of those global negotiations.

**carbon footprint** total carbon emissions, direct and indirect, resulting from the consumption of a nation, institution, or individual.
The Paris Agreement of 2015

After efforts to secure a binding global agreement on emissions reductions failed at the fifteenth COP in Copenhagen in 2009, it became increasingly obvious to negotiators that another approach would be needed in order to win broad support. The Copenhagen conference parties agreed only that the goal for future rounds of negotiations would be to keep the global temperature warming below the threshold of 2°C above pre-industrial levels. The most contentious point of disagreement was the question of whether developing countries should be bound by mandatory cuts in emissions. While some countries, particularly the United States, argued that all participants should agree to reductions, developing countries contended that mandatory cuts would limit their economic development and reinforce existing global inequities.

After the failure of Copenhagen, the idea of a binding agreement was rejected as unfeasible. In its place, negotiators came up with the idea that countries would instead propose their own voluntary goals, no matter how low or high – the hope being that countries would eventually feel “peer-pressure” to set the most ambitious possible goals within their reach. This new negotiating strategy laid the foundations for the global agreement reached at the twenty-first Conference of the Parties (COP21) in Paris. In the months that preceded the COP21, 186 countries submitted their INDCs – intended nationally determined contributions – indicating their willingness to contribute to the reduction of global CO2 emissions.

**intended nationally determined contribution (INDC)** a voluntary planned reduction in CO2 emissions, relative to baseline emissions, submitted by participating countries at the Paris Conference of the Parties (COP21) in 2015.

**carbon intensity** a measure of carbon emissions per unit of GDP.

The Paris Agreement, negotiated by 195 national delegations, formally expresses the global aim of holding temperatures to no more than 2°C above preindustrial levels, with a more ambitious target of 1.5°C. Since the current total of country pledges (INDCs) is not sufficient to secure the global goal of keeping warming under 2°C, the agreement includes 5 year cycles for countries to review their goals and ratchet up their targets, in order to reach more ambitious goals. The negotiating process has been designed to put pressure on every country to comply with its own pledges and to increase them over time.

A strong transparency and accountability regime is built into the agreement, based on regular inventories, regular reporting of the progress countries are making towards their targets, and regular review by expert teams. The Paris agreement entered into force, with over 55 countries representing over 55 percent of global emissions signing on, at the end of 2016, just a year after it was negotiated, a record speed for international agreements. A related binding agreement establishing specific timetables to eliminate the production of hydrofluorocarbons (HFCs), powerful greenhouse gases used in air-conditioners and refrigerators, was agreed on in October 2015.

The Paris agreement also provides for continuing financial and technical support to developing countries to help them adapt to the disruptive consequences of climate changes, as well as support for a transition away from fossil fuels toward cleaner renewable energy sources. The agreement included a loss-and-damage clause recognizing the importance of addressing the adverse effects of climate change in developing countries. While the agreement does not accept liability or provide for compensation, it does offer several conditions where support may be given. Starting in 2020, industrialized nations have pledged $100 billion a year in financial and technical aid to developing countries to fight climate change.
Many voices in the developing world have warned that $100 billion will fall far short of what is really needed, and that a conservative figure would be closer to $600 billion, which is about 1.5% of the GDP of industrialized nations. Some of the estimates, by organizations from the World Bank to the International Applied Systems Analysis, in Vienna, suggest that the sums needed would be as high as 1.7 or even 2.2 trillion dollars per year.\textsuperscript{22}

\textit{Country Commitments for Action}

Prior to the COP21, 186 delegations had submitted their INDCs to the UNFCCC. Because these commitments were made on a voluntary basis, there are discrepancies in the approaches adopted by different countries. Some countries have chosen their baseline year as 2005, and others as 1990 (which was the baseline of the Kyoto Protocol), and calculate their future emissions with reference to that baseline. Other countries have calculated their future emissions compared to what they would have been emitting in a Business-As-Usual (BAU) scenario. Some countries have pledged reductions of CO\(_2\) emissions in absolute terms, i.e. reductions in actual volumes of emissions, and others in relative terms, or reductions in \textbf{carbon intensity} (carbon emissions per unit of GDP).

Reductions in carbon intensity partly “decouple” emissions from growth, but overall emissions can still increase with economic growth. This option has generally been chosen by developing countries, including the biggest ones, such as China and India, as they are unwilling to commit to measures that would slow down their economic growth. They seek an increasing decoupling between economic growth and the growth of CO\(_2\) emissions, but in the meantime CO\(_2\) emissions will continue to grow in most of these countries. This introduces the important idea of “peaking” emissions in developing countries – allowing total emissions to grow only for a specific period, after which they must decline. China has committed to peaking emissions by 2030.

\textit{Commitments of Major Emitters}

The INDC submitted in March 2015 by the U.S. to the UNFCCC states that:

“...the United States intends to achieve an economy-wide target of reducing its greenhouse gas emissions by 26-28 per cent below its 2005 level in 2025 and to make best efforts to reduce its emissions by 28%.” U.S. emissions targets are shown in Figure 13.8. With an unsympathetic Congress blocking any attempt to pass a climate policy bill, the Obama Administration pursued its climate agenda using administrative action. In August 2015, the United States announced the Clean Power Plan, which aims to reduce CO\(_2\) emissions from the power sector to 32% below 2005 levels by 2030.\textsuperscript{23}

China’s official commitment includes:

- Peaking carbon dioxide emissions by around 2030 and making best efforts to peak earlier.
- Lowering carbon intensity (carbon dioxide emissions per unit of GDP) by 60% to 65% from the 2005 level.
- Increasing the share of non-fossil fuels in primary energy consumption to around 20%.
- Increasing forest stock volume by around 4.5 billion cubic meters above the 2005 level.\textsuperscript{24}
The European Union and its member states are committed to a binding target of reducing greenhouse gas emissions at least 40% by 2030 compared to 1990. "The EU and its Member States have already reduced their emissions by around 19% [relative to] 1990 levels while GDP has grown by more than 44% over the same period. As a result, average per capita emissions across the EU and its Member States have fallen from 12 tonnes CO\(_2\)-eq. in 1990 to 9 tonnes CO\(_2\)-eq. in 2012 and are projected to fall to around 6 tonnes CO\(_2\)-eq. in 2030. [Total] emissions in the EU and its Member States peaked in 1979."25 Commitments by major emitters are shown in Table 13.4.

### Table 13.4: INDC commitment by major emitters

<table>
<thead>
<tr>
<th>Country</th>
<th>Base Level</th>
<th>Reduction Target</th>
<th>Target Year</th>
<th>Land-use inclusion/accounting method</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>2005</td>
<td>Emissions peaking 60-65% (carbon intensity)</td>
<td>2030 (or before)</td>
<td>Target to increase forest stock volume by around 4.5 billion cubic meters</td>
</tr>
<tr>
<td>United States</td>
<td>2005</td>
<td>26-28%</td>
<td>2025</td>
<td>“Net-net” approach</td>
</tr>
<tr>
<td>EU</td>
<td>1990</td>
<td>40%</td>
<td>2030</td>
<td>Policy on land-use accounting to be decided prior to 2020</td>
</tr>
<tr>
<td>India</td>
<td>2005</td>
<td>33-35% (carbon intensity)</td>
<td>2030</td>
<td>Not specified</td>
</tr>
<tr>
<td>Russia</td>
<td>1990</td>
<td>25-30%</td>
<td>2030</td>
<td>Target depends on the “maximum absorption capacity of forests”</td>
</tr>
<tr>
<td>Japan</td>
<td>2013</td>
<td>26%</td>
<td>2030</td>
<td>Forest and agricultural sectors are accounted for using approaches similar to those under the Kyoto Protocol</td>
</tr>
</tbody>
</table>

Source: [ww.c2es.org/indc-comparison](http://ww.c2es.org/indc-comparison)
How adequate or inadequate are the commitments?

An independent organization, Climate Action Tracker, provides assessments and ratings of submitted INDCs. According to its grading system, the USA is rated “medium” for its commitment, China is rated as “medium with inadequate carbon intensity target”, and the European Union is also rated as “medium”. The Climate Action Tracker has rated as “inadequate” the commitments of a long list of countries including Russia, Japan, Australia, New Zealand, Canada, Argentina, South Africa, Chile, and Turkey.  

Figure 13.9 shows the differences between a business-as-usual emissions trajectory, the trajectory that would result from the current aggregation of INDCs commitments, and the path that would be necessary to reach 2°C (3.6°F) or less. Most current pledges do not extend beyond 2030, which is why emissions start to rise again after 2030 in Figure 13.9. Considerable strengthening of the pledges would clearly be needed before that date to keep overall emissions on a 2°C track – let alone 1.5°C. According to analysis by the Climate Action Tracker, if policies of comparable strength to those in the current INDCs were maintained after 2030, they would lead to a median warming of about 2.7°C (4.8°F) by 2100 – better than the 3.5°C (6.3°F) shown in Figure 13.9, but still far exceeding the Paris targets. (For a scientific perspective on the importance of reaching a 2°C or even 1.5°C target, see Box 13.3.)

Figure 13.9: Business as Usual, Paris Pledges, and 2°C Path


Note: 2°C = 3.6°F; 3.5°C = 6.3°F; 2.4°C = 8.1°F.
To see what is required to achieve a 2°C or 1.5°C target, the concept of a **global carbon budget** is useful. A global carbon budget attempts to quantify the cumulative emissions of carbon that can be added to the atmosphere without exceeding specified temperature increases. To reach a 2°C target, it is necessary to keep within a cumulative global carbon budget of no more than 270 additional gigatons of carbon – about 30 years of emissions at current levels. To reach the 1.5°C target, the budget would have to be a mere 110 gigatons – about 12 years of emissions at current rates. The current Paris commitments are inadequate to meet these goals, without a significant strengthening of the commitments in future rounds of negotiation.

**global carbon budget** the concept that total cumulative emissions of carbon must be limited to a fixed amount in order to avoid catastrophic consequences of global climate change.

### BOX 13.3 THE SCIENTIFIC BASIS FOR THE PARIS CLIMATE TARGETS

The Paris Agreement codifies a goal of no more than 2°C of temperature increase, with a more ambitious goal of no more than 1.5°C. What is the reason for these targets? A 2016 study argues that the temperature targets selected in Paris are the scientifically correct ones by comparing these targets to the probability that various catastrophic and irreversible losses will occur, such as the loss of alpine glaciers or the loss of the Amazon rainforest. The authors assessed the available research to determine the temperature range at which each impact is expected to occur. This is shown in Figure 13.10.

The bar for each impact reflects scientific uncertainty about how much temperatures must increase to make that impact inevitable. The darker the shading, the higher the probability the impact will occur. So, for example, if global average temperatures increase only 1°C there is a small probability alpine glaciers will be lost. But if temperatures increase more than 2.5°C it is nearly certain that alpine glaciers will be lost based on the current research.

The vertical bar represents the range of the Paris climate targets, from 1.5°C to 2.0°C. Comparing these targets to the various impacts, we see that limiting the temperature increase to 1.5°C offers a chance that the world’s coral reefs will not be lost. But at 2°C it is virtually certain that coral reefs will not survive. If the 2°C target can be met, the outlook is better for avoiding the loss of alpine glaciers, the Greenland ice sheet, and the West Antarctic ice sheet, although considerable uncertainty remains. At 4–6°C the Amazon and boreal forests, the East Antarctic ice sheet, and permafrost are all endangered, as is the thermohaline circulation in the oceans, including the Gulf Stream, which keeps much of Europe relatively temperate despite high latitudes. The article concludes that achieving the Paris targets, while ambitious, is therefore essential:

“Beyond 2°C the course would be set for a complete deglaciation of the Northern Hemisphere, threatening the survival of many coastal cities and island nations. Global food supply would be jeopardized by novel extreme-event regimes, and major ecosystems such as coral reefs forced into extinction. Yet, staying within the Paris target range, the overall Earth system dynamics would remain largely intact. Progressing [further] on the other hand, with global warming reaching 3–5°C, would seriously [risk most impacts]. For warming levels beyond this range, the world as we know it would be bound to disappear.”

Regional, National and Local Actions

While international efforts to establish a framework for emissions reduction have continued, policies have been implemented at regional, national, and local levels. These include:

- To help it meet its obligations under the Kyoto Protocol, the European Union set up a carbon trading system that went into effect in 2005 (see Box 13.4).
- Carbon trading systems have also been established in several regions in the United states. The Regional Greenhouse Gas Initiative (RGGI) is a cap-and-trade program for emissions from power plants in nine Northeastern states. Permits are mostly auctioned off (some are sold at a fixed price), with the proceeds used to fund investments in clean energy and energy efficiency. Permit auction prices have ranged from about $2 to $5 per ton of CO₂. In 2013, California initiated a legally binding cap-and-trade scheme. “The program imposes a greenhouse gas emission limit that will decrease by two percent each year through 2015, and by three percent annually from 2015 through 2020.”
- Carbon taxes have been instituted in several countries, including a nationwide tax on coal in India (about $1/ton, enacted in 2010), a tax on new vehicles based on their carbon emissions in South Africa (also enacted in 2010), a carbon tax on fuels in Costa Rica (enacted in 1997), and local carbon taxes in the Canadian provinces of Quebec, Alberta, and British Columbia (see Box 13.5).
- Networks of cities have also organized to address climate change. The C40 network of megacities, representing 25% of global GDP has focused on measuring and reducing urban emissions. Another network, the Compact of Mayors, a global
coalition of over 500 cities, was launched in 2014 with similar goals.\textsuperscript{32} By 2050, between 65\% and 75\% of the world population is projected to be living in cities, with more than 40 million people moving to cities each year. Urban population will grow from approximately 3.5 billion people now to 6.5 billion by 2050. Estimates suggest that cities are responsible for 75 percent of global CO\textsubscript{2} emissions, with transport and buildings being among the largest contributors.\textsuperscript{33}

**BOX 13.4 THE EUROPEAN UNION CARBON TRADING SYSTEM**

In 2005 the European Union (EU) launched its Emissions Trading Scheme (EU-ETS), which covers more than 11,000 facilities that collectively emit nearly half the EU’s carbon emissions. In 2012 the system was expanded to cover the aviation sector, including incoming flights from outside the EU. Under the EU-ETS, each country develops a national allocation plan to determine the overall number of permits available. Permits are both auctioned off and allocated to some firms for free based on historical emissions. Any unneeded permits can be sold on the open market.

The initial phase (2005–2007) of the EU-ETS produced disappointing results as permits were over-allocated, leading to a drop in the permit price from more than €30 per tonne to less than €1 by the end of 2007. In the second phase (2008–2012), fewer permits were initially allocated, leading to relatively stable prices of around €15–€20/tonne for a few years. But by mid-2012 prices had fallen to €5–€10/tonne as the market again experienced a glut of permits. Despite the volatility in prices, according to the EU the EU-ETS led to a reduction in emissions from large emitters of 8 percent between 2005 and 2010. Also, the costs of the EU-ETS have been less than expected, around 0.5 percent of European gross domestic product (GDP).

The EU has moved into the third phase of the ETS, covering 2013–2020. This phase will require more of the permits to be auctioned, include more greenhouse gases, and set an overall EU cap rather than allowing individual countries to determine their own cap. By the end of the third phase, the program’s goal is to reduce overall EU emissions 21 percent relative to 1990 levels, with a further goal of a 43\% reduction by 2030.


**BOX 13.5 BRITISH COLUMBIA’S CARBON TAX: A SUCCESS STORY**

In 2008 the Canadian province of British Columbia, on the Pacific Coast, implemented a carbon tax of $10 per ton of CO\textsubscript{2} (Canadian dollars). The tax rose incrementally by $5 each subsequent year, until it reached $30 in 2012. This translates into an additional 26 cents per gallon of gasoline at the pump, with comparable price increases in other carbon-based energy sources.

The carbon tax is revenue neutral, meaning that the province has cut income and corporate taxes to offset the revenue it gets from taxing carbon. British Columbia now has the lowest personal income tax rate in Canada, and one of the lowest corporate rates among developed countries.

In the first six years of its implementation, consumption of fuels dropped by between 5\% and 15\% in B.C., while it rose by about 3\% in the rest of Canada. During that time, GDP per capita continued to grow in British Columbia, at a slightly higher pace than for the rest of Canada. By lowering taxes on income and on corporations, this policy encouraged employment and investment, while discouraging carbon pollution.

British Columbia’s experience has been heralded by the OECD and the World Bank as a
successful example to follow. A recent study found that the tax had negligible effects on the
economy, and had overcome initial opposition to gain general public support. As of 2016, the
Canadian government planned to extend the tax to the whole of Canada.

Sources: The World Bank, *Development in a changing climate. British Columbia’s carbon tax shift: an*
*environmental and economic success*. Sept. 10, 2014; The Economist, *British Columbia’s carbon tax: the*
neutral carbon tax*; Murray and Rivers, 2015; Metcalf, 2015;
http://www.nationalobserver.com/2016/10/03/news/breaking-feds-announce-pan-canadian-carbon-price-plan-
2018.

**Forests and Soils**

While the major focus of climate policy has been on the reduction of emissions from carbon-
based fuels, the role of forests and soils is also crucial. Currently about 11% of greenhouse
gas emissions come from forest and land use change, especially tropical forest loss.34
International negotiations have also led to the adoption of a program known as REDD
*(Reduction of Emissions from Deforestation and Degradation)*. The Copenhagen Accord
(2009) acknowledged the need to act on reducing emissions from deforestation and forest
degradation and established a mechanism known as REDD-plus. The Accord emphasizes
funding for developing countries to enable action on mitigation, including substantial finance
for REDD-plus, adaptation, technology development and transfer and capacity building
(discussed further in Chapter 19).

**Reduction of Emissions from Deforestation and Degradation (REDD)** a United Nations
program adopted as part of the Kyoto process of climate negotiations, intended to reduce
emissions from deforestation and land degradation through providing funding for forest
conservation and sustainable land use.

In addition to reducing emissions, forests and soils have huge potential for absorbing
and storing carbon. The Earth’s soils store 2500 billion tons of carbon – more carbon than the
atmosphere (780 billion tons) and plants (560 billion tons) combined. But it is estimated that
soils have been depleted of 50 to 70 percent of their natural carbon in the last century.
Globally, those depleted soils could reabsorb 80 to 100 billion metric tons of carbon per year,
through regenerative agriculture including: polyculture, cover cropping, agroforestry,
nutrient recycling, crop rotation, proper pasture management, and organic soil amendments
like compost and biochar (discussed further in Chapter 16).35 It is likely that this vast
unexploited potential for carbon storage will be a major focus of future climate policy – a
crucial factor in the effort to move from the intermediate “pledges” path in Figure 13.9 to the
“goals” path necessary to hold global temperature change to no more than 2°C.

**regressive tax** a tax in which the rate of taxation, as a percentage of income, decreases with
increasing income levels.

**progressive taxes** taxes that comprise a higher share of income with higher income levels.

**distributionally neutral tax shift** a change in the pattern of taxes that leaves the distribution
of income unchanged.
13.5  **Other Economic Policy Proposals: Environment and Equity**

In the final section of this chapter, we take a look at proposals for balancing carbon reduction with equity issues on a national and international scale. While these policies have not yet been implemented on a national or global scale, they provide insight into economic principles that can guide future policymaking.

**A Distributionally Neutral Carbon Tax in the United States**

Placing a price on carbon emissions in developed countries would result in unequal impacts on households of different income levels. Specifically, a carbon tax would be a **regressive tax**, meaning that as a percentage of income the tax would affect lower-income households more than higher-income households. The reason is that lower-income households spend a higher percentage of their income on carbon-intensive goods such as gasoline, electricity, and heating fuels. Thus a carbon tax, implemented alone, would increase the overall level of income inequality.

A carbon tax does not necessarily mean that overall taxes must increase. Instead, implementing a carbon tax could be coupled with a decrease in one or more existing taxes such that the overall amount of taxes paid by the average household stays the same. Thus a carbon tax could be revenue neutral, meaning that the overall amount of tax revenue collected by the government is unchanged.

The distributional impacts will depend on which tax is reduced. Some taxes are regressive, affecting lower-income households more heavily, while other taxes are **progressive taxes**, affecting higher-income households more heavily. Given that a carbon tax is regressive and increases inequality, most proposals for a revenue-neutral carbon tax suggest achieving revenue neutrality by decreasing a regressive tax. In the United States, regressive taxes include sales taxes, the payroll tax, and excise taxes. Could one of these taxes be reduced such that the overall distributional impact of a carbon tax would be relatively constant across income levels?

An economic analysis by Gilbert Metcalf shows that offsetting a carbon tax in the United States with a decrease in the payroll tax could produce a result that is approximately **distributionally neutral**, meaning that the impact on households at different income levels would be nearly the same as a percentage of income.

Metcalf proposes offsetting the carbon tax by providing a tax credit for a worker’s payroll tax up to a maximum credit of $560 per year per individual—an amount that allows the overall effect on taxes to be revenue-neutral. For low-income households, this tax credit is relatively large as a percentage of income (over 2 percent), but for higher-income households this credit is only about 1 percent or less of income. The credit averages from about $200 to over $1,000, depending on household income level. The net effect, considering both the carbon tax and the tax credit, is never more than an average of $135 for any income group. Households in the middle and upper-middle income groups tend to end up slightly ahead, while households in the lowest income groups end up losing slightly. But the overall impact is nearly distributionally neutral. Some further minor adjustments could be instituted to eliminate the slightly negative impact on lower income households. Thus Metcalf’s analysis demonstrates that a carbon tax in the United States could achieve carbon reductions without increasing overall taxes or having a disproportionate impact on any income group.
Greenhouse Development Rights

On a global scale, equity issues relate to income differences between countries as well as income distribution within countries. What principles should be used to determine how emissions reductions and financing of mitigation and adaptation costs should be allocated among countries? Various approaches are possible, taking into account fairness, efficiency, and the concept of universally shared rights to the global commons. The greenhouse development rights (GDR) framework proposes that only those people living above a certain economic threshold of development should be obliged to address the climate change problem. Those who live below the threshold should instead be allowed to focus on economic growth, without any climate obligations.

The GDR analysis essentially develops a methodology for assigning each country’s obligation to provide financing for an international climate change mitigation and adaptation fund. It considers two factors to determine a country’s obligation:

- **Capacity:** The capacity of a country to provide financing is based on its GDP, yet all income below a defined development threshold is excluded. The GDR analysis sets the development threshold at $7,500 per capita, a level that generally allows one to avoid the problems of severe poverty, such as malnutrition, high infant mortality, and low educational attainment. Figure 13.11 illustrates the concept using China as an example. The graph shows the income distribution curve for China, starting with the person with the lowest income and moving to the right as incomes increase. All income below the horizontal line at the $7,500 development threshold is excluded from China’s capacity. The area above the development threshold line represents China’s total capacity to provide financing for climate change.

- **Responsibility:** The GDR approach defines responsibility for greenhouse gas emissions as a country’s cumulative emissions since 1990, the same baseline year used for the Kyoto Protocol. As with capacity, emissions associated with consumption below the development threshold are excluded from the responsibility calculation. Each country’s share of the global responsibility would be calculated by dividing its cumulative emissions by the global total.

The results indicate each country’s share of the global capacity and responsibility. Then, a responsibility-capacity index (RCI) is calculated as the unweighted average of the two values. The RCI represents each country’s obligation for financing a response to climate change.
The results for selected countries and country groups are presented in Table 13.5. The United States, which has by far the greatest cumulative responsibility for emissions, would be allocated one-third of the global bill for addressing climate change. The European Union would receive more than one-quarter of the bill. Japan would be asked to finance about 8 percent of the response, China about 6 percent, and Russia about 4 percent. The least developed countries are collectively asked to pay a negligible share of the global bill. These shares would change over time, as developing countries’ share of global emissions increases and their capacity to respond (assuming successful development) increases also.

Table 13.5 Responsibility Capacity Indices, Greenhouse Development Rights Framework, Selected Countries/Regions (percent of global total)

<table>
<thead>
<tr>
<th>Country or group</th>
<th>Population</th>
<th>Capacity</th>
<th>Responsibility</th>
<th>RCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>4.5</td>
<td>29.7</td>
<td>36.4</td>
<td>33.1</td>
</tr>
<tr>
<td>EU-27</td>
<td>7.3</td>
<td>28.8</td>
<td>22.6</td>
<td>25.7</td>
</tr>
<tr>
<td>Japan</td>
<td>1.9</td>
<td>8.3</td>
<td>7.3</td>
<td>7.8</td>
</tr>
<tr>
<td>China</td>
<td>19.7</td>
<td>5.8</td>
<td>5.2</td>
<td>5.5</td>
</tr>
<tr>
<td>Russia</td>
<td>2.0</td>
<td>2.7</td>
<td>4.9</td>
<td>3.8</td>
</tr>
<tr>
<td>Brazil</td>
<td>2.9</td>
<td>2.3</td>
<td>1.1</td>
<td>1.7</td>
</tr>
<tr>
<td>Mexico</td>
<td>1.6</td>
<td>1.8</td>
<td>1.4</td>
<td>1.6</td>
</tr>
<tr>
<td>South Africa</td>
<td>0.7</td>
<td>0.6</td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td>India</td>
<td>17.2</td>
<td>0.7</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Least-developed countries</td>
<td>11.7</td>
<td>0.1</td>
<td>0.04</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Source: Baer et al., 2007.
Following the principles suggested by the GDR proposal would be consistent with the principle of climate justice but would necessitate a substantial increase in the commitments of developed nations, well beyond the $100 billion included in the Paris agreement. According to the authors of the GDR proposal:

For a fully equitable climate agreement, substantial public funds for mitigation must be delivered... As a supplement to their domestic INDCs, each developed country party should set a target to provide the means of implementation to developing countries to address the emissions reduction gap. Significantly scaled-up public finance for adaptation and to address loss and damage are also imperative.  

13.6 CONCLUSION

Climate change is an issue that embodies many of the analyses discussed in this text, including externalities, common property resources, public goods, renewable and nonrenewable resources, and the discounting of costs and benefits over time. It has economic, scientific, political, and technological dimensions. Economic analysis alone cannot adequately respond to a problem of this scope, but economic theory and policy have much to offer in the search for solutions.

An effective response to the climate change problem requires much more sweeping action on a global scale than anything so far achieved. But whether we are discussing local initiatives or broad global schemes, we cannot avoid the issue of economic analysis. Economic policy instruments that have the power to alter patterns of energy use, industrial development, and income distribution are essential to any plan for mitigating or adapting to climate change. As noted in Chapter 12, evidence of climate change impacts is already clear, and the issue will become more pressing as greenhouse gas accumulation continues and costs of damages and of climate adaptation rise (see Box 13.6). The tools of economic analysis will provide critical insights as the world grapples with this continuing crisis.

BOX 13.6 FOR U.S. COASTAL CITIES, CLIMATE ADAPTATION STARTS NOW

In August 2016, torrential downpours along the Gulf Coast led to deadly floods in Southern Louisiana. With $9 billion in estimated damages, this natural catastrophe qualified as the worst in the United States since Hurricane Sandy in October 2012. Linking such “off-the-charts” episodes to climate disruption is not a simple cause-to-effect relation but scientists’ models can give orders of magnitude of probabilities for such events. What was considered a once-in-a-thousand year occurrence is becoming a new reality that coastal regions need to cope with. The National Oceanic and Atmospheric Administration found that global warming increases the chances of such intense rains by 40% due to increased moisture in a warmer atmosphere.

Already, coastal cities around the United States are investing massively to prepare for future floods. Fort Lauderdale, Florida, is spending millions of dollars fixing battered roads and drains damaged by increasing tidal flooding. Miami Beach increased local fees to finance a $400 million plan that includes raising streets, installing pumps and elevating sea walls. The cost of adapting to rising seas for the medium-size town of Norfolk, VA has been estimated at about $1.2 billion, or about $5000 for every resident.

These costs for individual cities imply that the order of magnitude of costs for the whole East Coast and Gulf Coast will be several trillions. 1.9 million shoreline homes worth a combined $882 billion might be lost to rising sea levels by 2100. The Pentagon too faces...
major adaptation issues, as many naval bases are facing serious threats and their land is at risk of disappearing within this century.


SUMMARY

Policies to respond to global climate change can be preventive or adaptive. One of the most widely discussed policies is a carbon tax, which would fall most heavily on fuels that cause the highest carbon emissions. The revenues from such a tax could be recycled to lower taxes elsewhere in the economy, or they could be used to assist people in lower income brackets, who will suffer most from higher costs of energy and goods. Another policy option is tradable carbon emissions permits which can be bought and sold by firms or countries, depending on their level of carbon emissions (also known as “cap-and-trade”). Both these policies have the advantage of economic efficiency, but it can be difficult to obtain the political support necessary to implement them. Other possible policy measures include shifting subsidies from fossil fuels to renewable energy, strengthening energy efficiency standards, and increasing research and development on alternative energy technologies.

Global carbon emissions could be stabilized by scaling up existing technologies, according to the idea of climate stabilization wedges. The greenhouse gas abatement cost curve indicates that numerous opportunities exist for actions that could reduce carbon emissions and also save households and businesses money, and that billions of tons of additional emissions can be avoided at low cost. One implication of the cost curve is that efficiency standards can be an important complement to a carbon pricing policy.

The Paris Agreement of 2015 replaced the earlier Kyoto Protocol mandating reductions of greenhouse gases by industrialized countries. Unlike Kyoto, which had limited success, the Paris Agreement involves almost all the world’s countries, but its provisions are based on voluntary pledges. It creates a framework for substantial reductions by the United States and other industrialized countries, and for reduction of emissions intensity (emissions per unit GDP) by China, India, and other developing countries, with a target date for a “peaking” of emissions by China. A review process is intended to strengthen the country commitments over time.

In addition to international commitments, many initiatives have been taken at regional, national and local levels, involving carbon taxes, cap-and-trade, and other emission reduction measures. Great potential for additional reductions exists through improving forest and agricultural practices, resulting in less emissions and increased carbon storage in forests and soils.

Well-designed economic analyses can provide potential blueprints for effective and equitable national and international climate change policies. For example, a carbon tax in the United States can be designed to be both revenue- and distributionally neutral. The “greenhouse development rights” framework proposes allocating the financing for climate change mitigation and adaptation based on each country’s responsibility for past emissions and economic capacity, while still allowing poor countries to achieve economic development.
KEY TERMS AND CONCEPTS

adaptive measures
cap and trade
carbon footprint
carbon intensity
carbon sinks
carbon tax
climate justice
climate stabilization wedge
cost-benefit analysis
cost-effectiveness analysis
distributionally neutral taxes
efficiency standards
elasticity of demand
greenhouse development rights (GDR)
global carbon budget
intended nationally determined contribution (INDC)
pollution taxes
preventive measures
price volatility
progressive taxes
reduction of emissions from deforestation and degradation (REDD)
regressive tax
revenue-neutral tax shift
social cost of carbon
technology transfer
transferable (tradable) permits

DISCUSSION QUESTIONS

1. Which economic climate change policy do you prefer: a carbon tax or a cap-and-trade system? Why? What are the main barriers to effective policy implementation?
2. Climate change policies can focus on changing behaviors or changing technology. Which approach do you think could be more effective? What policies can be used to encourage changes in each?
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 countries to enter and carry out agreements? What kinds of “win-win” policies could 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 United States and Brazil have to reduce their emissions:

   **United States:**

<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. Which policies are most efficient for each country in meeting their reduction targets? How much will be reduced using each option, at what cost, if the two countries must operate independently? Assume that any of the policy options can be partially implemented at a constant marginal cost. For example, the United States could choose to reduce carbon emissions with efficient machinery by 10 million tons at a cost of $2 billion. (Hint: start by calculating the average cost of carbon reduction in dollars per ton for each of the six policies).

   b. Suppose a market of transferable permits allows the United States 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 United States and Brazil so that they can meet the overall emissions reduction target of 250 million tons at the least cost? Can you estimate a range for the price of a permit to emit one ton of carbon? (Hint: use your average cost calculations from the first part of the question.)

2. Suppose that the annual consumption of an average American household is 1,000 gallons of gasoline and 200 Mcf (thousand cubic feet) of natural gas. Using the figures given in Table 13.2 on the effects of a carbon tax, calculate how much an average American household would save per year in gasoline and natural gas, assuming a marginal tax rate of $10 per ton of CO₂ emissions.
A household would pay per year with an added tax of $50 per ton of carbon dioxide if there was no initial change in demand. Then assuming a short-term demand elasticity of −0.1, and a long-term elasticity of −0.5, calculate the reductions in household demand for oil and gas in the short and long term. If there are 100 million households in the United States, what would be the revenue to the U.S. Treasury of such a carbon tax, in the short and long term? How might the government use such revenues? What would the impact be on the average family? Discuss the difference between the short-term and long-term impacts.

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**WEB SITES**


**NOTES**

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