In addition to this textbook, Dr. Callan has authored numerous applied microeconomic articles for economic journals including the Southern Economic Journal, Review of Industrial Organization, Journal of Business and Economic Statistics, and Journal of Sports Economics. His environmental economics research investigates the demand and supply characteristics associated with the market for municipal solid waste (MSW). The demand-side topics include the impact of pay-as-you-throw programs on waste generation, recycling, and overall MSW costs. The supply side topics focus on the output of economies of scale and scope in the province of MSW services.

His research findings have appeared in Land Economics and Environmental and Resource Economics as well as other academic journals. Recent research efforts explore the many facets of corporate social performance and its effect on firm behavior. In addition to the many publications, Dr. Callan has reviewed scholarly articles for a wide variety of academic publications as well as research grant proposals for the U.S. Environmental Protection Agency.

In addition to environmental economics, Dr. Thomas teaches intermediate microeconomics, industrial organization, principles of microeconomics, and principles of macroeconomics. She has been actively involved in course development and curriculum revision in environmental economics and has served as coordinator of the MBA Environmental Management Concentration Program at Bentley.

Dr. Thomas is an active researcher in applied microeconomics, corporate social responsibility, sports economics, and other fields of applied microeconomics. Her present research focuses on corporate social performance, corporate financial performance: determinable components. In addition to this textbook, she has published research results in academic journals such as Land Economics, Corporate Social Responsibility and Environment Management, Southern Economic Journal, Environmental and Resource Economics, Journal of Sports Economics, Review of Industrial Organizations, and Eastern Economic Journal. She is a member of the American Economic Association and has served as a reviewer for a number of academic journals and textbook publishers. Dr. Thomas was named Faculty Member of the Year by Bentley’s Student Government Organization in 1991. In 1995, she received the Gregory H. Adamian Award for Teaching Excellence. In 1998, she was honored with the Bentley University Scholar of the Year Award, and in 2005 she received the Outstanding Scholarly Contribution Award.
Dear Professor,

We are pleased to present you with this Preview Guide for the upcoming fifth edition of *Environmental Economics and Management* by Scott Callan and Janet Thomas. This text has always been at the forefront in providing students with a contemporary approach to environmental economics. And its modular structure, which has been much appreciated by adopters, allows for complete flexibility in adjusting the content of the text to your individual course needs.

This Preview Guide is designed to give you a sense of how the text has been revised. Look for the following updates in the fifth edition:

**More Boxed Applications with an International Context:** Ten new applications highlight recent issues that have affected or continue to influence policy decisions, such as property rights to China’s rivers, the ecological risk of climate change, Toyota’s hybrid technology, and certain composting.

**Updated International and Domestic Policy and Analysis:** All policy discussions present the most current information at the time of publication. Among the new policies discussed are the EPA’s Endangerment Finding of 2009 relating to the threat of greenhouse gases, environmental changes linked to the Emergency Economic Stabilization Act of 2008 and The American Recovery and Reinvestment Act of 2009, and the evolution of the European Union’s Emissions Trading Scheme.

**Updated Graphics and Supporting Data:** Numerous tables and figures throughout this edition clarify concepts at a glance, using the most current economic and environmental data available.

**Access to the Global Economic Watch:** Today’s financial turmoil transforms academic theory into real-life challenges that affect every family and business sector, making it one of the most teachable moments in modern history. *Cengage Learning’s The Global Economic Watch* helps bring these current events into the classroom through a powerful suite of compelling, discussion forums, testing tools, and more. Visit www.cengage.com/thewatch for more information.

To learn more, visit the text’s companion Web site at www.cengage.com/economics/callan.

The fifth edition and its ancillaries, including animated PowerPoint® slides and an Instructor’s Manual, will be available for classroom use for the 2010 spring semester. For a full exam copy, please complete the enclosed reply card and fax it to the number provided. I look forward to hearing from you!

Sincerely,

Betty Jung
Associate Marketing Manager
Environmental Economics & Management
Theory, Policy, and Applications

Scott J. Callan  Janet M. Thomas
Bentley University
LETTER FROM THE AUTHORS

ENVIRONMENTAL ECONOMICS AND MANAGEMENT
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Chapter 5: ECONOMIC SOLUTIONS TO ENVIRONMENTAL PROBLEMS: THE MARKET APPROACH

Chapter 13: GLOBAL AIR QUALITY: POLICIES FOR OZONE DEPLETION AND CLIMATE CHANGE
Dear Colleague,

We have just completed work on the new fifth edition of our text, *Environmental Economics and Management: Theory, Policy, and Applications*, and we are pleased to have this opportunity to introduce it to you and point out some of its distinctive elements and new features.

As we started our revision work for this edition, we began to realize how much the world has changed in the fourteen years since the first edition was published. Few would debate that there have been difficult challenges during that period, including the recent global economic downturn and financial market crisis. Yet we also recognize that society has witnessed stunning achievements and positive change—great strides in medical technology, advances in telecommunication, computing, and digitization, and measurable progress toward achieving a cleaner environment. As a society, we have come to recognize that economic activity and the natural environment are inexorably linked, and this profound relationship is at the core of environmental economics and continues to be the primary motivation for our textbook.

Arguably, environmental economics is a dynamic field. So over the years, an important ongoing objective for us has been to keep the content of this text current and, at the same time, keep it accessible and lively to students. In this fifth edition of our book, we again have had the opportunity to integrate suggestions offered by survey respondents, insightful comments made by our adopters, plus some new ideas of our own. We continue to believe that teaching environmental economics is an exciting opportunity to show students the broad applicability of economic thinking. Students are more environmentally literate and aware than ever before, and most are eager to understand how the market process can help explain and even solve environmental problems. It is, to say the least, an energizing challenge to present this evolving field to what typically is a diverse audience of students.

As with previous editions, our general approach is to illustrate in a practical manner how economic tools such as market models and benefit-cost analysis can be used to assess environmental problems and to evaluate policy solutions. Along with traditional discussions, we incorporate contemporary examples of business and consumer practices that are part of environmental decision making. In so doing, seemingly abstract concepts are given relevance through actual cases about
consumers, industry, and public policy. We invite you to take a look at our table of contents, which will convey the depth of coverage we provide along with interesting, real-world content in supporting applications.

A MODULAR APPROACH

Organizing the vast amount of material that an environmental economics course generally covers is a challenge at best. Mindful of the usual time constraint in a one-semester course, we devised a modular structure for the text. This approach not only organizes the presentation by major topic but also provides a format that facilitates customizing the material to suit a variety of course objectives. At your discretion, certain chapters within a given module can be omitted or covered less thoroughly without loss of continuity. Likewise, the order in which the modules are covered can be varied to suit your preferences and your students’ interests.

The first three modules form the foundation for the course. These are:

**Module 1. Modeling Environmental Problems:** A three-chapter module illustrating how environmental problems are modeled from an economic perspective. Primary topics include the materials balance model, a review of market theory and price determination, and the market failure of pollution, using a public goods model and externality theory.

**Module 2. Modeling Solutions to Environmental Problems:** A two-chapter module on environmental regulatory approaches—one on the command-and-control approach and one on the market approach.

**Module 3. Analytical Tools for Environmental Planning:** A four-chapter module introduced by an investigation of risk assessment, risk management, and benefit-cost analysis. Included is a thorough presentation of benefit estimation procedures.

Following these are three media-specific modules, which are actually comprehensive case studies of major environmental problems and policy solutions. These modules can be covered in any sequence following the foundational material in the first half of the text. You might even elect to focus on only one or two of these media modules over the course of a semester.

**Module 4. The Case of Air:** A four-chapter module assessing major air pollution problems, including urban smog, acid rain, ozone depletion, and climate change. In each
case, domestic and international policy initiatives are discussed and then analyzed economically.

**Module 5. The Case of Water:** A three-chapter module covering the problems of groundwater and surface water contamination and specific policies aimed at point and nonpoint polluting sources as well as drinking water supplies.

**Module 6. The Case of Solid Wastes and Toxic Substances:** A three-chapter module that presents and economically analyzes solid waste management and the use of pesticides and other toxic substances.

Each of these media modules utilizes the analytical tools presented in Modules 1 through 3, such as economic models, risk management, and benefit-cost analysis.

The concluding module covers topics in global environmental management. While international issues are integrated throughout the text, this module concentrates on environmental objectives, policies, and strategies that involve the global community. We focus here on sustainable development, international trade and environmental protection, industrial ecology, and pollution prevention.

**Module 7. Global Environmental Management:** A two-chapter module examining sustainable development as a worldwide objective and various efforts underway within the public and private sectors to achieve it.

**NEW TO THE FIFTH EDITION**

Because our adopters and reviewers have been pleased with the organization and writing of the text, we have maintained its basic style and structure in the fifth edition. That said, we did make revisions in response to policy changes, news events, and suggestions offered by survey respondents, reviewers, and adopters. Among the new policies reported in this edition are: the Montreal Adjustment of 2007, the Pesticide Registration Improvement Renewal Act, the EPA’s Endangerment Finding of 2009 relating to the threat of greenhouse gases, and environmental changes linked to the Emergency Economic Stabilization Act of 2008 and The American Recovery and Reinvestment Act of 2009. Wherever possible, proposals introduced by the Obama administration are also presented to alert students to pending revisions.
In addition to these policy changes, we added new topics and offered expanded coverage of others. Among these are:

- A revised ecological risk assessment model
- E10 ethanol and E85 ethanol
- Plug-in hybrids
- Zero-emission and partial-zero-emission vehicles
- The United Nations Climate Change Conference in Copenhagen
- The Regional Greenhouse Gas Initiative (RGGI)
- Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC)
- The TSCA Inventory Reset

To further our efforts to present a current perspective, we added about 10 new applications, deleted a few, and updated the remainder for a total of more than 50 boxed applications. Among the new applications are:

- Undefined Property Rights to China’s Rivers Leads to Environmental Damage
- Climate Change: Assessing Ecological Risk by International Region
- Benefit-Cost Analysis of a UK Climate Change Bill
- Hybrids and Plug-In Hybrids: Toyota Still in the Lead
- Reducing Smog: California’s Vehicle Buy-Back Program
- What Is a Carbon Footprint? Some Firms Are Finding Out

When preparing the previous edition, we were struck by the fact that, while most of our reviewers recommended at least one or two topics to be added to the text, many also suggested that we try to make the content more concise. Striving to achieve a balance of these seemingly mutually exclusive ideas, we arrived at what we believed was a workable solution: a topic-rich text with a more streamlined presentation. The result, according to our adopters and students, has been a success.

This time around, we did not need to identify major segments of the text to trim or consolidate. Nonetheless, we wanted to maintain the book’s readability without compromising on content.
We believe that this new edition is contemporary, concise, and relevant, capturing the rich, policy-based content of environmental economics in a way that will motivate your students. We remain dedicated to our goal of preserving the careful exploration of environmental economics that has become the hallmark of our text, while integrating revisions that make the material more accessible to students and more accommodative of instructor time constraints. We believe that the table of contents attests to the topic-rich character of the text, but that the presentation continues to be concise and approachable. We hope you agree.

Based on input from adopters and reviewers, we integrate quantitative problems and models throughout every chapter. These learning tools reinforce the economics and the analytical approaches introduced in the first three modules. Also, at the end of virtually every chapter, the Review Questions include at least one problem using algebra and/or a graphical analysis with complete solutions provided in the available Instructor’s Manual.

As in previous editions, we are pleased to continue our practice of offering an integration of international issues throughout our text. Reinforcing this approach in our fifth edition is the inclusion of at least one boxed application with an international context in each chapter. A quick scan of the table of contents will convey the depth of coverage and the interesting content in these supporting applications. With the same motivation, we made certain to retain the focus and relevance of Module 7, Global Environmental Management. Reviewers and adopters have responded positively to this module, which gives instructors the option of devoting a class or two strictly to international issues in environmental economics across air, water, and land contexts.

Lastly, we continue to offer students and instructors up-to-date Internet links to Web sites that support and enhance the text presentation. Every effort has been made to update all URLs and to add new Web sites that are relevant and useful. To facilitate using the Internet as a complement to instruction and study, an identifying icon has been placed next to each link within the main text.

PEDAGOGICAL TOOLS AND ANCILLARIES

Our new edition continues to use a number of features designed to help you prepare lectures and class materials and to make the material interesting and accessible to your students. There are both end-of-chapter and end-of-text pedagogical tools, including chapter summaries, review
questions, additional readings, a comprehensive glossary, and an extensive list of references. In every chapter, important definitions are given in the margins, key concepts are shown in boldface, and our extensive offering of more than 50 real-world applications are provided in shaded boxes. In addition to the new applications listed previously, other titles include:

- *The High Price of China’s Economic Advance*
- *BMW Group’s Sustainable Decisions and Design for Recycling*
- *The Green Dot Program in Europe*
- *The Environmental Kuznets Curve*
- *ISO 14000 International Standards on Environmental Management*
- *Remanufacturing: A Lucrative Approach to Pollution Prevention*

You also might find useful the available text supplements that are not often offered with upper-level texts. These include:

- An Instructor’s Resource CD-ROM, which includes an Instructor’s Manual that provides quantitative solutions and suggested responses to end-of-chapter Review Questions, and an updated collection of PowerPoint® slides with animated graphs and active links to relevant Internet sites.

- A companion Web site accessible at www.cengage.com/economics/callan, which offers the text ancillaries in downloadable form, a list of commonly used acronyms, a set of flashcards with terms and definitions, links to all Internet addresses cited in the book, and more.

- Online Economic Applications, which include South-Western’s dynamic Web features: EconNews, EconDebate, and EconData Online. Organized by pertinent economic topics and searchable either by topic or individual web feature, Economic Applications are easy to integrate into the classroom. For more information, visit www.cengage.com/economics/infoapps.

- InfoTrac College Edition through which students receive online access to a database of full-text articles from thousands of popular and scholarly periodicals, such as *Newsweek* and *Fortune*. For more information, visit www.cengage.com/economics/infoapps.
Taken together, we believe the fifth edition and the available supplements respond directly to what instructors need to prepare for and deliver an exciting, informative, and well-balanced course in environmental economics. Please take a look at the sample chapters—their layout, the rich content, and the learning tools. We hope you find our approach and our presentation to be precisely what you need for your course and that you will consider adopting *Environmental Economics and Management: Theory, Policy, and Applications* in its new edition.

Thank you and best wishes,

Scott Callan

Janet Thomas

Scott Callan and Janet Thomas
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Economic Solutions to Environmental Problems: The Market Approach

“The government’s view of the economy could be summed up in a few short phrases: If it moves, tax it. If it keeps moving, regulate it. And if it stops moving, subsidize it.”
Ronald Reagan (1911–2004)

Although the market fails to correct environmental problems on its own, the incentives that define the market process can be put to work by policymakers. The market approach to environmental policy, recommended for some time by economists, has begun to be adopted by governments as part of their overall response to the risks of pollution. Distinct from the use of more traditional command-and-control instruments, the market approach uses price or other economic variables to provide incentives for polluters to reduce harmful emissions.

Economists are strong proponents of the market approach because it can achieve a cost-effective solution to environmental problems. How? By designing policy initiatives that allow polluters to respond according to their own self-interests. Market instruments are aimed at bringing the external costs of environmental damage back into the decision making of firms and consumers. Taking its cue directly from market failure theory, the market approach attempts to restore economic incentives by assigning a value to environmental quality, or, equivalently, by pricing pollution. Once done, firms and consumers adjust their behavior to the resulting change in market conditions.

Awareness of the gains associated with market-based instruments is growing in both the private and public sectors. Consequently, it is important to understand this alternative policy approach and its advantages over more traditional forms of regulation. To that end, in this chapter, we examine the theory and the practical implications of environmental policy based on market incentives. Our primary tool of analysis will be economic modeling, and we will use the criteria of allocative efficiency and cost-effectiveness to make policy assessments.

To provide a framework for our investigation, we begin with a brief overview of the major categories of market-based instruments: pollution charges, subsidies, deposit/refund systems, and pollution permit trading systems. We then use these categories to structure our economic analysis. Taking each category in turn, we develop models of specific instruments, assess the results, and provide examples of how each is used in practice.
DESCRIPTIVE OVERVIEW

What distinguishes the market approach from the command-and-control approach is the way in which environmental objectives are implemented, as opposed to the level at which those objectives are set. From a practical perspective, standards-based objectives are set at a socially desirable level rather than at an efficient level. Where the market approach parts company with the command-and-control approach is in how it attempts to achieve those objectives, that is, in its design of policy instruments.

Types of Market Instruments

Because many policy instruments use market incentives, it is helpful to classify these instruments into major categories: pollution charges, subsidies, deposit/refund systems, and pollution permit trading systems. Table 5.1 offers a brief description of each.

Nations all over the world use market-based instruments to help control pollution. In fact, all OECD member nations1 use approximately 375 different environmental taxes as well as some 250 environmentally based fees and charges.2 Although the market approach continues to be a secondary form of control, its use in national policy prescriptions speaks to its importance as part of the range of available solutions to environmental problems. To further investigate international market-based policy, access the OECD/EEA database on instruments used for environmental policy and natural resources management, which is available online at http://www2.oecd.org/ecoinst/queries/index.htm.

| TABLE 5.1 | Categories of Market-Based Instruments |
| MARKET INSTRUMENT | DESCRIPTION |
| Pollution charge | A fee charged to the polluter that varies with the quantity of pollutants released. |
| Subsidy | A payment or tax concession that provides financial assistance for pollution reductions or plans to abate in the future. |
| Deposit/refund | A system that imposes an up-front charge to pay for potential pollution damages that is returned for positive action, such as returning a product for proper disposal or recycling. |
| Pollution permit trading system | The establishment of a market for rights to pollute, using either credits or allowances. |

NOTE: A good overview of market-based instruments used in the United States is found in U.S. EPA, Office of Policy, Economics, and Innovation (January 2001), which is also available online at http://yosemite1.epa.gov/ee/eca/ecd.nsf/webpages/USExperienceWithEconomicIncentives.html.

1For a complete list of the 30 OECD member nations, visit http://www.oecd.org, and click on “About OECD” and then on “Members and Partners.”
The theoretical premise of a pollution charge is to internalize the cost of environmental damages by pricing the pollution-generating activity. The motivation follows what’s known as the “polluter-pays principle,” a position rooted in the belief that the polluter should bear the costs of control measures to maintain an acceptable level of environmental quality.\(^3\) Let’s begin by modeling a product charge implemented as a tax—the classical solution to negative externalities.

**Modeling a Product Charge as a Per-Unit Tax**

Consider a good in a competitive market whose production generates a negative environmental externality. Because producers base their decisions solely on the marginal private cost (MPC) of production, ignoring the marginal external cost (MEC) of the environmental damage, too many resources are allocated to production. As shown in Figure 5.1, firms produce output level \(Q_C\), where the marginal social benefit (MSB) of consuming the good is equal to the marginal private cost (MPC) of producing it.\(^4\) Notice that the competitive equilibrium output \((Q_E)\) is higher than the efficient level \((Q_E)\), which corresponds to the point where the MSB equals the marginal social cost (MSC).

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\(^3\)OECD (1989), p. 27.

\(^4\)As we have done in previous discussions, we are implicitly assuming that there is no marginal external benefit (MEB) in this market, so \(MPB = MSB\).
The motivation of a **product charge** is to induce firms to internalize the externality by taking account of the MEC in their production decisions. One way this can be done is by imposing a unit tax on the pollution-generating product equal to the MEC at the efficient output level \((Q_e)\). This type of tax is called a **Pigouvian tax**, named after English economist A. C. Pigou, who initially formulated the theory. As illustrated in Figure 5.1, this policy instrument effectively shifts up the \(MPC\) curve by distance \(ab\) to \(MPC_t\), which generates an equilibrium at the efficient output level.

**Assessing the Model**

In theory, the Pigouvian tax forces firms to lower production to the efficient level. Although theoretically pleasing, this instrument is difficult to impose in practice and is not commonly used. Why? One problem is the difficulty in identifying the dollar value of \(MEC\) at \(Q_e\) and, hence, the level of the tax. A second problem is that the model implicitly allows only for an output reduction to abate pollution—an unrealistic restriction. To address both of these reservations, let’s consider a more practical alternative. The pollution charge also can be implemented as an emission charge, which is a tax levied on the pollution, instead of as a product charge. By moving out of the product market, the polluter’s response is not restricted to an output reduction.

**Modeling an Emission Charge: Single-Polluter Case**

An emission or effluent charge assigns a price to pollution, typically through a tax. Once this price mechanism is in place, the polluter can no longer ignore the effect of its environmental damages on society. Instead, the pollution charge forces the polluter to confront those damages, pay for them, and in so doing, consider them as part of its production costs. Faced with this added cost, the polluting firm can either continue polluting at the same level and pay the charge or invest in abatement technology to reduce its pollutant releases and lower its tax burden. Based on normal market incentives, the firm will choose whichever action minimizes its costs.

It is fairly simple to model an emission charge that allows polluters to make cost-minimizing decisions. To begin, we assume that the government sets an abatement standard at some “acceptable level,” \(A_{ST}\). Now, we consider a policy that presents the polluter with the following options to be undertaken singularly or in combination:

- The polluter must pay a constant per-unit tax \((t)\) on the difference between its existing abatement level \((A_0)\) and the standard \((A_{ST})\) such that Total Tax = \(t(A_{ST} - A_0)\); and/or
- The polluter incurs the cost of abating.

In Figure 5.2, we graph these options from a single firm’s perspective using marginal curves. Because the per-unit tax is constant at \(t\), the marginal tax \((MT)\) curve is a horizontal line at that tax level. The cost of abating at the margin is shown as the marginal abatement cost \((MAC)\) curve. At each unit of \(A\), the cost-minimizing firm will compare \(MAC\) to \(MT\) and choose whichever is lower.

In our model, the firm will abate up to \(A_0\), because up to that point \(MAC\) is below \(MT\). Assuming no fixed costs, total abatement costs \((TAC)\) are represented by the area under the \(MAC\) curve up to \(A_0\), or area \(0aA_0\). Notice that these costs are lower than what the...
taxes would be up to $A_0$, shown as area $0aA_0$. Beyond $A_0$ and up to $A_{ST}$, the firm will opt to pay the tax, because $MT$ is lower than $MAC$ in that range. The firm’s total tax payment for not abating between $A_0$ and $A_{ST}$ is represented by area $A_0abA_{ST}$, which is smaller than the cost of abating that amount, which is area $A_0acA_{ST}$.

In sum, the total costs to the polluter of complying with this policy are area $0abA_{ST}$, which comprises the following two elements:

- Area $0aA_0$, the total cost of abating $A_0$ units of pollution
- Area $A_0abA_{ST}$, the tax on pollution not abated up to $A_{ST}$

**Assessing the Model**

Be sure to recognize that the emission charge stimulates the natural economic incentives of the polluter. At any point in time, *static* incentives motivate the firm to choose among the available options, given its existing technology. Seeking to satisfy its own self-interest to maximize profit, the polluter makes a least-cost decision between paying the tax and abating. The result is that the externality is internalized, using the least amount of resources.

There are also *dynamic* incentives that encourage the firm to advance its abatement technology. More efficient abatement techniques would allow the firm to reduce pollution more cheaply and enjoy the associated cost savings. Furthermore, the lower abatement costs might even allow the firm to avoid paying any emission charges. Consider the effect of a hypothetical technological advance, shown in Figure 5.3 as a downward pivot of $MAC$ to $MAC'$. In this case, if the firm were faced with the same set of policy options based on $A_{ST}$, it would be better off abating all the way up to that standard. The firm would incur total abatement costs equal to $0bA_{ST}$ and would pay no emission charges. Relative to its
expenditures before the technological advance, which were $0abA_{ST}$, it saves an amount equal to $0ab$.

**Modeling an Emission Charge: Multiple-Polluters Case**

To evaluate the cost-effectiveness of an emission charge across multiple polluters, we return to the two-polluter model used in Chapter 4. As before, we assume that the government imposes a 10-unit abatement standard for the region. We repeat the cost functions from Chapter 4 to facilitate our discussion:

- **Polluter 1’s Marginal Abatement Cost (MAC):** $MAC_1 = 2.5A_1$
- **Polluter 1’s Total Abatement Costs (TAC):** $TAC_1 = 1.25(A_1)^2$
- **Polluter 2’s Marginal Abatement Cost (MAC):** $MAC_2 = 0.625A_2$
- **Polluter 2’s Total Abatement Costs (TAC):** $TAC_2 = 0.3125(A_2)^2$

where $A_1$ is the amount of pollution abated by Polluter 1, and $A_2$ is the amount of pollution abated by Polluter 2.

Assume that the government imposes the same emission charge as in the single-polluter case, that is, Total Tax = $t(A_{ST} - A_0)$. In this case, because $A_{ST} = 10$, the emission charge becomes $t(10 - A_0)$. We also assume that the tax rate ($t$) is set at $5, so Total Tax = $5(10 - A_0)$ for each polluter.

Now consider each firm’s response to the tax. As we proceed, refer to Figure 5.4, which reproduces the model used in Chapter 4, adding a horizontal line ($MT$) at $5 to represent the emission charge. When faced with the $5-per-unit charge, Polluter 1 would...
compare the relative costs of $MT$ and $MAC_1$ for each incremental unit of abatement, just as in the single-firm case. It would abate as long as $MAC_1 < MT$ and pay the tax when the opposite is true. Thus, Polluter 1 would abate up to the point where $MAC_1 = MT$, which occurs at $A_1 = 2$, and pay the tax on the remaining 8 units. Polluter 2 would proceed in the same way, abating to the point where $MAC_2 = MT$ at $A_2 = 8$ and paying the tax on the remaining 2 units. The corresponding calculations are as follows:

**Polluter 1**
- Abates up to the point where $MAC_1 = MT$: $2.5(A_1) = 5$, or $A_1 = 2$
- Incurs Total Abatement Costs of: $TAC_1 = 1.25(2)^2 = 5$
- Incurs Total Tax Payment of: $Total Tax = 5(10 - 2) = 40$

**Polluter 2**
- Abates up to the point where $MAC_2 = MT$: $0.625(A_2) = 5$, or $A_2 = 8$
- Incurs Total Abatement Costs of: $TAC_2 = 0.3125(8)^2 = 20$
- Incurs Total Tax Payment of: $Total Tax = 5(10 - 8) = 10$

**Combined Values for the Region**
- Total Abatement Level = $A_{ST} = 10$
- Total Abatement Costs = $25$
- Total Tax Payments = $50
There are two important observations to make about these results. First, the $5 unit tax achieves the 10-unit abatement standard. Second, this objective has been achieved using the cost-effective allocation of abatement resources across polluters.\(^5\) Because each polluter abates to the point where its \(MAC\) equals \(MT\), all \(MACs\) are equal, precisely in accordance with the cost-effective abatement criterion. Notice that most of the abating is done by the low-cost abater, Polluter 2. The high-cost polluter, Polluter 1, abates less but pays much higher emission charges in the form of taxes.

**Assessing the Model**

The emission charge exploits each polluter’s natural incentive to pursue a least-cost strategy. As a result, the low-cost abaters do most of the cleaning up, and the high-cost abaters pay more in taxes to cover the greater damages they cause. The benefits to society are not affected by who does the abating, but the costs are. In this case, costs are minimized because Polluter 2 does most of the abating. It does so, not because it is motivated by society’s objectives, but because doing so is in its own best interest. An added advantage is that the tax generates revenues, which can be used by the government to help finance the costs of enforcement and monitoring.

Notwithstanding the advantages of the emission charge, there are several caveats. The first concerns the setting of the emission charge. Realistically, the government will not know the tax rate at which polluters’ abatement levels collectively meet the standard and therefore will have to adjust the tax until the environmental objective is achieved.\(^6\) This adjustment process can be time intensive. Another consideration is that monitoring is likely to be more complex, and therefore more costly, when each polluter responds to a policy based on its own internal operations. Distributional implications also have to be considered. Because polluting firms pay higher taxes, part of the tax burden is shared with consumers in the form of higher prices. Job losses also may occur as firms adjust to the tax or change technologies to increase abatement. Finally, firms may try to evade the tax by illegally disposing of pollutants. To minimize that potential, the government may have to strengthen its monitoring programs, which adds to costs.

**Pollution Charges in Practice**

Internationally, the pollution charge is the most commonly used market-based instrument. Several countries, including Australia, Bulgaria, France, Germany, and Japan, use fees or taxes to control the noise pollution generated by aircraft. France, Mexico, and Poland are among the nations using effluent charges to protect water resources.

A real-world application of a product charge is one levied on batteries, which is done in Austria, Denmark, Finland, Hungary, and Italy. Another example is a fee charged on automobile tires. Finland uses this particular product charge to help cover the costs of collecting and recycling used tires. Other targeted products used by various countries

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\(^5\)Recall from Chapter 4 that using a uniform standard under a command-and-control approach generates total abatement costs of $39.06.

\(^6\)For example, if the government had set the tax at too low a level, say $4, each polluter would have abated to where its \(MAC\) equals $4. The result would have been \(A_1 = 1.6\) and \(A_2 = 6.4\) for a combined abatement level of 8.0 units—too low to satisfy the objective. So, the government would have had to raise the tax until the combined total reached the 10-unit abatement standard.
include lubricant oil, packaging, paint, paint containers, and gasoline. To access current data on gasoline tax rates in the United States, both at the federal and state levels, visit the American Petroleum Institute at http://www.api.org/statistics/fueltaxes/index.cfm.

For an overview of the international experience with gasoline taxes, read Application 5.1.

According to Kazuo Aichi, former chief of Japan’s environmental agency, “Gasoline is too cheap in the United States and should be taxed more to cut energy use.” Although Aichi’s comment was made over a decade ago, it remains relevant today. The argument is motivated in part by ongoing disagreements between the United States and some of its industrialized counterparts about the appropriate response to such problems as natural resource depletion and global air pollution. This criticism of U.S. policy on fuel taxes underscores the importance of price in encouraging conservation.

Consider how the U.S. tax on gasoline compares to what is imposed by other industrialized countries by examining the data in the accompanying table.

<table>
<thead>
<tr>
<th>Country</th>
<th>Total Gasoline Price per Liter (U.S. dollars)</th>
<th>Tax Rate % of Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>0.567</td>
<td>18.5</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>1.511</td>
<td>67.8</td>
</tr>
<tr>
<td>France</td>
<td>1.511</td>
<td>67.4</td>
</tr>
<tr>
<td>Germany</td>
<td>1.531</td>
<td>70.3</td>
</tr>
<tr>
<td>Italy</td>
<td>1.536</td>
<td>63.3</td>
</tr>
<tr>
<td>Japan</td>
<td>1.374</td>
<td>45.8</td>
</tr>
<tr>
<td>Spain</td>
<td>1.196</td>
<td>56.0</td>
</tr>
<tr>
<td>Canada</td>
<td>0.738</td>
<td>36.1</td>
</tr>
</tbody>
</table>

Sources: International Energy Agency (November 2008).

These data validate the claim that the price of gasoline in the United States is cheap in a relative sense and that much of the difference is due to a lower tax rate. Notice that the tax rate is between 56 percent and 70 percent of the unit price in European nations, 36 percent in Canada, and just over 45 percent in Japan. The comparatively low tax rate of 18.5 percent in the United States reflects its fuel tax policy.

Beyond this brief comparison of tax rates, there is the more important issue of the economic intent of a gasoline tax. In addition to boosting government revenues, taxing a commodity such as gasoline is designed to internalize the negative externalities of consumption, including air pollution caused by operating gasoline-powered vehicles. Other negative externalities are highway congestion and the increased risk of traffic accidents. These adverse effects have one thing in common—they extend to parties beyond those engaged in the market transaction. Consequently, the costs of these damages are not reflected in the price, and too much gasoline is brought to market. As other nations have apparently learned, raising the tax on gasoline can reduce consumption and bring the associated social costs and benefits closer together.

Sources: International Energy Agency (2008); Reifenberg and Sullivan (May 1, 1996); Tanner (June 9, 1992); “Japanese Environmentalist Says Gas Too Cheap in U.S.” (February 2, 1992).
Environmental Subsidies

An alternative market approach to reducing environmental damage is to pay polluters not to pollute through an environmental subsidy. There are two major types of subsidies—abatement equipment subsidies and pollution reduction subsidies. We discuss each of these in turn.

Modeling an Abatement Equipment Subsidy

Abatement equipment subsidies are aimed at reducing the costs of abatement technology. Because subsidies are “negative taxes,” they have a similar incentive mechanism to pollution charges except that they reward for not polluting as opposed to penalizing for engaging in polluting activities. In practice, abatement equipment subsidies are implemented through grants, low-interest loans, or investment tax credits, all of which give polluters an economic incentive to invest in abatement technology.

From a theoretical perspective, subsidies are used to internalize the positive externality associated with the consumption of abatement activities. If a subsidy were offered for installing specific abatement equipment, such as scrubbers, quantity demanded would increase because the effective price would be lower. To achieve an efficient equilibrium, the subsidy would have to equal the marginal external benefit (MEB) of scrubber consumption measured at the efficient output level. Notice that this is analogous to a Pigouvian tax, and in fact, this type of subsidy is known as a Pigouvian subsidy.

A model of a hypothetical competitive market for scrubbers is as follows:

\[ MSC = 70.0 + 0.5Q, \]
\[ MPB = 350.0 - 0.9Q \]
\[ + MEB = 56.0 - 0.2Q \]
\[ MSB = 406.0 - 1.1Q \]

where \( Q \) is the number of scrubber systems produced in a year, and \( MSC, MPB, \) and \( MEB \) are denominated in millions of dollars. The corresponding graph is shown in Figure 5.5. The competitive equilibrium arises where \( MPB = MSC \), or at \( Q_e = 200 \) and \( P_C = $170 \) million. However, the efficient equilibrium occurs where \( MSB = MSC \), or at \( Q_e = 210 \) and \( P_E = $175 \) million. In an unregulated competitive market, too few scrubbers are exchanged at too low a price because the external benefits of a cleaner environment are not recognized by the market participants. If a subsidy \( (s) \) equal to the \( MEB \) at the efficient output level were provided to demanders (i.e., polluters), it is as if \( MPB \) shifts up to \( MPB_s \), and more scrubbers would be traded. In this case, the Pigouvian subsidy would equal \( MEB = 56.0 - 0.2(210) = $14 \) million, shown as distance KL in Figure 5.5. The effective price to polluters would be the efficient market price less the subsidy, or \( (P_E - s) \), which in this case would be \( ($175 \) million \( - $14 \) million), or $161 million.

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\(^8\)For simplicity, we assume there are no marginal external costs \((MEC)\), so that \( MPC = MSC \).
Assessing the Model

Just as in the case of a Pigouvian tax, one problem with implementing a Pigouvian subsidy is measuring the MEB. Monetizing the marginal external benefits of such intangibles as better health and more stable ecosystems is difficult at best. So it is not likely that a subsidy of abatement equipment will achieve allocative efficiency. However, its associated effect of encouraging greater consumption because of an effectively lower price should still occur.

Even setting aside the difficulty in achieving efficiency, equipment subsidies may have other drawbacks. One commonly cited criticism is that this type of control instrument biases polluters’ decisions about how best to abate. Subsidies affect relative prices, making other alternatives less attractive from a financial perspective. However, some of these abatement alternatives might be more effective in reducing pollution. For the same reason, innovation of a potentially superior abatement system could be discouraged as long as the government is subsidizing existing equipment. Finally, subsidies must be financed through taxes or government borrowing. Thus, they effectively redistribute income from society to polluters, an outcome some view as unacceptable despite the associated gain of a cleaner environment.

Modeling a Per-Unit Subsidy on Pollution Reduction

An alternative type of subsidy is one based on emission or effluent reductions, called a per-unit subsidy on pollution reduction. In this case, the government agrees to pay the

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Fig 5.5: A Pigouvian Subsidy

Because of the positive externality in the scrubber market, the true measure of benefits is given by MSB, the vertical sum of MPB and MEB. If a Pigouvian subsidy equal to the MEB at Q_e were provided to purchasers, it is as if the MPB shifts up to MPB_s, and 210 scrubbers would be traded instead of the competitive output level of 200. In this case, the subsidy (s) is $14 million, labeled as distance KL. The effective price to polluters would be (P_e - s), which in this model is ($175 million - $14 million), or $161 million.

MSC

MSB

MPB

MPB_s

Subsidy = $14 million

P_e = 175

P_c = 170

P_e - s = 161

Q_e = 200

Q_e = 210

Q of scrubbers

($ millions)
polluter a subsidy \( (s) \) for every unit of pollution removed below some standard \( (Z_{ST}) \). This is modeled as:

\[
\text{Total Subsidy} = s(Z_{ST} - Z_0)
\]

where \( Z_0 \) is the actual level of pollution. Suppose, for example, that \( Z_{ST} \) is set at 200 tons of emissions per month and the subsidy \( (s) \) is set at $100 per ton per month. Then, if a polluter reduces its emissions to 180 tons per month, it would receive a subsidy of $100(200 - 180), or $2,000.

**Assessing the Model**

On the plus side, a per-unit pollution reduction subsidy might be less disruptive than an equipment subsidy, because it is established independent of the abatement method used and thus avoids any technological bias. On the other hand, these subsidies can have the perverse effect of elevating pollution levels in the aggregate. How does such a paradox arise? Because a per-unit subsidy effectively lowers a polluter’s unit costs, which in turn raises its profits. If the industry has limited entry barriers, these profits would signal entrepreneurs to enter the industry. In the long run, although each individual polluter reduces its emissions, the subsidy may cause the market to expand such that aggregate emissions end up higher than they were originally.\(^9\) The dilemma could be solved if entry were prohibited or at least limited in some way. Whether or not this is feasible or even desirable depends on the industry structure, the extent of environmental damage, and the associated costs.

**Environmental Subsidies in Practice**

Internationally, a common application of environmental subsidies is in the form of grants or low-interest loans, which are being used in many countries, including Belgium, Denmark, Finland, Japan, and Turkey.\(^10\) In the United States, the most common use of subsidies is federal funding for such projects as publicly owned treatment works. Federal subsidies also are used to promote the use of pollution control equipment and to encourage the use and development of cleaner fuels and low-emitting vehicles. Federal subsidies are implemented in a variety of ways, such as through grants, rebates, tax exemptions, and tax credits. At the state level, a common application of environmental subsidies is in the form of tax incentives to encourage recycling activities.\(^11\) See Table 5.2 for an overview of some of these state programs.

**Deposit/Refund Systems**

The potentially perverse consequences of abatement subsidies suggest that pollution charges might be a better alternative. In some contexts, however, pollution charges can be

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\(^9\)For further details, see Baumol and Oates (1975), Chap. 12.

\(^10\)OECD/EEA (2007).

costly to administer because of the associated expense of monitoring and enforcement. Recall that one of the drawbacks of pollution charges is that they may encourage illegal disposal of contaminants. This potential problem is an important motivation for using a deposit/refund system.

Operationally, deposit/refund systems attach a front-end charge (the deposit) for the potential occurrence of a damaging activity and guarantee a return of that charge (the refund) upon assurance that the activity has not been undertaken. This market instrument combines the incentive element of a pollution charge with a built-in mechanism for controlling monitoring costs. Its intent is to capture the difference between the private and social costs of improper waste disposal, with its most common targets being beverage containers and lead-acid batteries.

TABLE 5.2  Selected State Subsidies for Recycling

<table>
<thead>
<tr>
<th>State</th>
<th>General Description</th>
<th>Eligible Applicants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona</td>
<td>Income tax credit on recycling equipment equal to 10 percent of the installed cost.</td>
<td>Individuals and corporations.</td>
</tr>
<tr>
<td>Delaware</td>
<td>Recycling investment tax credit of $500 for every $100,000 invested.</td>
<td>Recycling companies using at least 25 percent of recycled or recovered materials.</td>
</tr>
<tr>
<td></td>
<td>Recycling employment income tax credit of $500 for every new employee associated with adding recycled products into the process.</td>
<td></td>
</tr>
<tr>
<td>Georgia</td>
<td>Personal income tax credit for investing in recycling facilities, equipment, or machinery equal to 3, 5, or 8 percent of the investment.</td>
<td>Manufacturing industries.</td>
</tr>
<tr>
<td>Hawaii</td>
<td>Sales tax reduction on recycling equipment of between 0.5 and 4.0 percent.</td>
<td>Solid waste processing facilities.</td>
</tr>
<tr>
<td>Idaho</td>
<td>Income tax credit on recycling equipment of up to 20 percent of equipment costs up to $30,000 per year.</td>
<td>Recycling firms handling post-consumer paper, glass, and plastic.</td>
</tr>
<tr>
<td>Maryland</td>
<td>Personal property tax exemption on tools, machinery, and manufacturing apparatus or engines for certain counties.</td>
<td>Recycling firms.</td>
</tr>
<tr>
<td>New Jersey</td>
<td>Exemption from sales tax on recycling equipment.</td>
<td>Recycling firms.</td>
</tr>
<tr>
<td>South Carolina</td>
<td>Sales and use tax exemption for recycling equipment.</td>
<td>Recycling and manufacturing firms.</td>
</tr>
<tr>
<td>Virginia</td>
<td>Income tax credit equal to 10 percent of recycling equipment purchase price.</td>
<td>Recycling firms.</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Property tax exemption for machinery and equipment used exclusively and directly in recycling or reducing waste.</td>
<td>Recycling firms.</td>
</tr>
</tbody>
</table>

NOTE: For further detail and other examples, visit [http://www.epa.gov/epawaste/conserve/rrr/rmd/bizasst/rec-tax.htm](http://www.epa.gov/epawaste/conserve/rrr/rmd/bizasst/rec-tax.htm).

Economics of Deposit/Refund Systems

Improper or illegal waste disposal gives rise to a negative externality. The external costs include health damages, such as lead contamination from discarded lead-acid batteries, and aesthetic impairment from litter and trash accumulation. Deposit/refund systems are designed to force the potential polluter to account for both the marginal private cost (MPC) and the marginal external cost (MEC) of improper waste disposal, should that activity be undertaken.

As with the pollution charge, the deposit is intended to capture the MEC of improper waste disposal. The deposit forces the polluter to internalize the cost of any damage it may cause by making it absorb this cost in advance. Unique to the deposit/refund system is the refund component, which introduces an incentive to properly dispose of wastes and hence prevent environmental damage from taking place at all. Taken together, the deposit/refund system targets the potential polluter instead of penalizing the actual polluter, using the refund to reward appropriate behavior.

Modeling a Deposit/Refund System

A model of a deposit/refund system is shown in Figure 5.6. From left to right, the horizontal axis measures improper waste disposal ($IW$) as a percentage of all waste disposal activity. Implicitly, then, the percentage of proper waste disposal ($PW$) is measured right to...
left. Thus, if 25 percent of all wastes is improperly disposed of, then by default, 75 percent is disposed of appropriately and safely.

The $MPC_{IW}$ includes expenses for collecting and illegally dumping wastes plus the costs of improperly disposing recyclable wastes, such as the expense of trash receptacles, collection fees paid to refuse companies, and the opportunity costs of forgone revenue associated with recycling. The $MSC_{IW}$ includes the $MPC_{IW}$ plus the $MEC_{IW}$, represented implicitly as the vertical distance between $MSC_{IW}$ and $MPC_{IW}$. The $MPB_{IW}$ is the demand for improper waste disposal. It is motivated by the avoidance of time and resources to collect wastes, bring nonrecyclables to a landfill, and haul recyclables to a collection center.\(^{12}\) Because we assume no external benefits in this case, $MPB_{IW} = MSB_{IW}$.

In the absence of environmental controls, equilibrium is determined by the intersection of $MSB_{IW}$ and $MPC_{IW}$, or $Q_{IW}$. The efficient equilibrium occurs where $MSC_{IW}$ equals $MSB_{IW}$ or at $Q_E$, which is smaller than $Q_{IW}$. Predictably, we observe that in the presence of a negative externality, too much improper waste disposal is produced because market participants do not consider the full impact of their actions.

To correct the negative externality, assume that a deposit/refund system is instituted whereby the deposit equals the $MEC_{IW}$ at $Q_E$. This is labeled as distance $ab$ in Figure 5.6. Once imposed, the deposit effectively elevates $MPC_{IW}$ by distance $ab$, forcing the market participants to a new equilibrium at $Q_E$. In so doing, a percentage of waste disposal is converted from improper methods to appropriate ones, measured by distance $(Q_{IW} - Q_E)$. Notice that the deposit serves the same function as a pollution charge. The critical difference is that the refund helps to deter improper waste disposal. The potential polluter has an explicit incentive to properly dispose of wastes, because doing so allows it to reclaim the deposit. Should disposers choose instead to illegally discard waste, at least they will have paid for the external costs in advance. Authorities also have the flexibility to adjust the deposit or refund amounts to enhance the built-in incentives.

**Assessing the Model**

The value added of the deposit/refund system is that the refund encourages environmentally responsible behavior without adding significantly to government’s monitoring and compliance costs. What makes this instrument unique is that once established, the incentives operate with limited supervision.

Another advantage of the deposit/refund instrument is that it can be used to encourage more efficient use of raw materials. An inordinate amount of used products and materials ends up in landfills or burned in incinerators, when they could be recycled. The availability of recycled products and wastes can help slow the depletion of such virgin raw materials as aluminum and timber and may result in associated price declines as well. Charging firms a deposit on raw materials acts as a tax, encouraging more efficient use of resources during the production process. The refund encourages proper disposal or recycling of raw material waste at the end of the production phase. Firms that elect to ignore this incentive face not only conventional disposal costs but also the opportunity cost of the forgone refund.

\(^{12}\)The $MPB_{IW}$ measured left to right is equivalent to the $MPC_{IW}$ measured right to left.
Deposit/Refund Systems in Practice

Perhaps the best known applications of deposit/refund systems are those used to encourage proper disposal of beverage containers. In the United States, such programs typically are initiated through state bottle bills. As of 2009, 11 states have passed legislation requiring deposits on beer and soft drink containers: California, Connecticut, Delaware, Hawaii, Iowa, Maine, Massachusetts, Michigan, New York, Oregon, and Vermont. As noted in Table 5.3, deposits range from 2 cents to 15 cents per container.

Attesting to the effectiveness of these programs, Oregon, the first state to enact a bottle bill, reported that roadside litter was reduced by 75 to 85 percent just two years after its bill became law.13 Similar results also have been observed in other countries. Examples include

<table>
<thead>
<tr>
<th>State</th>
<th>Containers Covered</th>
<th>Amount of Deposit</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>Beer, soft drinks, wine coolers, mineral water</td>
<td>5¢ for &lt; 24 oz. 10¢ for &gt; 24 oz.</td>
</tr>
<tr>
<td>Connecticut</td>
<td>Beer, malt, soft drinks, mineral water</td>
<td>5¢</td>
</tr>
<tr>
<td>Delaware</td>
<td>Nonaluminum beer, malt, soft drinks, mineral water under 2 quarts</td>
<td>5¢</td>
</tr>
<tr>
<td>Hawaii</td>
<td>Beer, mixed spirits, mixed wine, soft drinks, tea, coffee, noncarbonated water</td>
<td>5¢</td>
</tr>
<tr>
<td>Iowa</td>
<td>Beer, soft drinks, wine, liquor</td>
<td>5¢</td>
</tr>
<tr>
<td>Maine</td>
<td>Beer, soft drinks, wine, wine coolers, liquor, juice, water, tea</td>
<td>Beer, soft drinks, juice: 5¢ Wine, liquor: 15¢</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>Beer, soft drinks, carbonated water</td>
<td>5¢</td>
</tr>
<tr>
<td>Michigan</td>
<td>Beer, soft drinks, canned cocktails, carbonated and mineral water</td>
<td>10¢</td>
</tr>
<tr>
<td>New York</td>
<td>Beer, soft drinks, wine coolers, carbonated mineral water, soda water</td>
<td>5¢</td>
</tr>
<tr>
<td>Oregon</td>
<td>Beer, malt, soft drinks, carbonated mineral water</td>
<td>Standard refills: 2¢ Others: 5¢</td>
</tr>
<tr>
<td>Vermont</td>
<td>Soft drinks, beer, malt, mineral water, liquor</td>
<td>Soft drinks, beer: 5¢ Liquor: 15¢</td>
</tr>
</tbody>
</table>


Canada, Hungary, and the Netherlands. As might be expected, success of these programs varies greatly across countries. For example, across the Canadian Provinces, return rates range between 47 and 96 percent of targeted bottles, and for Hungary, the return rate is between 70 and 80 percent. While impressive, these rates pale in comparison to the Netherlands, which has been able to achieve a 95 to 99 percent return rate for bottles and cans targeted under its deposit/refund system. Figure 5.7 presents the mechanics of these types of deposit/refund systems.

Other deposit/refund initiatives are aimed at encouraging responsible disposal of such products as used tires, car hulks, and lead-acid batteries. Proper discard of lead-acid batteries is of particular concern because of the health risks linked to lead exposure. Consequently, in the United States, some states have imposed mandatory deposit/refund systems for lead-acid batteries. Typically, the deposit is $5 or $10 per battery, and the

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**FIGURE 5.7** Typical Phases of a Deposit/Refund System for Beverage Containers

**PHASE 1**
A deposit is paid by the retailer to the bottler or wholesaler for each beverage container received. If the product is a soft drink, retailers pay the deposit to the bottler; for beer, the retailer pays the wholesaler.

**PHASE 2**
Consumers pay the same deposit to the retailer as part of the product’s purchase price.

**PHASE 3**
After the beverage is consumed, the consumer returns the used container to the retailer, who refunds the consumer for the amount of the initial deposit.

**PHASE 4**
Retailers reclaim the deposit from either the bottler or the wholesaler when they return the empty container. In addition, bottlers and wholesalers typically pay a per-unit handling fee to retailers to cover their costs to collect and return the containers.

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consumer can obtain a refund by returning a used battery within a specified period along with proof that the deposit was paid.\textsuperscript{15} Denmark, Mexico, and Poland have set up similar systems for lead-acid batteries with return rates ranging between 60 and over 99 percent. Other applications of deposit/refund systems include Poland and Spain for product packaging, Denmark for used tires, and Denmark, Norway, and Sweden for scrapped vehicles. In this latter instance, Denmark and Norway charge a deposit that is actually less than the refund, presumably to further enhance the incentive to return unwanted vehicles for proper disposal or recycling.\textsuperscript{16}

\section*{Pollution Permit Trading Systems}

Thus far, we have illustrated that market instruments can be used to set prices for polluting and abatement activities. It is also possible for government to use the price-quantity relationship in the opposite direction—by establishing the quantity of pollution or abatement to be achieved and letting the market determine the price. With perfect information, either approach is viable, and both will lead to the same outcome. However, pricing instruments can be problematic in that government does not know in advance what price will achieve a quantity-based environmental objective. That means it has to monitor the quantity response to some initially established price and continually make adjustments until the proper pollution level is achieved, essentially a trial-and-error process.

It may be more efficient to use a policy instrument that operates from the known variable, that is, the socially desirable quantity of pollution or abatement, and let the market establish the price. This is the underlying premise of a pollution permit trading system, which can be implemented through the use of credits or allowances. Under a pollution credit system, a polluter earns marketable credits only if it emits below an established standard. If instead the trading system uses pollution allowances, each permit gives the bearer the right to release some amount of pollution. These too are marketable, so that polluters can buy and sell allowances as needed, based on their access to abatement technologies and their costs.

\subsection*{Structure of a Pollution Permit Trading System}

A system of marketable pollution permits has two key components:

\begin{itemize}
  \item the issuance of some \textit{fixed number of permits} in a region
  \item a provision for \textit{trading} these permits among polluting sources within that region
\end{itemize}

The fixed number of permits issued is bound by whatever pollution level is mandated by law, capping emissions to meet that regulated level. For example, if the level were set at 200 units of emissions, a maximum of 200 one-unit permits could be issued. Any polluter releasing emissions not authorized by permits would be in violation of the law. Once the

\textsuperscript{15}U.S. EPA, Office of Policy, Economics, and Innovation (January 2001), p. 64.
\textsuperscript{16}OECD/EEA (2007).
limited permits are distributed, polluters may trade them with one another, hence the common description of such a program as a cap-and-trade system.

A bargaining process should develop, which gives rise to a market for pollution rights. Following their own self-interest, polluters either purchase these rights to pollute or they abate, whichever is the cheaper alternative. High-cost abaters have an incentive to bid for available permits, whereas low-cost abaters have an incentive to abate and sell their permits on the open market. The result is a cost-effective abatement allocation. But notice that trading is critical to the cost-effective outcome. For example, if the permits were allocated equally across all polluters and no trading were allowed, the result would be no different than a command-and-control system of uniform standards.

The tradeable permit system accommodates environmental objectives, defined at an aggregate level. For example, in the United States, air pollution policies are designed to achieve national ambient air quality standards within well-defined regions. Within any region, however, some polluters might perform above the standard and others below it, which is acceptable as long as in the aggregate the region is in compliance. This is exactly how the permit system operates—controlling the total amount of emissions in a region but not the releases for each source within that region.\(^\text{17}\)

The trading component of the permit system capitalizes on differences in polluters’ abatement technologies and opportunities. Sources that can abate efficiently are given the incentive to do so because they can sell their unused permits to their less efficient counterparts. As long as the environmental goal is achieved in the aggregate, the benefit to society is the same whether the task is undertaken by a select few or by all firms doing an equal amount of abating. The costs, however, will be markedly lower if abatement is done by more efficient polluters.

### Modeling a Pollution Permit System for Multiple Polluters

To illustrate the operation of a permit system, we return to our two-polluter model, where each firm faces distinct abatement costs:

- **Polluter 1:**
  \[
  \begin{align*}
  TAC_1 &= 1.25(A_1)^2 \\
  MAC_1 &= 2.5A_1 
  \end{align*}
  \]

- **Polluter 2:**
  \[
  \begin{align*}
  TAC_2 &= 0.3125(A_2)^2 \\
  MAC_2 &= 0.625A_2 
  \end{align*}
  \]

Before any government intervention, we assume that each firm releases 10 units of pollution for a total of 20 units in their region. The government has determined that the “acceptable” level of pollution for this region is 10 units, and it decides to meet this objective by using a tradeable permit system. It therefore issues 10 permits, each of which allows the bearer to emit 1 unit of pollution. For simplicity, assume that the government allocates

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\(^\text{17}\)Contrast this scenario with a command-and-control instrument that forces every polluting source to meet identical standards of emission or effluent levels. Such instruments equalize the level of control across polluters rather than the marginal costs of control.
5 permits to each polluter. Under the permit system, each firm is required to hold a permit for each unit of pollution released and to undertake abatement on all remaining units.

Based on the initial allocation of permits, each polluter must abate 5 units of pollution. This initial condition, termed Round 1 of the permit system, is summarized as follows:

**ROUND 1: Government Issues Five Permits to Each Polluter**

Polluter 1:  
- Current pollution level: 10 units  
- Number of permits held: 5  
- Abatement required: 5 units  

\[
MAC_1 = 2.5A_1 = 2.5(5) = 12.50
\]

\[
TAC_1 = 1.25(A_1)^2 = 1.25(5)^2 = 31.25
\]

Polluter 2:  
- Current pollution level: 10 units  
- Number of permits held: 5  
- Abatement required: 5 units  

\[
MAC_2 = 0.625A_2 = 0.625(5) = 3.125
\]

\[
TAC_2 = 0.3125(A_2)^2 = 0.3125(5)^2 = 7.81
\]

If the permit system did not allow for trading, each firm would have no choice but to abate 5 units each. Although the environmental objective would be met, it would not be achieved in a cost-effective manner. The combined abatement cost for both sources without trading is $39.06.

Now, consider how the result changes when permit trading is allowed. Because the two firms face different MAC levels at the end of Round 1, there is an incentive for trade. Polluter 1 has an incentive to buy permits from Polluter 2 as long as the price of each permit is less than its MAC. Likewise, Polluter 2 has an incentive to sell permits to Polluter 1 as long as it can obtain a price greater than its MAC.

Suppose that in Round 2 of the trading process, the two firms agree on the purchase and sale of one permit at a price of $8.00. Polluter 1 purchases one permit from Polluter 2, giving Polluter 1 the right to pollute 6 units and the obligation to abate 4 units. Polluter 2 now possesses the right to release 4 units of pollution, which means it must abate 6 units. Round 2 is summarized as follows:

**ROUND 2: Polluter 1 Purchases One Permit from Polluter 2**

Polluter 1:  
- Current pollution level: 10 units  
- Number of permits held: 6  
- Abatement required: 4 units

---

18The government could have introduced the permits through a direct sale, assigning a price to each permit, or through an auction. Either method has the advantage of generating revenue to the government, and the revenue could help absorb some of the administrative costs.

19Recall from Chapter 4 that this is precisely the same expenditure incurred by the two polluters if a uniform standard is used under a command-and-control approach.

20Any negotiated price between MAC and MAC would be acceptable. The ultimate selling price within that range would be determined by the two firms’ relative bargaining strengths.
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\[
\begin{align*}
MAC_1 &= 2.5A_1 = 2.5(4) = 10.00 \\
TAC_1 &= 1.25(A_1)^2 = 1.25(4)^2 = 20.00 \\
\text{Cost of one permit purchased} &= 8.00
\end{align*}
\]

Polluter 2:  
Current pollution level: 10 units  
Number of permits held: 4  
Abatement required: 6 units  

\[
\begin{align*}
MAC_2 &= 0.625A_2 = 0.625(6) = 3.75 \\
TAC_2 &= 0.3125(A_2)^2 = 0.3125(6)^2 = 11.25 \\
\text{Revenue from one permit sold} &= 8.00
\end{align*}
\]

This outcome can be analyzed from two perspectives—that of society and that of the firm. From the vantage point of society, the total costs of abating 10 units of pollution are now $31.25, which is $7.81 less than the costs without permit trading. Qualitatively, this is exactly what should happen, because trading has brought the two firms’ MAC values closer together. Polluter 1 now faces a lower MAC of $10 (compared to $12.50 in Round 1), and Polluter 2 now has a higher MAC of $3.75 (compared to $3.125 in Round 1).

Next, consider the gains that accrue to each firm as a result of the trade. Polluter 1 is better off, because its total expenditures have decreased. Its outlay for abating plus the cost of the added permit is $28.00 (i.e., TAC of $20.00 plus the cost of the additional permit, $8.00), which is $3.25 less than its TAC in Round 1. Likewise, Polluter 2 is better off because its net expenditures on abating and trading are $3.25 (i.e., TAC of $11.25 minus the revenue received from selling one permit, $8.00), which is $4.56 less than its TAC at the end of Round 1.

Because there is an incentive for trade as long as the two firms face different MAC levels, it should be apparent that Round 2 does not represent a cost-effective solution. After the exchange of one permit, Polluter 1 still faces a higher MAC level than Polluter 2 (i.e., $10.00 for Polluter 1 versus $3.75 for Polluter 2). Thus, it is in each polluter’s best interest to continue to trade. The rule of thumb is that in the presence of differing MAC levels among polluting sources, high-cost abaters have an incentive to purchase permits from low-cost abaters, and low-cost abaters have an incentive to sell them. The result? Low-cost abaters will do what they do best—clean up the environment—and high-cost abaters will pay for the right to pollute by buying more permits. Trading will continue until the incentive to do so no longer exists, that is, when the MAC levels across both firms are equal. At precisely this point, the cost-effective solution is obtained.

By applying this equimarginal principle to our model, we come to the final round, or equilibrium.

**FINAL ROUND: Polluter 1 Purchases Three Permits from Polluter 2**  
Equalization of MAC Levels Across Polluters Is Achieved\(^1\)

Polluter 1:  
Current pollution level: 10 units  
Number of permits held: 8  
Abatement required: 2 units

---

\(^1\)We assume that the second permit is sold for $7 and the third for $5. These values plus the $8 price for the first permit results in a total payment of $20 for permits.
Chapter 5 Economic Solutions to Environmental Problems

\[
MAC_1 = 2.5A_1 = 2.5(2) = $5.00 \\
TAC_1 = 1.25(A_1)^2 = 1.25(2)^2 = $5.00 \\
\text{Cost of three permits purchased} = $20.00
\]

Polluter 2:  
Current pollution level: 10 units  
Number of permits held: 2  
Abatement required: 8 units  
\[
MAC_2 = 0.625A_2 = 0.625(8) = $5.00 \\
TAC_2 = 0.3125(A_2)^2 = 0.3125(8)^2 = $20.00 \\
\text{Revenue from three permits sold} = $20.00
\]

At this point, each polluter faces an \( MAC \) of $5, and society’s total cost to achieve the environmental objective is $25. (Notice that the $20 payment for permits is not included in society’s abatement costs, because this amount is just a transfer from one firm to another.) As predicted, the low-cost abater, Polluter 2, is doing most of the abating at 8 units, whereas the high-cost abater, Polluter 1, abates only 2 units.

Assessing the Model

It is no coincidence that the final abatement allocation for these firms is identical to what happens if a $5 pollution charge is used. Logically, the outcome is the same because both instruments use incentives linked to the firm’s \( MAC \). There are, however, three important differences.

First, with a pollution charge, the government has to search for the price that will bring about the requisite amount of abatement. In the permit system, trading establishes the price of a right to pollute without outside intervention. Second, the trading system is more flexible; the number of permits can be adjusted to change the environmental objective. If the objective is too stringent, more permits can be introduced. If it is too lenient, the government, environmental groups, or concerned citizens can buy up permits, effectively reducing the amount of pollution allowed in the affected region. Third, the pollution charge generates tax revenues on all units of pollution not abated, whereas no revenues are generated from the permit system. This distinction may be critical in jurisdictions with tight fiscal budgets. However, a trading system can be designed to generate revenues if the government sells or auctions off the initial allocation of permits.

Some measure of controversy surrounds the use of trading systems. Economists typically tout the advantages of a system that so explicitly uses the market. On the other side of the coin, opponents argue that trading systems can create pollution hot spots, localized areas facing high concentrations of pollutants where most of the permit buying takes place. Another objection is the potential for elevated administrative costs to keep records of trades and the emissions of buyers and sellers. Hypotheticals aside, the true test will be in observing how these permit systems perform in practice.

Pollution Permit Trading Systems in Practice

Of all the available control instruments, pollution permit trading systems are by far the most market-oriented. Much of the initial development of these programs has occurred in the United States at the federal level. In attempting to combat the adverse effects of acid rain, the Clean Air Act Amendments of 1990 established an allowance-based trading program to control sulfur dioxide (SO₂) emissions. Application 5.2 describes the major events that characterized the first day of official trading on March 31, 1993.

Application 5.2: Fighting Acid Rain with Pollution Rights: The First Annual Auction

In March 1993, the first annual auction of sulfur dioxide (SO₂) emission permits was held. The event was administered by the Chicago Board of Trade (CBOT), the largest commodity exchange in the world. Although most of the available permits are allocated by the EPA directly to the largest polluting sources, a relatively small number (150,000 one-ton permits per year) are set aside in an auction subaccount for direct sale.

Most of the bids in the 1993 auction came from the nation’s major utilities, who are the largest SO₂ polluters. A case in point is Illinois Power, a utility that releases about 240,000 tons of SO₂ emissions each year. This facility was unable to operate on the 171,000 permits issued by the EPA, so it bought more from other utilities at about $225 each. It subsequently submitted bids for another 5,000 permits at the 1993 auction. For Illinois Power and others like it, the costs to abate were apparently greater than the expected outlay to purchase permits.

Despite the predominance of utilities in the bidding, there was at least one important exception—a not-for-profit environmental group called National Healthy Air License Exchange. According to the group’s president, any permits bought in the auction would be retired and kept off the market. That private citizens can exercise such a tangible influence over environmental policy is one of the advantages of an emissions trading program. National Healthy Air License Exchange submitted bids for 1,100 permits but came away with only one, for which it paid $350. Nonetheless, the organization was able to participate in the auction and eliminate some emissions from the atmosphere.

In an apparently philanthropic move, Northeast Utilities of Connecticut donated 10,000 of its permits to the American Lung Association just before the auction. The association retired the permits to keep them out of the bidding process. The utility, which did not need the permits to operate, could have sold them for an estimated value of $3 million on the open market. However, the gesture was not totally without financial incentive. Northeast Utilities was expected to enjoy tax deductions for the contribution that would offset any sacrifice of pollution rights’ revenues. Hoping to encourage other such donations, Northeast Utilities and the American Lung Association established a repository for permits donated by other utilities.

How did the bidders fare in the first pollution rights auction? Rights to emit the 150,000 tons of SO₂ were purchased by utilities, brokers, and environmentalists for a total of $21 million. Permit prices ranged from $122 to $450. The largest single purchaser was Carolina Power and Light Company, a utility that bid for and won over 85,000 permits. In accordance with the law, all auction proceeds went to the EPA, which then allocated the funds to those utilities from which the permits were originally obtained.

For direct access to all the annual auction results through the present, visit the EPA’s Acid Rain Program Allowance Auctions Web page at http://www.epa.gov/airmarkets/trading/auction.html.

Sources: Allen (March 20, 1993); Taylor and Gutfeld (September 25, 1992); Taylor (March 31, 1992); Taylor and Kansas (March 26, 1992).
More recent developments in U.S. trading programs have occurred at the regional and state levels. For example, in an effort to reduce urban smog, a group of northeastern states organized the Ozone Transport Commission, which ultimately designed and implemented a tradeable permit system to reduce nitrogen oxide (NOx) emissions. An analogous state-level system was devised by California’s Regional Clean Air Incentives Market (RECLAIM) to combat urban smog in the Los Angeles area.23

On a global scale, a trading program that has received considerable worldwide attention is the tradeable permit system for greenhouse gases (GHGs) established by the Kyoto Protocol, an international accord that addresses global warming.24 To meet their obligations under the Protocol, member states of the European Union executed a formal directive to establish the European Union Greenhouse Gas Emission Trading System (EU ETS), which was launched in 2005. This multi-nation trading program effectively limits aggregate carbon dioxide (CO2) emissions of participating countries and grants each nation marketable emissions allowances. More on this innovative program is available at http://ec.europa.eu/environment/climat/emission/index_en.htm.

**Conclusions**

No environmental policy instrument is without flaws. In truth, this less than perfect outcome should be expected. The market process works as well as it does because it operates autonomously, without external guidance. Therefore, it should not be surprising that any attempt to correct a market problem by imposing third-party controls is likely to have its share of pitfalls.

This line of defense is precisely the motivation of market-based policy approaches. The aim is not to add more restraint but to restore the market forces that broke down in the first place. In one form or another, market-based instruments effectively assign a price to environmental goods, such as clean air and clean water. Once this signaling mechanism is in place, polluters are forced to internalize the costs of pollution damage and adjust their decisions accordingly.

Of course, not all market-based instruments are well suited to all environmental problems. Both the nature of the problem and the market context must be understood before any policy can be implemented with success. Environmental problems are complex, both in origin and in implication. Likewise, today’s markets are sophisticated and dynamic. However, evidence is beginning to accumulate that the link between the two is a fundamental step toward finding solutions.

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24 More detail on the Kyoto Protocol, including the trading program, is provided in Chapter 13.


**SUMMARY**

- The market approach to pollution control uses economic incentives and the price mechanism to achieve an environmental standard.
- The major categories of market-based instruments are pollution charges, subsidies, deposit/refund systems, and pollution permit trading systems.
- A pollution charge is a fee that varies with the quantity of pollutants released. It can be implemented as a product charge or as an effluent or emission charge.
- A Pigouvian tax is a unit charge on a pollution-generating product equal to the MEC at the efficient output level.
- An emission charge is levied directly on the actual release of pollutants. Given a choice of abating or paying the fee, the profit-maximizing polluter will choose the least-cost option.
- When multiple polluters face an abatement standard, the emission charge yields a cost-effective allocation of abatement responsibilities where the MAC levels for all sources are equal.
- Abatement equipment subsidies are designed to reduce the costs of abatement.
- If the subsidy equals the MEB at the efficient output level, it is called a Pigouvian subsidy.
- Per-unit pollution reduction subsidies pay the polluter for abating beyond some predetermined level.
- A deposit/refund system imposes an up-front charge to pay for potential pollution damage and later refunds the charge when the product is returned for proper disposal or recycling. The deposit is intended to capture the MEC of improper disposal, and the refund provides an incentive to properly dispose of or recycle wastes.
- A pollution permit trading system involves the issuance of tradeable pollution rights based on a given environmental objective. Following natural incentives, polluters will either purchase these rights or abate, whichever is the cheaper alternative.

**REVIEW QUESTIONS**

1. Suppose that a chemical manufacturing plant is releasing nitrogen oxides into the air, and these emissions are associated with health and ecological damages. Economists have estimated the following marginal costs and benefits for the chemical market, where \( Q \) is monthly output in thousands of pounds and \( P \) is price per pound.

\[
MSB = 50 - 0.4Q \\
MSC = 2 + 0.4Q \\
MEB = 0 \\
MEC = 0.2Q
\]

a. Find the competitive equilibrium, \( Q_C \) and \( P_C \), and the efficient equilibrium, \( Q_E \) and \( P_E \).

b. Find the dollar value of a product charge that would achieve an efficient solution.

2. Despite economists’ support of a market approach to environmental policy, the command-and-control approach continues to dominate the policy of most nations. Explain why this is the case. In your response, cite and then comment on some of the common criticisms of market-based initiatives.

3. In 1996, Michigan launched a voluntary emissions trading program, which allows polluters to achieve cost-effective solutions when meeting requirements of the U.S. Clean
Air Act. (For more on this program, visit http://www.michigan.gov/deq, and click on Air, Assessment and Planning, and Emissions Trading.) Suppose that Michigan’s objective for two major firms in an urban area is a 16 percent reduction in carbon monoxide (CO) emissions and that each firm faces the following costs:

Firm 1:  
\[ TAC_1 = 1,000 + 2.5(A_1)^2 \]
\[ MAC_1 = 5A_1 \]

Firm 2:  
\[ TAC_2 = 500 + 1.5(A_2)^2 \]
\[ MAC_2 = 3A_2 \]

where \( A_1 \) and \( A_2 \) represent the percentages of CO emission abatement achieved by firm 1 and firm 2, respectively, and \( TAC \) and \( MAC \) are measured in thousands of dollars.

a. Calculate the \( TAC \) and \( MAC \) for each firm if a uniform abatement standard were used.

b. Based on your answer to part a, is there an economic incentive for the sources to participate in the trading program? Explain.

c. Quantify the cost savings associated with a cost-effective abatement allocation that could be achieved through trading.

d. At what price must each tradeable permit be set to achieve the cost-effective solution?

**ADDITIONAL READINGS**


For related Web sites, go to www.cengage.com/economics/callan
Global Air Quality: Policies for Ozone Depletion and Climate Change

“Many people today assume mistakenly that the Earth is so big that we humans cannot possibly have any major impact on the way our planet’s ecological system operates. That may have been true at one time, but it is not the case anymore.”

While most air pollutants produce localized effects, others have more far-reaching implications. Such is the case for contaminants that alter atmospheric conditions, posing a risk that is geographically without bound and generating a free-ridership problem that crosses national boundaries. Of course, the effects can vary by degree across different locations. In any case, since the associated damage is widespread and since the source cannot be linked to a specific site or region, this air quality problem is termed global air pollution. Controlling global air pollution is a unique policy challenge, because solutions must be developed not only through domestic initiatives but also through international treaties and programs.

In this chapter, we investigate the principal issues associated with global air pollution by studying ozone depletion and climate change. In each case, we consider theories about the causes and sources of the atmospheric disturbance and the available evidence to support these theories. Using this as a foundation, we then explore policy responses that have been set in motion in the United States and other nations, along with proposals for alternatives. Ultimately, our objective is to economically evaluate the effectiveness of these policies, given what we know about the origin of the problem and the associated risks. As in the previous three chapters, there is a reference list of acronyms and terms at the end of the chapter.

THE PROBLEM OF OZONE DEPLETION

ozone layer
Ozone present in the stratosphere that protects the earth from ultraviolet radiation.

Starting in the 1950s, scientists began measuring the earth’s ozone layer in the stratosphere, which is the atmospheric layer lying between 7 and 25 miles above the earth’s surface. The effort was motivated by more than scientific curiosity. Stratospheric ozone protects the earth from ultraviolet radiation.
Some variability in the depth of the ozone layer was assumed normal, including an observed thinning above Antarctica during the Southern Hemisphere spring. This would generally fill back in by November each year. However, in the early 1980s, scientists became concerned when this thinning was found to be increasing in size and persisting into December. In 1985, an “ozone hole” the size of North America was discovered over Antarctica. It was then that world attention was drawn in earnest to the problem of ozone depletion and the pollutants responsible for the damage.1

While all the implications are not known with certainty, there are some consequences of increased ultraviolet radiation about which there is agreement. Scientists tell us that rising levels of ultraviolet radiation can alter delicate ecosystems, diminish human immune systems, and increase the risk of skin cancer. The National Academy of Sciences estimates that 10,000 more cases of skin cancer per year would result for every 1 percent decline in stratospheric ozone. A good resource on the science of ozone depletion is available at http://www.epa.gov/ozone/science.

**Searching for the Causes of Ozone Depletion**

Scientists debate about the principal cause of the ozone hole, which extends approximately 9 million square miles over the Antarctic.2 Figure 13.1 presents an image from the National Aeronautics and Space Administration (NASA) that shows the ozone thinning over Antarctica during the 2008 ozone season. Although no one theory has been able to fully explain the extent of ozone depletion, scientists agree that the presence of chlorofluorocarbons (CFCs) in the atmosphere is the most likely explanation—a theory originally advanced in 1974 by F. Sherwood Rowland and Mario Molina, two University of California researchers. The pair won the Nobel Prize in chemistry for this theory in 1995.

CFCs are a family of chemicals that were commonly used in refrigeration, air conditioning, packaging, and insulation and as aerosol propellants. They are sometimes referred to by their trade names, Freon and Styrofoam. In fact, the energy crisis in the 1970s was responsible for an even greater use of CFCs as foaming agents in the production of home insulation. The rise of the fast-food industry was also a contributing factor to intensified CFC use, because polymer foams were utilized to produce disposable cups and food containers. These long-lived compounds are not destroyed in the lower atmosphere and therefore are able to drift up into the stratosphere, where their chlorine components destroy ozone. In addition, because of their long atmospheric lifetimes, CFCs released today affect the ozone layer for decades to come.

From an economic perspective, production of goods like Styrofoam cups is associated with a negative externality. As discussed in Chapter 3, a negative externality arises when there is an external effect that generates costs to a third party. Graphically,

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1For the published report, see Farman, Gardiner, and Shanklin (1985).

2Research shows that ozone depletion is truly a global issue, occurring over latitudes that include Asia, parts of Africa, Australia, Europe, North America, and South America (U.S. EPA, Office of Air and Radiation, February 5, 2002).
this externality would be modeled as a marginal external cost \((MEC)\), which causes the marginal social cost \((MSC)\) to be higher than the marginal private cost \((MPC)\). Therefore, the \(MEC\) is represented as the vertical distance between \(MSC\) and \(MPC\) at each output level. This relationship is shown in Figure 13.2 for the Styrofoam cup market. Notice that the competitive equilibrium output \((Q_c)\) is higher than the efficient equilibrium \((Q_e)\), indicating that too much of the good is produced in the absence of third-party intervention.

Another major group of ozone depleters are halons, which have long atmospheric lifetimes. Before government controls, these substances were becoming increasingly important in the production of fire extinguishants. Their use is not as widespread as CFCs, but halons are known to have a higher potency for ozone depletion than their chlorine-containing counterparts.

Despite the lack of hard evidence at the time, the United States opted to ban the use of CFCs in most aerosol sprays in 1978, and other countries followed suit. However, other uses of these ozone depleters were not controlled, and little effort was aimed at finding substitutes. As a result, domestic and international CFC use continued to grow. Until governments intervened in the late 1980s, there was little question that a stronger policy position was needed to control ozone-depleting substances.
As a global air pollution problem, ozone depletion cannot be controlled without an integrated international effort. More formally, think of this environmental problem as an externality with transboundary implications. Domestically, the 1990 Clean Air Act Amendments (CAAA) call for the president to enter into international agreements that encourage joint research on ozone depletion and to establish regulations consistent with those in the United States. Although not without political implications, a number of international agreements and multilateral treaties have been executed or are on the negotiating table. A brief summary of the most significant of these follows.

International Agreements to Control Ozone Depletion

**Montreal Protocol**

In 1987, 24 countries as well as the European Community Commission signed the Montreal Protocol on Substances that Deplete the Ozone Layer. Among the signatories were the major producers of CFCs. This landmark agreement called for a 50 percent reduction in CFC consumption and production, a target that was to be achieved

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3General information in the subsequent discussion is drawn from U.S. EPA (June 21, 2004).
gradually by 2000. To achieve this objective, each party to the protocol was responsible for designing and implementing an effective control program in accordance with the agreed-upon deadlines. Current ratification status of the Montreal Protocol and subsequent amendments is available at [http://www.unep.ch/ozone/ratification_status/index.shtml](http://www.unep.ch/ozone/ratification_status/index.shtml). As of 2009, 195 nations have ratified this accord.4

**Amendments to the Protocol**

In 1990, 59 countries executed the London Amendment to the protocol. This amendment, which strengthened the worldwide commitment to protecting the ozone layer, was in direct response to reports that ozone depletion might be more severe than originally believed. The new agreement outlined a full phaseout plan for CFCs and halons, and added controls for other ozone-depleting substances, such as carbon tetrachloride and methyl chloroform. At subsequent conferences, controls for other substances were added, including additional CFCs, hydrochlorofluorocarbons (HCFCs), hydrobromofluorocarbons (HBFCs), methyl bromide, and bromochloromethane (BCM). In addition, various phaseout deadlines were advanced and then formalized. The Protocol does include special provisions for developing nations, allowing them an additional 10 to 12 years to phase out ozone depleters.5 Table 13.1 gives a summary of how these phaseout agreements are defined for both developed and developing nations.

**International Allowance Trading**

A market approach was integrated as part of the international effort to protect the ozone layer. Specifically, production and consumption allowances were issued to the protocol participants, and transfers were permitted under certain guidelines. To ensure that the phaseouts were achieved, trading was conditioned upon revision of each country’s aggregate production limits to levels lower than what would have occurred without the transfers.

**Multilateral Fund**

Ongoing negotiations are aimed at encouraging more nations to ratify the protocol amendments. Some countries have been hesitant because of the high costs of converting production technology to eliminate the use of ozone-depleting substances. This is particularly problematic for developing nations. In response to these concerns, an Interim Multilateral Fund of $160 million was established in 1990 to help developing countries transition toward the requisite CFC replacement technologies. In 1992, the fund became permanent, and it is replenished every three years. The replenishment amount for 2009–2011 is $400 million. As of 2008, 49 industrialized nations, including Countries with Economies in Transition, or CEIT countries, have contributed over $2.4 billion to this fund. More information is available at [http://www.multilateralfund.org](http://www.multilateralfund.org).

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4Note that Title VI of the CAAA provides the legislative guidelines for U.S. compliance with the Montreal Protocol.

5Changes at these later conferences became known as the 1992 Copenhagen Amendment, 1995 Vienna Convention, the 1997 Montreal Amendment, the 1999 Beijing Amendment, and the 2007 Montreal Adjustment.
U.S. Policy to Control Ozone Depletion

The 1990 CAAA significantly strengthened U.S. policy on ozone-depleting substances through Title VI (accessible at http://www.epa.gov/oar/CAA/title6.html). These provisions must comply with the nation’s commitment to the Montreal Protocol. Under these rulings, Congress charged the EPA with the responsibility of identifying ozone-depleting substances. Each substance is assigned a numerical value that signifies its ozone depletion potential (ODP) relative to chlorofluorocarbon-11 (CFC-11). The agency also must distinguish between Class I and Class II substances, where Class I refers to those having a greater potential for damage. Then, for each substance class, phaseout schedules were outlined.

With the exception of HCFCs, which are to be phased out by 2020, all ozone-depleting substances were phased out of production in or prior to 2005. However, because these substances have extended lifetimes, they affect the environment long after they have

\[
\text{TABLE 13.1} \quad \text{Montreal Protocol Phaseout Schedules for Production and Consumption of Ozone Depleters}
\]

<table>
<thead>
<tr>
<th>Developed Nations</th>
<th>Developing Nations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CFCs</strong></td>
<td>Phase out by 1996</td>
</tr>
<tr>
<td></td>
<td>Freeze at average 1995–1997 levels by July 1, 1999; reduce by 50 percent by 2005, by 85 percent by 2007; phase out by 2010</td>
</tr>
<tr>
<td><strong>Carbon-tetrachloride</strong></td>
<td>Phase out by 1996</td>
</tr>
<tr>
<td></td>
<td>Freeze at average 1995–1997 levels by July 1, 1999; reduce by 50 percent by 2005, by 85 percent by 2007; phase out by 2010</td>
</tr>
<tr>
<td><strong>Halon</strong></td>
<td>Phase out by 1994</td>
</tr>
<tr>
<td></td>
<td>Freeze at average 1995–1997 levels by July 1, 1999; reduce by 50 percent by 2005, by 85 percent by 2007; phase out by 2010</td>
</tr>
<tr>
<td><strong>HCFCs</strong></td>
<td>Reduce by 35 percent by 2004, by 75 percent by 2010, by 90 percent by 2015; phase out by 2020 (allowing 0.5 percent for servicing reasons between 2020 and 2030)</td>
</tr>
<tr>
<td></td>
<td>Freeze at average 2009–2010 levels by 2013; reduce by 10 percent by 2015, by 35 percent by 2020, by 67.5 percent by 2025; phase out by 2030 (allowing 2.5 percent annual average for servicing reasons between 2030 and 2040)</td>
</tr>
<tr>
<td><strong>Methyl bromide</strong></td>
<td>Reduce by 25 percent by 1999, by 50 percent by 2001, by 70 percent by 2003; phase out by 2005</td>
</tr>
<tr>
<td></td>
<td>Freeze at average 1995–1998 levels by 2002; reduce by 20 percent by 2005; phase out by 2015</td>
</tr>
<tr>
<td><strong>Methyl chloroform</strong></td>
<td>Phase out by 1996</td>
</tr>
<tr>
<td></td>
<td>Freeze at average 1998–2000 levels by 2003, reduce by 30 percent by 2005, by 70 percent by 2010; phase out by 2015</td>
</tr>
<tr>
<td><strong>HBFCs</strong></td>
<td>Phase out by 1996</td>
</tr>
<tr>
<td></td>
<td>Phase out by 1996</td>
</tr>
<tr>
<td><strong>BCM</strong></td>
<td>Phase out by 2002</td>
</tr>
<tr>
<td></td>
<td>Phase out by 2002</td>
</tr>
</tbody>
</table>

For more detail on the Montreal Protocol or any of the subsequent amendments, visit the Ozone Secretariat at the United Nations Web site at http://ozone.unep.org/.

**NOTE:** Phaseouts shown include changes through the 2007 Montreal Adjustment.

**Source:** United Nations Environment Programme (September 2008).

ozone depletion potential (ODP)
A numerical score that signifies a substance’s potential for destroying stratospheric ozone relative to CFC-11.
been produced. By way of illustration, a subset of ozone-depleting substances is listed in Table 13.2 with their ODP values and their atmospheric lifetimes.

Recognizing the industry’s dependence on CFCs, the 1990 Amendments also include provisions to establish a mandatory national recycling program for Class I and II substances, with the intent that recycled refrigerants could be used as substitutes for virgin materials. Related provisions call for federal programs and research aimed at finding safe alternatives to identified ozone depleters. In addition, two policy instruments are legislated that explicitly use market incentives to eliminate ozone-depleting substances: an excise tax and a marketable allowance system.

**Excise Tax on Ozone Depleters**

One market-based instrument used to control ozone depletion and achieve the phaseout deadlines is an escalating excise tax on the production of ozone-depleting substances. Enacted by Congress in 1990, the tax rate per pound is a base dollar amount multiplied by the chemical’s ODP, where the base amount increases with each successive year in the phaseout schedule. The tax rate was initially set at $1.37 per pound, and by 1995, it had

### TABLE 13.2 ODP Values of Selected Ozone-Depleting Substances

<table>
<thead>
<tr>
<th>Substance</th>
<th>Atmospheric Lifetime in Years</th>
<th>ODP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Class I Substances</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CFC-11</td>
<td>45</td>
<td>1.0</td>
</tr>
<tr>
<td>CFC-12</td>
<td>100</td>
<td>1.0</td>
</tr>
<tr>
<td>CFC-113</td>
<td>85</td>
<td>0.8</td>
</tr>
<tr>
<td>CFC-114</td>
<td>300</td>
<td>1.0</td>
</tr>
<tr>
<td>CFC-115</td>
<td>1,700</td>
<td>0.6</td>
</tr>
<tr>
<td>Halon 1211</td>
<td>16</td>
<td>3.0</td>
</tr>
<tr>
<td>Halon 1301</td>
<td>65</td>
<td>10.0</td>
</tr>
<tr>
<td>Halon 2402</td>
<td>20</td>
<td>6.0</td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>26</td>
<td>1.1</td>
</tr>
<tr>
<td>Methyl Chloroform</td>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Class II Substances</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCFC-22</td>
<td>12.0</td>
<td>0.055</td>
</tr>
<tr>
<td>HCFC-123</td>
<td>1.3</td>
<td>0.02</td>
</tr>
<tr>
<td>HCFC-124</td>
<td>5.8</td>
<td>0.022</td>
</tr>
<tr>
<td>HCFC-141b</td>
<td>9.3</td>
<td>0.11</td>
</tr>
<tr>
<td>HCFC-142b</td>
<td>17.9</td>
<td>0.065</td>
</tr>
</tbody>
</table>

**NOTES:** The ODP is a score signifying a substance’s potential for destroying the ozone layer relative to CFC-11. The listed ODP values are those defined by the Montreal Protocol. **Source:** U.S. EPA (October 2, 2008).
increased to $5.35 per pound. Starting in 1996, the tax was to increase by $0.45 per pound each year, bringing it to $11.65 per pound in 2009. Although the phaseout deadline has passed, the tax is still applicable to imported recycled CFCs.

From an economic perspective, the excise tax acts as a **product charge** on the ozone-depleting substance. Since production of ozone-depleters generates a negative externality, the tax can internalize this externality by elevating the producer’s marginal private cost (**MPC**). If, in fact, the excise tax is set equal to the **MEC** at the efficient output level, **QE**, an efficient allocation of resources is achieved. This is illustrated in Figure 13.3. Notice also that because the tax elevates the effective price of CFCs, it motivates a reduction in quantity demanded along the **MPB** curve. According to Cook (1996), consumption of ozone-depleting substances (expressed in CFC-11 equivalents) decreased from 318,000 metric tons in 1989 to 200,000 metric tons in 1990, the year the tax was put into effect.

**Allowance Market for Ozone-Depleting Chemicals**

The EPA is establishing an **allowance market** to facilitate the phaseout of HCFCs. Implementation will follow the allowance program put in place prior to 1996 to control CFCs and certain other ozone-depleting substances. Firms will be allowed to produce or import these substances only if they hold an appropriate number of allowances. Each allowance will authorize a one-time release of one kilogram of an HCFC based on its ODP. The number of available allowances eventually will be brought to zero to meet the phaseout deadlines. For more information on this program, visit [http://www.epa.gov/ozone/title6/phaseout/index.html](http://www.epa.gov/ozone/title6/phaseout/index.html).

**FIGURE 13.3  Excise Tax on Ozone-Depleting Substances**

Since production of ozone-depleters generates a negative externality, an excise tax can internalize this externality by shifting up the producer’s marginal private cost (**MPC**) curve. If the excise tax is set equal to the **MEC** at the efficient output level, **QE**, an efficient allocation of resources is achieved.
To understand the implications of ozone depletion policy, we can use economics to analyze key initiatives, such as the phaseout plan and the allowance trading, as well as to examine the influence of these initiatives on the market for CFCs and the market for CFC substitutes. To begin, we review the Regulatory Impact Analysis (RIA) that was done to evaluate the phaseout plan.

Regulatory Impact Analysis (RIA) of the Phaseout

As part of its Regulatory Impact Analysis (RIA), the EPA conducted a benefit-cost study of the phaseout plan. Given the long life of ozone depleters, the agency considered the regulatory implications over a long time period, out to 2075. The agency’s benefit assessment assigned a value to the damages that would be prevented by controlling these substances. These included health effects associated with increased exposure to ultraviolet radiation and nonhealth effects, such as reduced crop yields and rising sea levels. In total, the EPA estimated that accumulated damages would be approximately $6.5 trillion by 2075.6

On the cost side, a value had to be assigned to all anticipated market disruptions that would arise from a phaseout plan. Some 84 distinct-use categories for CFCs were analyzed—the two largest being mobile air conditioning and refrigeration. All told, the EPA’s estimate of control costs associated with a phaseout plan was $27 billion through 2075.

Although the costs of the phaseout plan are significant, they pale in comparison to the dollar value of damages that would result if the United States took no action at all. Consequently, U.S. regulations to control ozone depleters were announced in August 1988, less than one year after the signing of the Montreal Protocol.7

Assessing Cost-Effectiveness

Following the 1978 ban of CFCs in all nonessential aerosols, the EPA began investigating the feasibility of further controls. In an EPA-commissioned study conducted by the Rand Corporation, three alternative control approaches were analyzed: a technology-based command-and-control approach, a fixed emission charge, and a tradeable emission permit system.8 Each approach was modeled to achieve a given level of reductions over a 10-year period so that the accumulated costs of each plan could be compared. The study showed that the estimated costs for each approach were as follows:

- Technology-based command-and-control approach: $185.3 million
- Fixed emission charges: $107.8 million
- Tradeable emissions permit system: $94.7 million

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7See U.S. Federal Register 53, 30598.
8Palmer et al. (1980).
These estimates support the expectation that allowance trading would approach a cost-effective solution. At the same time, trading should act as an incentive for the development of substitutes by firms that could do so at least cost. Hence, the phaseout in the CFC market had implications for other markets, in particular, the market for CFC substitutes, which can be analyzed using supply and demand and price movements.9

Price Changes

Because U.S. policy was implemented through market-oriented instruments, its progress could be observed through price changes. Prices of CFCs and other ozone-depleting chemicals signaled the impact of the phaseout and the underlying market adjustments. As the phaseout plan advanced, availability of CFCs declined. In addition, an excise tax was levied on production, as discussed previously. These events are illustrated in Figure 13.4a by the shift leftward of the supply of CFCs, which in turn elevated their price. Manufacturers of CFC-dependent products faced higher production costs as a result and passed on at least some of this cost increase to consumers. Thus, buyers of commodities such as refrigerators and auto air-conditioning units paid higher prices over time.10

![Figure 13.4](image)

**Figure 13.4** Price Adjustments of CFCs and CFC Substitutes

Panel (a) shows that reduced availability of CFCs coupled with an excise tax on production caused supply to shift left, which elevated the price. This price increase caused demand for CFC substitutes to rise, as shown in panel (b). Over time, cost declines arose in this market due to technological advance in production, which caused supply of substitutes to shift to the right.

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9Of interest is the EPA’s report on the supply and demand of CFC-12 in 1999 (U.S. EPA, Stratospheric Protection Division, Office of Air and Radiation, June 9, 1999).

10Of course, the ultimate change in price depended on the elasticity of demand for these products, which in turn depended on the availability of substitutes. The more substitutes there are for a product, the more elastic the demand is for that product. Because there are few good substitutes for refrigerators, we would expect demand to be price inelastic. Hence, much of the cost increase from the phaseout plan likely was passed on to refrigerator buyers.
Also, as CFC prices increased, the demand for CFC substitutes rose, as shown in Figure 13.4b. One potential consequence of these events is the evolution of a black market for CFCs. This developed in large part because the phaseout dates established by industrialized nations preceded those set by developing nations. The excise tax also may have contributed to this problem.

**Incentives and Disincentives to Develop CFC Substitutes**

Because costs and prices were allowed to move naturally, the usual incentives encouraged a market adjustment to the observed industry declines and price changes. Theoretically, two opposing reactions were possible.

One possibility is that firms would perceive a profit advantage in developing ozone-friendly substitutes, since prices of these substances were relatively high at the outset. For example, the 1987 price of CFC-12, which was commonly used in automobile air-conditioning units, was about $0.50 per pound, whereas a substitute, HFC-134a, was $3 per pound. However, this relative price difference would diminish over time as technology-driven cost declines would shift the supply of HFC-134a to the right, as shown in Figure 13.4b, and as CFC prices continue to rise. Indeed, in 1999, the price of CFC-12 ranged between $25 and $30 per pound, while the price of HFC-134a remained stable, at about $3 per pound. This price stability likely reflects proportionate increases in supply and demand, as shown in Figure 13.4b.

A second possibility is that the relatively few firms holding allowances possessed some measure of market power and price control. These firms would have enjoyed above-normal profits and would therefore not have been motivated to find alternatives to ozone-depleting substances. One solution would have been to transfer any excess profit to the government, which in turn could redistribute the windfall. Such a safeguard was implemented when Congress approved the escalating excise tax on ozone-depleting chemicals. A redistribution of income was achieved because fiscal spending was funded in part by the tax revenues collected from CFC producers.

The 1990 Amendments also called for a national recycling program for CFCs used in refrigeration and air conditioners. Consider the economics of this approach. By making recycled substances available in the market as a substitute, firms reduce their demand for virgin compounds needed to produce ozone-depleting products. Moreover, firms can use recycled materials beyond the phaseout deadlines, thus avoiding costly retrofitting until new substitute products are available.

Overall, the use of the tradeable allowance plan along with the excise tax, the recycling program, and the safe alternatives policy achieved the phaseout objectives in a more cost-effective manner. Such a control program was less disruptive than an immediate ban on production, which would have affected virtually every segment of society with no time to make proper adjustments.

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12Learner (2001).
Climate change refers to a major alternation in a climate measure such as temperature, wind, and precipitation that is prolonged, i.e., lasts decades or longer. This type of response might be associated with a natural phenomenon like variances in sun intensity or alterations to oceanic circulation. It might also be linked to human activities, such as deforestation or the burning of fossil fuels. To learn more, visit the EPA’s site on climate change, [http://www.epa.gov/climatechange/](http://www.epa.gov/climatechange/).

A source of controversy is the predicted climate response to the increasing production of what are termed greenhouse gases (GHGs). On the agenda of the 1992 Rio Summit, the issue of accumulating greenhouse gases and the associated predictions of global temperature changes is one that continues to be discussed and debated. In fact, during 1997, the international community formulated the Kyoto Protocol, which continues the climate change initiative first discussed in Rio. The scientific community is not in complete agreement about climate change and its implications, although accumulating information and data have helped improved awareness and understanding. In any case, because of the associated complexity and uncertainty, national and international policy responses to climate change issues have been somewhat tentative.

Understanding the Potential Problem of Global Warming

The phenomenon of global warming is based on the following scientific facts. Sunlight, passing through the atmosphere, hits the earth’s surface and is radiated back into the atmosphere, where it is absorbed by naturally present gases such as carbon dioxide (CO₂). This absorption process heats the atmosphere and warms the earth’s surface. This is somewhat like a greenhouse that allows sunlight through the glass but prevents the heated air from escaping back outside, thus the phrase “greenhouse effect.” This natural phenomenon is responsible for the existence of life on earth as we know it. In fact, without the so-called greenhouse gases, the earth’s temperature would be some 30° to 40° Celsius cooler. Global warming falls under the broader heading of climate change, although the two phrases are often used interchangeably.

If this warming is a natural occurrence, what, then, is the problem? The issue is that GHG emissions have increased considerably over time, particularly CO₂. This trend is believed to be linked mainly to increasing human activity, such as combustion of fossil fuels (i.e., oil, coal, and natural gas) and deforestation. Because GHGs affect the earth’s temperature, a significant disruption to their natural levels would generate climate changes. A landmark study conducted by the National Academy of Sciences in 1979 predicted that a doubling of CO₂ would generate a rise in the earth’s temperature of 1.5° to 4.5° Celsius (or 2° to 8° Fahrenheit). Climate changes in turn would alter agricultural

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13U.S. EPA, Climate Change (October 29, 2008).
14Similar estimates have been found by current analyses, such as those conducted by the Intergovernmental Panel on Climate Change (IPCC). See, for example, IPCC (2001).

Although a number of GHGs are responsible for this warming phenomenon, the primary ones are carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). Figure 13.5 gives estimates of their proportionate contribution to global warming. The relative contributions differ not only because these gases exist in varying amounts, but also because they have dissimilar capacities to absorb heat. The ability of a GHG to trap heat in the atmosphere is measured relative to CO₂ by its global warming potential (GWP). Selected GWPs are shown in Table 13.3. For example, the GWP for methane is 21, which

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**FIGURE 13.5** U.S. Greenhouse Gas Emissions by Gas, 2007

NOTES: Data shown are based on U.S. preliminary emissions data for 2007. Other carbon dioxide refers to carbon dioxide from noncombustion sources. High-GWP gases include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF₆).


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**TABLE 13.3** GWP Values for Selected GHGs

<table>
<thead>
<tr>
<th>Gas</th>
<th>GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>1</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>21</td>
</tr>
<tr>
<td>Nitrous oxide (N₂O)</td>
<td>310</td>
</tr>
<tr>
<td>Hydrofluorocarbon-125 (HFC-125)</td>
<td>2,800</td>
</tr>
<tr>
<td>Tetrofluoromethane (CF₄)</td>
<td>6,500</td>
</tr>
<tr>
<td>Perfluoroethane (C₂F₆)</td>
<td>9,200</td>
</tr>
<tr>
<td>Hydrofluorocarbon-23 (HFC-23)</td>
<td>11,700</td>
</tr>
<tr>
<td>Sulfur hexafluoride (SF₆)</td>
<td>23,900</td>
</tr>
</tbody>
</table>

means that one unit of methane has 21 times the capacity for heat absorption as one unit of CO₂.

Despite growing consensus that rising amounts of CO₂ will change the earth’s climate, no one knows with certainty the timing or the extent of the outcome, in part because there are numerous factors to consider. Not the least of these is the influence of feedback effects that can either lessen or intensify the warming phenomenon. For example, volcanic dust acts to filter the sun’s warming rays, which would counter some of the influence of accumulating GHGs. Similarly, oceans and forests, which act as carbon sinks, are major absorbers of CO₂, although higher temperatures tend to diminish this capacity. Because of factors such as these and the overall inherent uncertainty, scientific research is ongoing in an attempt to settle at least some of the controversy.

Meanwhile, as society has become more aware of climate change issues, more attention is being drawn to carbon emissions and the influence of various products and activities on carbon levels in the atmosphere. Measuring this effect is referred to as carbon footprinting. Application 13.1 discusses this trend and how some firms are assessing and communicating the carbon footprints of their products.

Predicting the Potential Effects

National Assessment Synthesis Team

Because the science of global warming is itself the subject of some debate, it is not surprising that there has been a symmetric lack of substantive information on what the eventual outcome of accumulated GHGs might be. Nonetheless, through the use of computer simulation models, researchers have been able to assimilate some information about the expected implications. A comprehensive study was conducted as part of the U.S. Global Change Research Program, and the findings were published in a 2001 report by the National Assessment Synthesis Team. Carbon sinks

Estimated U.S. changes cited in the report range from an increase of 13 centimeters to as much as 95 centimeters (or 5 to 37 inches) by 2100. Other changes include substantial losses of U.S. coastal wetlands, regional flooding, and beach erosion.

On the plus side, there is some evidence to support the possibility of a beneficial fertilization effect from increased levels of CO₂, since it is a necessary component of photosynthesis. Furthermore, certain parts of the world such as Canada, Russia, and Northern Europe would profit from the northward shift of viable agricultural land that

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15See National Assessment Synthesis Team, U.S. Global Change Research Program (2001), the source of much of this section. No subsequent report was done by this team. Instead, more than 20 synthesis and assessments on different topics were called for over a 4-year period, according to the 10-year strategic plan for the Climate Change Science Program (CCSP) launched in 2002 (U.S. Climate Change Science Program, July 2003).
In recent years, society has become increasingly aware of climate change and global warming—perhaps even more so when the Nobel Peace Prize was awarded jointly to the Intergovernmental Panel on Climate Change (IPCC) and former U.S. Vice President Al Gore in 2007. Concerns about the potential risks of climate change prompted a grassroots interest in reducing emissions of GHGs, including CO₂. Along the way, the notion of a carbon footprint evolved as a way to communicate the contribution to carbon releases generated by an individual, a household, a product, or an activity.

As this trend has emerged, both public and private sectors have begun to respond. For example, many private entities, organizations, and government agencies offer an interactive carbon footprint calculator online. A few examples are:

- BP Energy Calculator [http://www.bp.com/iframe.do?categoryId=9023118&contentId=7045317]
- Berkeley Institute of the Environment Carbon Footprint Calculator [http://coolclimate.berkeley.edu/]

Most of these online tools estimate a household’s GHG annual emissions based on user-provided information such as place of residence, vehicles driven, fuels used, and recycling practices. At face value, not all footprint calculators employ the same calculating method or use the same information, so the estimates are strictly that—estimates—as opposed to exact measures. Nonetheless, the intent is to educate society about energy use and to promote energy conservation and environmentalism.

Predictably, the automobile industry is a market in which carbon footprinting has become commonplace. As a point of reference, the EPA estimates that the average automobile is responsible for about 5.5 metric tons of carbon dioxide equivalent emissions per year, or about 55 metric tons over the 10-year life of the vehicle. Toyota’s well-known hybrid, the Prius, has a carbon footprint of 44 metric tons, markedly less than the average, giving it a competitive edge in attracting environmentally conscious consumers. Annual carbon footprint estimates for other vehicles can be found at the U.S. Department of Energy’s fuel economy Web site, [http://www.fueleconomy.gov](http://www.fueleconomy.gov).

Other less-obvious products are also becoming the object of carbon footprinting. Examples include milk, fruit smoothies, shoes, detergent, and beer. Specifically, the New Belgium Beer Company finds that the carbon footprint of a six-pack of its Fat Tire Amber Ale is about 7 pounds, most of it attributable to refrigeration at the retail level. And a fruit smoothie made by a British firm, Innocent, bears a footprint of 294 grams, which even accounts for emissions linked to producing pesticides and fertilizers for the orchards.

Some firms have taken the idea to a higher level. The New Hampshire-based outdoor shoe manufacturer and retailer Timberland Company has assigned some 60 pairs of its shoes a numerical carbon rating from 0 to 10, which is marked inside the shoe. It plans to do the same for its entire product line by 2010. Zero represents less than 2.5 kilograms of carbon emissions, and 10 represents 100 kilograms, which is about equal to the emissions from an automobile driven over 200 miles. According to Timberland, the assigned value captures both a carbon footprint and the amount of chemicals used in production. With similar zeal, U.K. retailer Tesco PLC intends to give carbon labels to all the products it sells, ranging from food items to electronics. Its laundry detergent, for example, now bears a carbon footprint ranging from 1.3 to 1.9 pounds per load, depending on whether it is in liquid, powder, or solid form.

At this point, there is no standard method for computing a carbon footprint, a reality that has drawn criticism, particularly from climate change researchers who are keenly aware of the inherent complexities. Whether standardization comes to pass or whether the carbon footprint is more hype than good information remains to be seen. But for now, most agree that it is calling attention to GHG generation and raising awareness, which should be a positive to society.

**Sources:** U.S. EPA, Office of Transportation and Air Quality (February 13, 2009); Ball (October 6, 2008); Green and Capell (March 17, 2008).
may occur with a warming trend. Conversely, other areas, such as the southern United States, may suffer losses should this shift occur. Therefore, because some regions would gain while others lose, most global warming models predict that the net economic effect on agriculture would be relatively minor.

To read more about the specific forecasts of the National Assessment Synthesis Team, visit http://www.usgcrp.gov/usgcrp/Library/nationalassessment/overview.htm.

**Intergovernmental Panel on Climate Change (IPCC)**

In 2007, the Intergovernmental Panel on Climate Change (IPCC) completed its Fourth Assessment Report (AR4) on the earth’s climate. The IPCC was established in 1988 by the World Meteorological Organization and United Nations Environment Programme. The AR4, the fourth in a series of reports published every five or six years, is a compilation of in-depth research by three working groups: Working Group I on “The Physical Science Basis,” Working Group II on “Impacts, Adaptation and Vulnerability,” and Working Group III on “Mitigation of Climate Change.”

The findings of this assessment are comprehensive, complex, and highly detailed, but at a high level, the chief conclusions of the IPCC are as follows:

- Global warming is unequivocal, based on observed increases in air and ocean temperatures, snow and ice melting, and rising sea levels.
- GHGs associated with human activity have risen by 70 percent between 1970 and 2004, and carbon dioxide (CO₂) increased by 80 percent during that period. Much of the observed rise in global average temperatures since the middle of the twentieth century is very likely linked to the observed rise in anthropogenic GHG concentrations.
- Based on current climate change policies and practices, GHG emissions are projected to grow over the next 30 years, and the effects on the climate are very likely to be greater than what was observed during the twentieth century.
- A broad range of adaptation options are available, but more are needed to lessen vulnerability to climate change. Also, there are barriers, costs, and limits that are not completely understood.
- Reasons for concern identified in the prior IPCC report remain important to defining vulnerabilities, and some are assessed as stronger than originally believed.

Detail on any of these findings as well as the full reports from the three working groups are available at the IPCC’s Web site, http://www.ipcc.ch/

Taken together, scientific predictions about the effects of global warming are not conclusive. Given the complexity of the science as well as the long-range nature of the forecasts, it is understandable that there is not complete agreement about which of the conjectured events may occur, the degree of impact, and the timing of any associated outcome. However, scientists are achieving greater clarity, and the research continues.

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16See IPCC (2008), from which this section is drawn.
In the interim, policymakers must decide how to respond to rising CO₂ levels and other GHGs, even in the face of uncertainty about the implications.

**Policy Response to Climate Change**

Setting policy in response to climate change is a difficult problem for two reasons. First, as discussed, global warming and other climate variations are complex issues, and there is some degree of uncertainty associated with them. Second, because both the source of the problem and the predicted effects are global in scope, any effective policy solution relies on international agreement. Many nations contribute significantly to the aggregate level of GHG emissions. The top 12 national emitters of the primary GHG, CO₂, are shown in Figure 13.6.

**International Response**

*U.N. Framework Convention on Climate Change (UNFCCC)*

At the 1992 Rio Summit, global climate change was an important agenda item for the many national representatives who gathered at the 12-day worldwide conference. Among the major agreements produced at the summit was the U.N. Framework Convention on Climate Change (UNFCCC), which deals with global warming and other air quality issues. Among its major provisions are:

- Countries must implement national strategies to limit GHG emissions with the objective of reducing emissions to their 1990 levels by 2000.

**Figure 13.6** Top 12 National Emitters of Carbon Dioxide in 2006

Chapter 13  Global Air Quality

- Differences in political and economic conditions among nations are to be accommodated by avoiding uniform emission targets and timetables for only one GHG.
- Signatories are encouraged to recognize climate change in the formulation of economic, social, and environmental policies.
- Industrialized nations will assist developing countries in obtaining data and in limiting emissions.

The UNFCCC was to become effective following ratification by 50 nations. In October 1992, the United States became the first industrialized country, and the fourth overall, to do so, following a unanimous vote by the U.S. Senate.17 By the close of 1993, the requisite number of nations had ratified the treaty, and it became legally binding in March 1994.

**Kyoto Protocol to the UNFCCC**

In December 1997, a Conference of the Parties (COP) was held in Kyoto, Japan. The goal was to reach an agreement, or protocol, that would address the issue of GHG emissions beyond 2000. A key outcome was the establishment of emissions limits for developed nations. These were to become effective once 55 nations ratified the protocol as long as these nations included developed countries responsible for at least 55 percent of CO₂ emissions for 1990. Achieving these limits was to be accomplished in part through emissions trading.

Further details of the international accord, including its market-based approach, were discussed during a 1998 meeting in Buenos Aires. While the meeting was in progress, the United States signed the protocol, though the signing was more symbolic than substantive. The protocol was not submitted to the Senate for ratification, because there was strong opposition to the treaty among senators. In addition to apprehensions about limited scientific evidence of global warming, the Senate also was concerned that the stated emissions limits would negatively affect industry and the American economy. Furthermore, the United States would not ratify the treaty until developing countries made a commitment to meet binding emissions targets along with developed nations.

Discussions, often contentious, continued at a series of COPs. Before the 2001 conference, President Bush announced his opposition to the Kyoto Protocol and took the United States out of the agreement in March 2001, a decision discussed in Application 13.2. At the same time, the Bush administration promised to deliver a domestic initiative to combat global warming. Moreover, the United States would remain involved in negotiations and funding for the UNFCCC.

Ultimately, in July 2001, 178 nations reached an agreement—without the United States. The accord called for 38 industrialized countries to cut their GHG emissions to 5.2 percent below 1990 levels by 2012, leaving developing countries without any emissions requirements. Emissions targets are to be achieved during the so-called commitment

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phase from 2008 to 2012, using several market-based instruments, referred to as **flexible mechanisms**. Chief among these is a cap-and-trade system of GHG allowances for participating developed nations. These countries also could earn credits for carbon-absorbing forestry practices and for implementing emissions-reducing projects in other nations. But the agreement still had to be ratified.

Many believed that ratification of the accord was unlikely without the United States because of the requirement that participating developed nations represent at least 55 percent

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**APPLICATION 13.2 Why the United States Is Not Participating in the Kyoto Protocol**

In November 2001, the parties to the United Nations Framework Convention on Climate Change (UNFCCC) met in Marrakech, Morocco, to finalize the language and operational elements of the Kyoto Protocol. In attendance were 171 national governments and 4,500 participants. The protocol would become legally binding once ratified by at least 55 industrialized nations that account for over 55 percent of 1990 GHG emissions. Ratification was achieved in 2004 following Russia’s signing of the accord, which brought the total number of participating nations to 141. Interestingly, the United States was not one of them. Why? Because in March 2001, President Bush declared the Kyoto Protocol to be “... fatally flawed in fundamental ways” and proceeded to take the United States out of the accord.

The Bush administration’s position was based on the initial findings of a cabinet-level climate-change working group established by the president. In its analysis of the Kyoto Protocol, the group expressed concern that the agreement would not impose emissions cuts on developing countries, even though the net emissions from those nations exceed those of industrialized countries. Another reservation cited was that the treaty’s emissions targets were based on political negotiations rather than on science.

There were also economic concerns. The protocol’s emissions reduction target for the United States had been set at 7 percent from 1990 levels for each year in the 2008–2012 period. However, this target ignored emissions growth between 1990 and 2012, which, if considered, would translate to greater than a 30 percent reduction for the period. Achieving this objective would have had serious economic consequences, according to the analysis. In fact, most models predicted that U.S. GDP would have declined by 1 to 2 percent as a result.

Beyond the White House report, independent economists had used models to assess and quantify the protocol’s implications for the U.S. economy. For example, Richard Schmalensee, an economist and dean emeritus at MIT’s Sloan School of Management, forecasted that the United States would have had to shut down all its coal-fired facilities by 2012 just to meet the Kyoto targets halfway. In another study, analysts at MIT’s Joint Program on the Science and Policy of Global Change estimated implementation costs of the Kyoto treaty on a per-household basis. Their predictions ranged from a high of $1,000 to a low of $140, with the latter assuming efficient implementation of emissions trading.

In lieu of participating in the Kyoto Protocol, the United States opted to pursue independent actions, including researching climate change and implementing domestic and international strategies aimed at reducing GHG emissions. On the research front, the Climate Change Research Initiative (CCRI) was created to facilitate the integration of scientific understanding of climate change, including areas of uncertainty, into policy decisions. Strategic initiatives included developing government-business partnerships to promote source reduction and recycling, promoting energy efficiency in government buildings, developing cleaner technologies for electricity generation and transmission, and supporting the development of fuel-efficient vehicles and renewable resources such as solar energy and hydropower.

**Sources:** Hilsenrath (August 7, 2001); Fialka and Winestock (July 16, 2001); Revkin (July 24, 2001); U.S. Government, White House (June 2001).
of 1990 CO₂ emissions. The United States alone was responsible for 36 percent of 1990 CO₂ emissions. Essentially, this meant that Russia, the second largest CO₂ emitter in the world, held the deciding vote. In 2004, Russia ratified the protocol, bringing the number of participants to 141, and in February 2005, the much-debated Kyoto Protocol entered into force.  

As of 2009, over 180 nations have ratified the protocol. Its key features, including the flexible mechanisms, are described in Table 13.4.

**United Nations Climate Change Conference COP15**

In December 2009, the UNFCCC holds its COP15, the United Nations Climate Change Conference in Copenhagen. The first commitment phase under the Kyoto Protocol expires in 2012, and hence the parties to the protocol must negotiate a new agreement. Negotiations are likely to be difficult given the global economic recession. Moreover, the existing protocol has not been without its share of problems. Among them is the reality that neither China nor the United States is subject to Kyoto’s emissions caps—China, because it is a developing nation, and the United States, because it did not ratify the treaty. Yet the two nations are the largest emitters of GHGs, jointly responsible for over 40 percent of the world’s releases. (Refer back to Figure 13.6.) Consequently, industries

<table>
<thead>
<tr>
<th>TABLE 13.4</th>
<th>Major Elements of the Kyoto Protocol to the UNFCCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>· Developed nations must reduce overall greenhouse gas (GHG) emissions by at least 5.2 percent below 1990 levels in the first commitment period, 2008–2012, by meeting individual emissions targets assigned to each country. Negotiations for subsequent commitment periods will follow.</td>
<td></td>
</tr>
<tr>
<td>· Emissions targets cover the primary GHGs: carbon dioxide (CO₂); methane (CH₄); nitrous oxide (N₂O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); and sulfur hexafluoride (SF₆).</td>
<td></td>
</tr>
<tr>
<td>· Emissions targets are to be achieved by international emissions trading of GHG allowances.</td>
<td></td>
</tr>
<tr>
<td>· Carbon-absorbing activities, such as reforestation, can be used to offset emissions targets. Any GHGs removed through such activities earn credits called removal units (RMUs).</td>
<td></td>
</tr>
<tr>
<td>· Under the Clean Development Mechanism (CDM), a developed nation can enter into emissions-reducing projects in a developing nation and use the resulting certified emissions reductions (CERs) to meet its own emissions targets.</td>
<td></td>
</tr>
<tr>
<td>· Using Joint Implementation, a developed nation can implement an emissions-reducing project in another developed nation and use the resulting emissions reduction units (ERUs) against its own emissions target.</td>
<td></td>
</tr>
<tr>
<td>· Participants failing to meet their emissions targets must resolve the difference in the second commitment period plus a 30 percent penalty.</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:** The full text of the Kyoto Protocol is available online at [http://unfccc.int/resource/docs/convkp/kpeng.pdf](http://unfccc.int/resource/docs/convkp/kpeng.pdf).

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19 The following is drawn from UNFCCC (January 2009) and Ball (December 3, 2007).
within participating developed countries must face the potential disadvantage of facing emissions limits that their competitors within two world powers do not.

According to the UNFCCC, although the Copenhagen meeting cannot resolve all matters, four issues are in need of clarity: (1) emissions reduction targets for developed countries; (2) mitigation options that developing countries could implement; (3) financing solutions for the developing world; and (4) institutions to deploy technology and finance that allows developing nations to be equal participants in decision making.

**Chicago Climate Exchange (CCX)**

In addition to formal programs developed for the Kyoto Protocol, a voluntary multinational program also has been devised to mitigate climate change. Called the Chicago Climate Exchange (CCX), the institution runs the only GHG emissions trading system for North America. Members of the exchange, which include private corporations and municipalities, make a voluntary but legally binding pledge to reduce their GHG emissions to meet predefined targets. During the first phase of the program, between 2003 and 2006, the members pledged to reduce emissions by 1 percent per year for a total of 4 percent below the baseline. In the second phase, between 2007 and 2010, members commit to achieving a 6 percent reduction by the end of the period.

Operating as a true cap-and-trade system, any member of the CCX that achieves greater reductions than the target level can sell or bank excess emissions allowances. Members unable to reach their goal can purchase these excess allowances through electronic trading. Technically, they purchase CCX Carbon Financial Instrument® (CFI®) contracts. Current members of CCX include DuPont, American Electric Power, Sony Electronics, Inc., the city of Chicago, the state of New Mexico, and Waste Management, Inc. For more information on CCX, including pricing data for GHG allowances, visit its Web site at [http://www.chicagoclimatex.com](http://www.chicagoclimatex.com).

**U.S. National Response**

After removing the United States from the Kyoto agreement, President Bush called for a cabinet-level review of the nation’s policy on climate change, and a climate change working group was formed. The group in turn requested a report from the National Academy of Sciences (NAS) on what was known about the science of climate change. Initial findings of the working group were presented in a report that included an analysis of the Kyoto Protocol, proposals to advance needed technologies, plans to establish international partnerships, and an assessment of existing domestic strategies, including those promoting voluntarism through incentives. An example is the Energy Star program discussed in Application 13.3, which the working group recommended expanding in scope to improve energy efficiency. Both the working group’s report and the NAS report were released in June 2001.

President Bush took the reports under advisement and then formulated his climate change plan to act as the U.S. alternative to the Kyoto Protocol. Presented as the Global Climate Change Policy Book, the new program was released by the White House in

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February 2002. According to the plan, the overall objective for the nation was to reduce greenhouse gas (GHG) intensity by 18 percent by 2012, where GHG intensity refers to the ratio of GHG emissions to economic output. This translates to a reduction in emissions from 183 metric tons per million dollars of GDP in 2002 to 151 metric tons per million dollars of GDP in 2012, which the president argued was equivalent to the average outcome for Kyoto Protocol participants. Notice that the use of GHG intensity in this context explicitly considers economic growth in the nation’s assessment of progress.

Formal reports on U.S. climate change progress and activities are prepared periodically in accordance with the articles of the UNFCCC and are available from the U.S. Department of State.

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**APPLICATION 13.3 The Energy Star Program**

To promote energy efficiency through collaboration between the public and private sectors, the EPA launched the Energy Star Program in 1992. The initiative is a voluntary labeling program that identifies energy-efficient products and allows them to bear the Energy Star logo. This logo acts as an explicit market signal that communicates to prospective consumers the potential cost savings and the emissions reduction associated with more efficient energy use. In 1996, Energy Star teamed up with the U.S. Department of Energy, with each entity assuming responsibility for certain product categories.

The now-familiar logo first appeared on qualifying computers and monitors. By 1995, it had been made available to other types of office equipment, such as fax machines and copiers, as well as to heating and cooling products for private residences. Today, the label appears on over 50 product categories, including lighting, major appliances, windows, consumer electronics, even new homes and commercial buildings. Over 5,000 contractors have built about 840,000 Energy Star qualified new homes, which is said to save homeowners more than $200 million each year.

To communicate information about energy-efficient products, Energy Star has set up partnerships with more than 12,000 private and public organizations. These alliances also are used to provide technical assistance aimed at helping consumers and organizations make energy-efficient decisions. The program touts that these efforts generate cost savings of over $16 billion a year on utility bills along with important energy and air quality gains. In 2007, the avoided GHG emissions associated with the program were reportedly equivalent to taking 27 million cars off America’s highways.

In addition to the explicit cost savings and the environmental gains of partnering with Energy Star, participating businesses might observe increased demand for their energy-saving products, which translates directly to revenue gains. Increased demand can arise directly from the positive image linked to the logo and from national Energy Star performance awards that receive some measure of media attention. Visit the Energy Star Web site at [http://www.energystar.gov](http://www.energystar.gov) for more information.


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The Obama administration has taken a different position toward climate change than the previous administration, asserting that the United States should become a world leader in addressing the problem. In fact, President Obama expects that the United States will be a major participant in negotiating a new treaty to replace the Kyoto Protocol at the climate change conference in Copenhagen. On the domestic front, a key objective of the Obama administration’s Energy Plan is to implement a national cap-and-trade program for GHG emissions. This proposal mirrors what some developed countries already are using to meet their commitments under the Kyoto Protocol.23

In the interim, the Obama administration announced early in 2009 that it expects the EPA to propose new rulings to control GHG emissions. This followed a contentious Court decision in April 2007 during the Bush administration, which found that the EPA is in fact authorized to regulate GHGs under the Clean Air Act, including CO2. The 5-to-4 decision was diametrically opposed to the Bush administration’s long-held position that the Clean Air Act Amendments (CAAA) provide no authority to regulate CO2 and other GHGs. In any case, the Court’s ruling placed the onus on the EPA to respond, either with new regulations or with scientific evidence that a regulatory response is unfounded.24

In April 2009, the EPA announced two critical proposed findings: (i) the Endangerment Finding: that six GHGs—(CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6)—pose a threat to public health and welfare of both current and future generations; and (ii) the Cause or Contribute Finding: that CO2, CH4, N2O, and HFC emissions from motor vehicles add to concentrations of these GHGs in the atmosphere and therefore contribute to climate change. Support for these findings arises from the EPA’s review of existing scientific evidence and the agency’s consideration of projected effects of GHGs, critical uncertainties, and associated risks to public health and welfare in the United States. The two findings, which are subject to public comment under normal procedure, do not by themselves impose any new rulings on industry. However, they do set the stage for new regulations once the proposed findings are finalized. For more information and updates on this landmark decision, visit http://www.epa.gov/climatechange/endangerment.html.25

The EPA’s and the Court’s decisions dovetail with efforts by the state of California to implement regulations the state had passed previously to control CO2 emissions from motor vehicles. Automakers had opposed this state law in part because CO2 had not been an identified pollutant under the CAAA. Once the Court ruled that the EPA has authority to control these emissions, California’s position was strengthened. Under the CAAA, California is permitted to adopt tougher pollution standards than those set at the federal level (and other states can follow suit if they wish), but it must receive a waiver from the EPA to do so. It had requested the waiver in December 2005 so that the CO2 emission controls could take effect with the 2009 model year. Despite the Court’s ruling on the EPA’s power to control GHGs, the EPA blocked California’s progress, denying the waiver.

23Obama Administration (March 9, 2009); Rosenthal (March 1, 2009).
24Greenhouse (April 3, 2007). The official case is filed as Massachusetts et al. v. EPA et al., No. 05–1120.
in early 2008. California requested a reconsideration of the decision, and once President Obama took office, he urged the EPA to do so. In June 2009, the agency did grant the waiver. For more information, visit http://www.epa.gov/otaq/climate/ca-waiver.htm.

U.S. Regional Response

A new program recently has been launched in the Northeast and Mid-Atlantic regions of the United States. Known as the Regional Greenhouse Gas Initiative (RGGI), this collaborative involves 10 states participating in a mandatory cap-and-trade GHG program, the first of its kind in the nation. RGGI participants set a multi-state cap on CO₂ emissions released by power plants and agree to lower the cap over time until it is 10 percent below its initial level by 2018. To meet the emissions cap, the participating states sell tradeable allowances at quarterly auctions and use the proceeds to invest in low-carbon, clean energy technologies, such as solar and wind power. Offsets are also provided for emissions reduction activities or carbon sequestration projects external to the electricity industry. At the first auction held in September 2008, over 12.5 million CO₂ allowances were sold at a market clearing price of $3.07 per ton. For further information and updates, visit RGGI’s Web page at http://www.rggi.org/home.

ECONOMIC ANALYSIS OF CLIMATE CHANGE POLICIES

Ideally, environmental policy should achieve an efficient allocation of resources, where net benefits are maximized, or equivalently, where the marginal social benefit from implementing policy is exactly offset by the marginal social cost. Although assessing benefits is always the more difficult process, it is particularly so for global warming because of the gray areas that weaken scientific predictions. Hence, before we can analyze specific policy proposals, we first need to consider the dilemma of estimating the potential benefits from any initiative designed to control climate change.

Estimating the Benefits

To illustrate how benefit assessment is at the root of the global warming policy dilemma, let’s consider the findings of several research efforts.

A report prepared by the OECD Environment Committee estimates expected benefits from controlling global warming in the United States. The values, presented as estimated damages associated with climate change, are based on two global warming scenarios. The first assumes the conventional prediction of a temperature rise of 2.5°C Celsius, while the second presents estimates based on a temperature rise of 10°C Celsius over a very long term. According to the findings, the benefits of controlling global warming based on conventional predictions would be $61.6 billion ($1990), or approximately 1.1 percent of

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26 U.S. EPA, Office of Transportation and Air Quality (February 17, 2009); McCarthy (July 28, 2008); “Air Pressure; Global Warming” (April 7, 2007).
27 RGGI (April 1, 2009).
GDP, and as high as $338.6 billion ($1990), or at least 6 percent of GDP, over the very long run of 250 to 300 years.

Economist Wilfred Beckerman (1990) argues that not only are the damages from global warming difficult to assess, but even if the most dire predictions are correct, most are not sufficient to warrant the high costs of avoidance. Beckerman cites a 1988 EPA report that estimates the net effect of global warming on U.S. agriculture to be within a range of a net gain of $10 billion and a net loss of $10 billion. The net gain is actually possible because some parts of the nation would enjoy longer growing seasons, enhanced by increased precipitation and the fertilization of increased CO2 concentrations. At the other extreme, even if the maximum estimated loss of $10 billion is incurred, this is only about 0.2 percent of U.S. GDP.

More recent studies conducted by Mendelsohn and Neumann (1999) and Nordhaus and Boyer (2000) present benefit estimates that align more closely with those discussed by Beckerman. Specifically, Mendelsohn and Neumann (1999) estimate that the net benefit to the United States from climate change control would be 0.1 percent of GDP, while Nordhaus and Boyer (2000) estimate the comparable value at approximately −0.5 percent of GDP, or a net cost to society. In a more recent assessment, Sir Nicholas Stern (2007) presents much different estimates. Specifically, Stern argues that without a policy response, the costs of climate change, and hence the benefits of responding, are likely to be 5 percent of global GDP per year and possibly as high as 20 percent per year, but that the costs of responding to the problem by controlling GHGs can be limited to about 1 percent of GDP each year.29

Although these studies share a common perspective—that benefit assessment is critical to developing climate change policy, the implications are different. The OECD study suggests that long-term benefits might be more relevant to assessing global warming initiatives. The other studies, which use a shorter-term approach, determine much lower benefit estimates that may not outweigh the associated costs. What this means is that if time is explicitly considered, policy development might take a very different direction. In any case, these analyses suggest the need for more research and help to explain the challenge policymakers face in deciding how to respond to global warming concerns.

Recognizing this challenge, economists strongly promote market-based policies designed to consider the benefits and costs of government controls. Although there are many types of instruments that use market forces to operate, all of them can be motivated by modeling the cause of global warming, rising GHG emissions, as a market failure.

**Economic Model of the Market Failure**

To simplify our analysis and give it context, we focus on the release of CO2—the most prevalent GHG, arising mainly from the production of electricity. Figure 13.7 illustrates a hypothetical market for electricity generation, which consists of two groups of electric power plants: one using fossil fuels that generate CO2 emissions and the other using alternative fuel technologies such as solar, wind, or nuclear power.

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29The Stern study is available online at [http://www.hm-treasury.gov.uk/sternreview_index.htm](http://www.hm-treasury.gov.uk/sternreview_index.htm). The study sparked debate in part because Stern’s estimates were markedly different from those presented by other researchers and because certain of his assumptions are questionable. For more on this debate, see Nordhaus (2007) and Weitzman (2007).
Figure 13.7a depicts the marginal private cost of fossil fuel users (MPCF) and the associated marginal social cost (MSCF). By definition, MSCF is the vertical sum of the MPCF and the marginal external cost (MECF) of electricity production, where the MECF is capturing the negative production externality. This means that MECF is implicitly shown as the vertical distance between MSCF and MPCF and represents the cost of health and property damages associated with CO2 emissions. Figure 13.7b shows the marginal social cost of alternative fuel users (MSCA). For simplicity, it is assumed that this segment of the market does not generate any negative externalities. Thus, MSCA is exactly equal to MPCA.

Figure 13.7c presents the aggregate market for electricity, shown with a demand curve (D) measuring the marginal social benefit of electricity usage (MSB) and two distinct supply curves, SP and SS. The SP is the private market supply of electricity, found as the horizontal sum of MPCF and MPCA, and the SS is the social market supply, found as the horizontal sum of MSCF and MSCA.

In the absence of CO2 emission controls, equilibrium is determined by the intersection of market demand (D) and private market supply (SP). At PC, fossil fuel utilities supply QF, and alternative fuel users supply less at QA. The efficient equilibrium at QE and PE is determined by the social market supply (SS). PE is higher than PC because demanders pay the full cost of their consumption activity. Fossil fuel-based production has declined from QF to QF’, reducing CO2 emissions, and alternative fuel-based production has risen from QA to QA’.

Although the market segments shown in Figure 13.7 are hypothetical, note that as of November 2008, about 71 percent of electricity generated in the United States was produced by burning carbon-based fuels (U.S. Department of Energy, Energy Information Administration, 2009).
because their $MPC_e$ is relatively low. Without policy controls, these utilities do not consider the external costs of their CO$_2$ emissions. This results in private market incentives allocating too many resources to their production processes and too few resources to alternative fuel users. Consequently, $P_C$ is sending a false signal about how to efficiently allocate productive inputs, and the market fails.

To correct the market failure, the external cost of fossil fuel emissions must be brought into the market transaction. As shown in Figure 13.7c, this means that market price must be determined by market demand ($D$) and the social market supply ($S_S$), which includes both external and private costs. Notice that the efficient equilibrium price ($P_E$) is higher than what the private market determines, because electricity demanders are now paying the full cost of their consumption activity. That is, the per-unit price ($P_E$) paid for electricity is exactly equal to the marginal social cost incurred to produce it.$^{31}$

At this higher price level, the quantity of electricity has been reduced to its efficient level ($Q_E$). This new price level corrects the mix of fossil and alternative fuels used to produce electricity. At $P_E$, fossil fuel-based production appropriately has declined from $Q_{F1}$ to $Q_{F2}$, effectively reducing the emissions of CO$_2$. At the same time, the higher price provides an incentive to alternative fuel users to supply more electricity, shown as the increase from $Q_{A1}$ to $Q_{A2}$.

**Evaluating Market-Based Policy Instruments**$^{32}$

Anthropogenic emissions of GHGs are a negative externality because the effects of these gases are not captured within the market transaction and therefore are borne by society. To correct the problem, policy instruments must internalize the externality so that the market participants absorb the cost of the damages. Two types of market-based controls that can accomplish this are pollution charges and tradeable allowance systems.

**Pollution Charges**

The use of some type of pollution charge to reduce CO$_2$ emissions has received a fair amount of attention in both domestic and international policy discussions. However, the specific form of the charge has been the subject of debate. In general, three types of product charges commonly are proposed as possible candidates: a gasoline tax, a Btu tax, and a carbon tax.

- A **gasoline tax** is a per-unit tax levied on each gallon of gasoline consumed.
- A **Btu tax** is a per-unit charge based on the energy or heat content of fuel measured in British thermal units (Btus).
- A **carbon tax** is a per-unit charge based on the carbon content of fuel.

$^{31}$Notice that $Q_E$ still includes some fossil fuel-based production, meaning that CO$_2$ emissions are not totally eliminated. However, they are reduced to the level that society believes is acceptable, based on the trade-off between the MSB of electricity usage and the MSC.

$^{32}$For an interesting overview of market-based policies on global warming, see Parker (June 20, 2002), which is a Congressional Research Service report accessible online at [http://www.cnie.org/nle/crsreports/climate/clim-5.pdf](http://www.cnie.org/nle/crsreports/climate/clim-5.pdf).
Unlike taxes on income or consumption that generate market distortions, these charges are referred to as **corrective taxes**, because they are aimed at internalizing a negative externality and hence at correcting a market failure. By design, these taxes should *reduce* market inefficiency. In addition, all three taxes are revenue generating, an attribute that is sometimes used to promote this type of policy, particularly if there are national budget deficits. Beyond these common characteristics, these taxes differ in terms of their applicability, ease of implementation, and overall effectiveness in achieving environmental objectives.

Because gasoline is a carbon-based fuel, its combustion produces CO₂ as a by-product. By levying a tax on gasoline, its effective market price will increase, discouraging consumption and encouraging the use of cleaner alternative fuels. As fewer gallons of gasoline are burned, less CO₂ is emitted. In the United States, gasoline taxes already are being collected by state and federal governments, making an increase in the tax rate to bring about a reduction in carbon emissions relatively easy to implement.

The major drawback is that the gasoline tax targets only polluting sources using gasoline, which are relatively minor CO₂ emitters, and ignores more significant sources that burn other fossil fuels such as oil and coal. Furthermore, it imposes a disproportionate burden on some segments of the economy, such as rural communities that lack good public transportation and certain industries like interstate trucking. This explains why the broader-based carbon tax or the Btu tax is often proposed as a superior alternative.

Although the Btu tax and the carbon tax each use a slightly different tax base, the general purpose of each is the same—to encourage fuel switching and conservation by elevating fuel prices. Of the two, the carbon tax is more specific, because it targets only carbon-based fuels. In fact, it is considered the more relevant form of taxation to mitigate CO₂ emissions, because the carbon content of fuel and carbon emissions are generally proportional to one another. Effectively, the carbon tax changes *relative* fuel prices and theoretically could elevate the price of fossil fuel by the *MEC* of the environmental damage caused by its combustion. In the context of Figure 13.7a, the tax should equal the vertical distance between the *MPC_F* and the *MSC_F* for fossil fuel users measured at the efficient output level, *Q_F2*. Such a unit charge would successfully internalize the external costs associated with the burning of fossil fuels.

In practice, the carbon tax is being used in a number of European countries, including Belgium, Denmark, Finland, France, Italy, Norway, and Sweden.³³ In the United States, the EPA has studied this tax as part of its investigation of alternative control options. In fact, according to an EPA report, a tax of $5 per ton of carbon would reduce CO₂ emissions by approximately 1 to 4 percent, with estimated revenues of $7 to $10 billion per year. By increasing the tax to $25 per ton, emissions would decline by some 8 to 17 percent, and revenues would be between $38 and $50 billion per year.³⁴ In addition, a carbon tax would increase the effective price of crude oil, leading to a reduction in oil imports and less dependence on foreign oil sources.

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Tradeable Allowance Systems

Another market instrument used to control global warming is a tradeable allowance system for GHGs. Within the Kyoto Protocol, the international GHG allowance market is the primary means by which developed nations are to achieve their emissions targets. This market operates in much the same manner as national and international trading of CFC permits used to combat ozone depletion. Under Kyoto’s provisions, nations also can earn credits for engaging in carbon-absorbing activities like reforestation and for initiating carbon-reducing projects in other nations.

To align with its commitment under the Kyoto Protocol, the European Union (EU) launched its own GHG trading program in 2005 for member states. This program, called the European Union Emissions Trading Scheme (EU ETS), is a true “cap-and-trade” program designed to help the EU achieve its emissions reduction commitment under the protocol of 8 percent below 1990 levels. As such, it substantiates the claim that Europe is the only world power to establish and use a carbon market. The EU ETS will be implemented in two trading phases, with the second trading phase aligned with the first commitment phase of the Kyoto accord. Exchanges located all over Europe facilitate trade among the member countries, and allowance prices are market-determined. Allowances are not printed but instead are exchanged through electronic registries.

In the first phase of trading (i.e., between 2005 and 2007), too many emission allowances were allocated relative to actual emissions released throughout the EU. The result is rooted in fundamental economics. The excess supply of allowances drove down the price, in this case to less than one EURO per ton of CO₂ emissions in 2007. Implementing mid-course corrections, the European Commission placed stringent limits on allowances during the second trading period (between 2008 and 2012), targeting the number to 6 percent below the emission releases observed during the first trading period. As a consequence, allowance prices held to between EUR 19 ($28.00) and EUR 29 ($42.74) in 2008.35 According to the IPCC, prices ranging between $20 and $80 per ton of CO₂-equivalent should achieve stabilization of these emissions at about 550 parts per million (ppm) by 2100.36

Just as economic theory suggests, the trading of GHG permits can lead to a cost-effective solution. Countries able to reduce emissions below the amount initially allowed by agreement can sell their excess permits to the highest bidding country, whereas those that could not achieve the needed reductions would buy the permits. If the system operates efficiently, the price of the allowance should be the dollar value of the MEC associated with the emissions. Again, as shown in Figure 13.7a, this price should equal the vertical distance between $MSC_F$ and $MPC_F$.

The EU ETS, which accounts for over 40 percent of total GHG emissions for the European Union, is predicted to bring about “... significant emission reductions between 2008 and 2012.” Moreover, across 10 policies implemented in Member States, the largest predicted declines in GHG emissions are linked to renewable energy initiatives and the EU

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36IPCC (2008), p. 59. CO₂-equivalent represents the emissions of a GHG adjusted by its GWP to be in terms of CO₂.
ETS. As a consequence, the EU as a group is expected to meet and even exceed its Kyoto commitment, based on the use of existing domestic policies along with the adoption of additional measures under discussion and Kyoto mechanisms as planned by Member States.  

Numerous papers and reports have been written assessing the EU ETS, and more undoubtedly will follow. Not only are the specific environmental outcomes important, but from a policy perspective, so too is the observed operation of such a complex and large trading platform. Consider that the EU ETS controls 12,000 polluting sources, compared to 3,000 under the U.S. Acid Rain Program (ARP). And the value of allowances issued annually by the ARP of $2.25 billion pales in comparison to the comparable value issued by the EU ETS of $37 billion. In a very real sense, the progress of this large trading program could influence similar efforts in other countries, including the proposed use of a national cap-and-trade GHG program in the United States. For more detail on the EU ETS, visit http://ec.europa.eu/environment/climat/emission/index_en.htm.

**Conclusions**

Formulating sound policy in response to global air pollution is a major undertaking. Scientific knowledge about atmospheric disturbances and the associated implications is still limited, particularly for global warming. As long as the extent of environmental risk is unknown, the benefits of corrective policy initiatives are likewise indeterminate. Consequently, public officials are unable to justify the social costs of policy controls with reliable information about the comparable benefits.

Even when the knowledge base is stronger, such as for ozone depletion, policy development is still complicated by the global nature of the problem. A successful resolution depends critically on international commitment, supported in turn by domestic initiatives. On this front, there have been several achievements. Examples include the Montreal Protocol and its subsequent amendments to control ozone depletion and the ratification of the Kyoto Protocol to limit GHG emissions. Nonetheless, there are still important issues to be worked out, not the least of which is how to gain the cooperation of developing nations. These countries lack the financial resources and the technology to innovate around the causes of global air pollution. Yet their cooperation is critical, given the expected rate of industrial and economic growth in these nations and the associated ramifications for the global environment.

Despite the difficulties, there has been progress in recognizing the relevant issues, acknowledging the unknowns, and investigating alternative solutions. Furthermore, scientific research is ongoing in the hope of reaching a general consensus about the implications of global air pollution. That policy development has been tentative, particularly in responding to the risks of climate change, is recognition of how important a balancing of benefits and costs is to that process.

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37 European Environment Agency (2008). In this context, the EU refers to the EU-15.
38 Pew Center on Global Climate Change (2005).
Module 4  The Case of Air

SUMMARY

- Ozone depletion refers to damage to the stratospheric ozone layer caused by certain pollutants. Scientists agree that the presence of chlorofluorocarbons (CFCs) in the atmosphere is the most likely explanation for ozone depletion.
- The Montreal Protocol is an international agreement aimed at ozone depletion. This agreement and its amendments, which include provisions for allowance trading, call for a phaseout of ozone-depleting substances.
- Title VI of the 1990 Clean Air Act Amendments is dedicated to protecting the ozone layer. Included are two market-based instruments: an excise tax and a marketable allowance system.
- According to an EPA-commissioned study, a tradeable permit system achieves ozone-depletion reductions in the most cost-effective manner.
- Price changes for ozone-depleting chemicals signaled the effect of the phaseout and the underlying market adjustments. The excise tax helped to counter the accumulation of excess profits to those firms holding the limited number of allowances.
- Global warming is caused by the absorption of sunlight by greenhouse gases (GHGs) such as carbon dioxide (CO₂). Accumulating CO₂ arises from fossil fuel combustion and widespread deforestation.
- Significant disruption to the natural levels of GHGs is expected to cause climate changes that would alter agricultural regions, weather conditions, and sea levels. The timing and magnitude of these effects are uncertain.
- One agreement generated at the Rio Summit was the U.N. Framework Convention on Climate Change (UNFCCC), which became legally binding in March 1994.
- In 1997, a Conference of the Parties (COP) was held in Kyoto, Japan. The resulting Kyoto Protocol set emissions targets for developed nations. The accord would become effective with ratification by 55 nations that included developed countries responsible for at least 55 percent of 1990 CO₂ emissions.
- In March 2001, President Bush took the United States out of the accord.
- In February 2005, the Kyoto Protocol entered into force. Emissions targets would be achieved using GHG allowance trading, credits for carbon-absorbing forestry practices, and credits for emissions-reducing projects in other nations.
- In December 2009, the UNFCCC holds its COP15, the United Nations Climate Change Conference in Copenhagen. The first commitment phase under the Kyoto Protocol expires in 2012, and hence the parties to the protocol must negotiate a new agreement.
- The Chicago Climate Exchange (CCX) runs the only GHG emissions trading system for North America. Members of the exchange make a voluntary but legally binding pledge to reduce their GHG emissions to meet predefined targets.
- President Bush formulated a climate change plan aimed at reducing GHG intensity by 18 percent over the next decade. The plan included energy tax credits, emission reduction credits, and joint research with other nations.
- The Obama administration believes that the United States should become a world leader in addressing climate change and plans to implement a national cap-and-trade program for GHG emissions.
Chapter 13  Global Air Quality

- A Court decision in 2007 found that the EPA is authorized to regulate GHGs, including CO₂, released from motor vehicles. California applied for a waiver to implement GHG emissions limits on vehicles. In 2009 the EPA announced that six GHGs pose a threat to public health and welfare of both current and future generations and that GHG emissions from motor vehicles contribute to climate change.
- A new program known as the Regional Greenhouse Gas Initiative (RGGI) sets a multi-state cap on CO₂ emissions released by power plants. To meet the emissions cap, participating states sell tradeable allowances at quarterly auctions and use the proceeds to invest in low-carbon, clean energy technologies.
- A number of economic researchers have estimated the benefits associated with controlling global warming. A major difference across these studies is the time period used to assess benefits.
- Accumulating GHG emissions can be modeled as a negative externality. To internalize the external costs, pollution charges or tradeable allowances can be used.
- Three types of product charges commonly proposed to reduce GHG emissions are: a gasoline tax, a Btu tax, and a carbon tax, all of which are corrective taxes.
- An international system of tradeable allowances is a market-based instrument being used by developed countries to achieve emissions targets set by the Kyoto Protocol. To align with its commitment under the Kyoto Protocol, the European Union (EU) launched its own GHG trading program for member states, called the European Union GHG Emissions Trading Scheme (EU ETS).

**REVIEW QUESTIONS**

1. To meet its commitments under the Montreal Protocol, the United States implemented certain market-based policy instruments, including an excise tax on ozone depleters. Consider the following market for CFC-12 before the excise tax is imposed, where \( P \) is price per pound.

   \[
   \text{Demand: } Q = 18.40 - 0.5P \\
   \text{Supply: } Q = 10.00 + 2.5P
   \]

   Now assume that a 60 cent excise tax is used, which shifts the supply curve to \( Q' = 8.50 + 2.5P \).
   a. Find the equilibrium price before and after the tax is implemented.
   b. What do you conclude about who bears the primary burden of the tax—buyers or sellers? Briefly explain the economic sense of this outcome in this particular context.

2. Other than financial assistance, how might industrialized countries help developing countries to control ozone depletion?

3. Suppose that two major manufacturers of commercial refrigerants, Firm J and Firm K, face the following marginal abatement costs (MAC) for HCFCs.

   \[ MAC_J = 1.2A_J \quad MAC_K = 1.8A_K \]

   In the aggregate, the two firms do not hold enough HCFC allowances to cover their production activity and must abate a combined level of 20 units. Should each firm abate 10 units each? Explain economically, and support with calculations.

4. Consider the distributional effects of agricultural productivity due to global warming. Discuss some of the ramifications this outcome
would have on regional economies, national economies, and world trade.

5. a. Why is it that a carbon tax is preferred to either a Btu tax or a gasoline tax when the objective is to reduce carbon dioxide (CO₂) emissions?
   b. Instead of enacting a carbon tax, assume that Congress decides to provide tax incentives to non–carbon-based energy sources, such as solar and wind power. Would this instrument be cost-effective in reducing CO₂ emissions?
   c. Now suppose that the government chooses to initiate tax incentives (e.g., a tax credit) for these energy alternatives along with the carbon tax. Would this be a more socially optimal solution? Explain briefly.

6. Suppose the marginal benefits and costs per gallon of gasoline in the United States are modeled as follows to illustrate the negative externality of gasoline combustion:

\[
\begin{align*}
MSB &= 12.80 - 0.42Q \\
MPB &= 12.80 - 0.4Q \\
MSC &= MPC = 1.25 + 0.02Q,
\end{align*}
\]

where \( Q \) is millions of gallons.

   a. State the equation that represents the market externality. Give the economic interpretation of this equation, using its specific numerical value(s).
   b. Find the efficient equilibrium, \( P_E \) and \( Q_E \), for this market. (Do not round off.)
   c. Find the dollar value of a per-unit gasoline tax that would achieve the efficient solution, and calculate the tax revenues generated to the government as a result.

**Additional Readings**


Chapter 13  Global Air Quality

“Selling Hot Air.” The Economist (September 6, 2006), pp. 17–19.
# A Reference to Acronyms and Terms in Global Air Quality Control Policy

## Environmental Economics Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Term</th>
<th>Description</th>
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<tbody>
<tr>
<td>MEB</td>
<td>Marginal external benefit</td>
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<td>MEC</td>
<td>Marginal external cost</td>
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<td>MPB</td>
<td>Marginal private benefit</td>
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<tr>
<td>MPC</td>
<td>Marginal private cost</td>
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<tr>
<td>MSB</td>
<td>Marginal social benefit</td>
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<tr>
<td>MSC</td>
<td>Marginal social cost</td>
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<tr>
<td>$S_p$</td>
<td>Private market supply</td>
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<td>$S_s$</td>
<td>Social market supply</td>
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## Environmental Science Terms

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<th>Term</th>
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<tbody>
<tr>
<td>BCM</td>
<td>Bromochloromethane</td>
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<tr>
<td>Btu</td>
<td>British thermal unit</td>
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<td>CF₄</td>
<td>Tetrafluoromethane</td>
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<td>CFCs</td>
<td>Chlorofluorocarbons</td>
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<td>CFC-11</td>
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<td>CH₄</td>
<td>Methane</td>
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<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
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<td>GHG</td>
<td>Greenhouse gas</td>
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<td>GWP</td>
<td>Global warming potential</td>
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<tr>
<td>HBFC</td>
<td>Hydrobromofluorocarbons</td>
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<td>HCFCs</td>
<td>Hydrochlorofluorocarbons</td>
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<tr>
<td>HFCs</td>
<td>Hydrofluorocarbons</td>
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<tr>
<td>N₂O</td>
<td>Nitrous oxide</td>
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<td>ODP</td>
<td>Ozone depletion potential</td>
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<td>PFCs</td>
<td>Perfluorocarbons</td>
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<tr>
<td>SF₆</td>
<td>Sulfur hexafluoride</td>
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## Environmental Policy Acronyms

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<tr>
<th>Acronym</th>
<th>Term</th>
<th>Description</th>
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<tbody>
<tr>
<td>ARP</td>
<td>Acid Rain Program</td>
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<td>CAAA</td>
<td>Clean Air Act Amendments</td>
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<td>CCX</td>
<td>Chicago Climate Exchange</td>
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<tr>
<td>CDM</td>
<td>Clean Development Mechanism</td>
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<td>CER</td>
<td>Certified Emissions Reduction</td>
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<tr>
<td>COP</td>
<td>Conference of the Parties</td>
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<tr>
<td>CEITs</td>
<td>Countries with Economies in Transition</td>
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<tr>
<td>ERU</td>
<td>Emissions reduction unit</td>
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<td>EU ETS</td>
<td>European Union Emissions Trading Scheme</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<td>RGGI</td>
<td>Regional Greenhouse Gas Initiative</td>
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<tr>
<td>RIA</td>
<td>Regulatory Impact Analysis</td>
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<tr>
<td>RMU</td>
<td>Removal Unit</td>
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<tr>
<td>UNFCCC</td>
<td>U.N. Framework Convention on Climate Change</td>
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For related Web sites, go to [www.cengage.com/economics/callan](http://www.cengage.com/economics/callan)