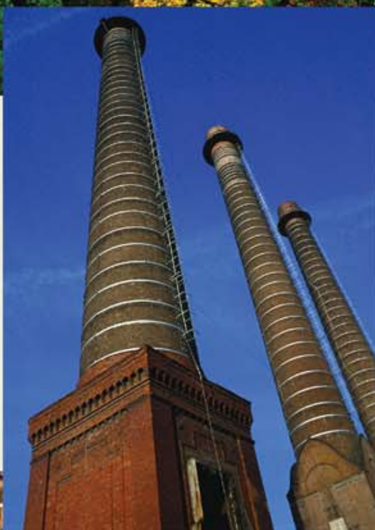
T. H. TIETENBERG

EMISSIONS TRADING

Principles and Practice

Second Edition



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T. H. Tietenberg

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About Resources for the Future *and* RFF Press

RESOURCES FOR THE FUTURE (RFF) improves environmental and natural resource policymaking worldwide through independent social science research of the highest caliber. Founded in 1952, RFF pioneered the application of economics as a tool for developing more effective policy about the use and conservation of natural resources. Its scholars continue to employ social science methods to analyze critical issues concerning pollution control, energy policy, land and water use, hazardous waste, climate change, biodiversity, and the environmental challenges of developing countries.

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Contents

Figures and Tables

Dedication

This book is dedicated to
the memory of
Allen V. Kneese
1930–2001

Pathbreaking scholar and one of the principal founders
of the field of environmental economics.

Preface

This second edition of *Emissions Trading* represents the culmination of more than 30 years of study about the role of tradable permit systems in environmental policy. My interest in this topic first arose during my graduate school years in the late 1960s and early 1970s. Inspired by the work of Allen V. Kneese and his colleagues at Resources for the Future (RFF), I became an environmental economist and in my dissertation crafted a general equilibrium model to evaluate the properties of various economic incentive approaches to pollution control, including tradable permits.

Despite the fact that an accumulating body of research at RFF and elsewhere seemed to suggest that building economic incentives into environmental policy could well offer promising opportunities for achieving better environmental and economic outcomes, during that time policy interest in any economic incentive system, including emissions trading, was nil. As the laws of physics tell us, a body at rest tends to stay at rest in the absence of a sufficiently powerful outside force. The fact that the advice was coming from academics (not practitioners) and economists (not lawyers) may have diminished, or at least delayed, its influence.

This disconnect between the academic and policy communities did not last long, however, as in the mid-1970s the U.S. Environmental Protection Agency began implementing some aspects of what subsequently became known as the Emissions Trading Program. In retrospect, on the basis of its outcomes, I think most of us would now judge that program as, at best, a very limited success and, at worst, a failure. In another sense, however, it was an important milestone, because, as the cliché goes, the camel's nose was now under the tent. Even failures have lessons to teach and, if they are not large enough to kill further interest, they can provide the foundation for what follows.

In this case, of course, that is exactly what happened. In 1984–1985, I was extremely fortunate to have been awarded a Gilbert White Fellowship at RFF, which allowed me to spend a year analyzing and writing about what was then a very new venture in environmental policy. The first edition of this book, *Emissions Trading: An Exercise in Reforming Pollution Policy*, was the result of that intellectually stimulating year.

Much has happened since that book was published in 1985. The tradable permits approach now has been extended to new pollutants including, notably, greenhouse gases, and to new geographic areas including, among others, the European Union and Santiago, Chile, and even to new, related areas of environmental protection, including the promotion of renewable energy sources. All of this developing implementation experience as well as the theoretical sophistication contributed by a whole new generation of scholars made the urge to bring that book up to date irresistible.

A full-year sabbatical from Colby College in 2004–2005 offered just the opportunity I needed to absorb and make sense of this exploding field, and this book is the result. In it, I have tried to capture the central lessons about emissions trading that have emerged to date from the theoretical and empirical research, as well as the implementation experience.

The picture that emerges, not surprisingly, is positive but mixed. Emissions trading certainly has accumulated some clear, impressive successes and because of those successes probably has irreversibly carved out a niche for itself in modern pollution control policy. The story also, however, uncovers many weaknesses of emissions trading, particularly in specific contexts, and this approach still faces many challenges that are as yet unresolved. I have tried to be equally clear about both its successes and the remaining challenges.

Readers of this book also may be interested in a rather extensive bibliography on tradable permits that is available on my web site at: http://www.colby.edu/~thtieten/trade.html. This bibliography contains sources dealing with subjects as diverse as the historical and theoretical foundations of emissions trading, design considerations, ethical dimensions, and studies that examine specific applications in air, water pollution control, energy, forestry, and fisheries, among others.

This book was improved significantly by the extremely helpful comments on the first draft that I received from Roberton C. Williams III, Thomas Sterner, Denny Ellerman, and Juan-Pablo Montero. I am deeply grateful for their assistance.

Tom Tietenberg
Colby College
Waterville, Maine

Abbreviations

ATS	Allowance Tracking System
CEM	Continuous emissions monitoring
CERs	Certified emission reductions
EPA	U.S. Environmental Protection Agency
ERMS	Emissions Reduction Market System
ETP	Emissions Trading Program
EU ETS	European Union Emissions Trading Scheme
NBP	NO_x Budget Trading Program
OTC	Ozone Transport Commission
RACT	Reasonably available control technology
RECLAIM	Regional Clean Air Incentives Market
RTC	RECLAIM tradable credits
SIP	State implementation plan
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile organic chemical
VOM	Volatile organic matter

1
Introduction

A long tradition in economics suggests that treating resources as a commons that are shared jointly by many users could lead to overexploitation in the absence of some kind of access rationing (Ostrom et al. 2002). Since the atmosphere is one such commons, it is not surprising to find that in the absence of some kind of access rationing for polluters, the atmosphere would be excessively polluted. The policy question, therefore, is what form should the control over access take?

One increasingly common form involves the use of emissions trading. In contrast to more traditional regulation, where the regulatory authority specifies a specific maximum level of emissions for each emissions source within a plant, emissions trading is a regulatory program that allows pollution emitters considerable flexibility in how they comply with the regulation. With emissions trading, as long as the total emissions reduction is the same or greater, firms can comply by either: (1) reducing emissions from any combination of sources within the plant; or (2) acquiring emissions reductions from another facility.

The logic behind the growing prominence of this approach is simple. One of the insights derived from the empirical literature is that traditional command-and-control regulatory measures, which depend upon government agencies to define not only the goals but also the means for reaching them, are in many cases insufficiently protective of those resources or economically inefficient. Emissions trading provides, at least in principle, a cost-effective alternative.

Applications of this general approach have spread not only to many different types of pollution in many different countries but are also being used to ration access to many other resources, including fisheries, forests, water, and land use control, among others.[1] Though the lessons from emissions trading are certainly useful for those considering this approach for other resources, this book will focus on the use of this technique to control air pollution.

Early History

By the late 1950s, both economists and policymakers had formed well-developed and deeply entrenched visions of how pollution control policy should be conducted. Unfortunately, the two visions were worlds apart.

Economists viewed the world through the eyes of Pigou (1920). Professor A.C. Pigou had argued that in the face of an externality such as pollution, the appropriate remedy involved imposing a per-unit tax on the emissions from a polluting activity. The tax rate would be equal to the marginal external social damage caused by the last unit of pollution at the efficient allocation. Faced with this tax on emissions, firms would "internalize" the externality. By minimizing their private costs, firms would simultaneously minimize the costs to society as a whole. According to this view, rational pollution control policy involved putting a price on pollution.

Policymakers, particularly, but not exclusively, in the United States, held an equally firm, if substantially different, view. According to this view, the proper way to control pollution was through a series of legal regulations ranging from controlling the location of polluting activities (to keep them away from people) to the specification of emissions ceilings (to limit the amount ejected into the air). Under this regulatory regime, the public sector would be responsible for: (1) figuring out how much pollution to allow each emitter (usually by identifying the specific control technology that should be used); (2) mandating either a specific technology or level of emissions flow achievable by that technology; (3) monitoring emissions to verify compliance with these mandates; and (4) using financial penalties or other sanctions to bring non-complying sources into compliance.

While some exchanges of ideas took place between the two groups, most of it was highly critical and not viewed by the recipients as particularly helpful. Economists would point out, for example, that legal regimes, which became known as "command-and-control" regimes, generally were not cost-effective. Hence, they argued that by simply switching to Pigouvian taxes, more pollution control could be gained with the same expenditure or the same pollution control could be gained with less expenditure.

Policymakers responded that the information burden imposed on the bureaucracy by the design of efficient taxes was unrealistically high. And taxes based upon very limited information might not be any better than legal regulations. Furthermore, they argued, if bureaucrats had sufficient information to set efficient tax rates, they could use the same information to set efficient legal regimes.

The result was a standoff in which policymakers focused on quantity-based policies while economists continued to promote price-based remedies. While the standoff continued, legal regimes prevailed. Taxes made little headway, particularly in the United States.

In 1960, Ronald Coase published a remarkable article in which he sowed the seeds for a different mind-set. Arguing that Pigou had used an excessively narrow focus, Coase went on to suggest:

> It is my belief that the failure of economists to reach correct conclusions about the treatment of harmful effects cannot be ascribed simply to a few slips in analysis. It stems from basic defects in the current approach to problems of welfare economics. What is needed is a change in approach. (1960, *42*)

His proposed change in approach involved refocusing on property rights:

> If factors of production are thought of as rights, it becomes easier to understand that the right to do something which has a harmful effect (such as the creation of smoke, noise, smell, etc.) is also a factor of production. . . . The cost of exercising a right (of using a factor of production) is always the loss that is suffered elsewhere in consequence of the exercise of that right—the inability to cross land, to park a car, to build a house, to enjoy a view, to have peace and quiet or to breathe clean air. (1960, *44*)

Coase argued that by making these property rights explicit and transferable, the market could play a substantial role. To his fellow economists, Coase pointed out that a property rights approach allowed the market to value the property rights, as opposed to the government in the Pigouvian approach. To policymakers, Coase pointed out that control regimes based purely on emissions limits provided no means for the rights to flow to their highest valued use.

It remained for this key insight to become imbedded in practical programs for controlling pollution. Dales (1968) pointed out its applicability for water and Crocker (1966) for air. Among his other contributions, Dales noted that the legal regimes imposed by the government for pollution control in fact had already established a property right in the right to emit. Unlike the property right system envisioned by Coase, however, this property right was not efficient because it was not transferable:

> The "regulatory" branches of modern governments create an enormous variety of valuable property rights that are imperfectly transferable, and that tend to be capitalized and monetized in ways that are usually unsuspected by their creators. (1968, *796*)

One possibility to correct that inefficiency, of course, would be to make the existing system of property rights transferable. In a section that foreshadows much of what was to come, Dales (1968, *801*) suggested a means for doing this:

> The government's decision is, let us say, that for the next five years no more than x equivalent tons of waste per year are to be discharged into the waters of region A. Let it therefore issue x pollution rights and put them up for sale, simultaneously passing a law that everyone who discharges one equivalent ton of waste into the natural water system during a year must hold one pollution right throughout the year. Since x is less than the number of equivalent tons of waste being discharged at present, the rights will command a positive price—a price sufficient to result in a 10 percent reduction in waste discharge. The market in rights would be continuous. Firms that found that their actual production was likely to be less than their initial estimate of production would have rights to sell, and those in the contrary situation would be in the market as buyers. Anyone should be able to buy rights; clean-water groups would be able to buy rights and not exercise them. A forward market in rights might be established. . . . The virtues of the market mechanism are that no person, or agency, has to *set* the price—it is set by the competition among buyers and sellers of rights.

In his discussion of how this approach could be used to control air pollution, Crocker (1966, *81*) noted a more basic point, namely that this approach fundamentally changes the information requirements imposed on the bureaucracy:

> Although the atmospheric pollution control authority's responsibilities will continue to be a good deal broader than the basic governmental function of providing legal and tenure certainty in property rights, its necessary work will not have to include the guesswork involved in attempting to estimate individual emitter and receptor preference functions.

When emissions trading is used to pursue a predetermined goal that specifies the level of allowable emissions, the authority does not have to know anything about either damage or cost functions.[2] Transferability, at least in principle, allows the market to handle the task of ensuring that the assignment of control responsibility ultimately ends up being placed on those who can accomplish the previously stipulated reductions at the lowest cost.

The final stage in this evolution was reached with the publication of a couple of now classic articles. The first, by Baumol and Oates (1971), formalized the theory behind these practical insights for the case of uniformly mixed pollutants, those for which only the level, not the location, of the emissions matters. This was followed shortly by an article by Montgomery (1972) that generalized the results for the more complicated case of non-uniformly mixed pollutants, those for which both the level and the location of emissions matters. These articles were instrumental in legitimizing the concept of emissions trading in the eyes of those theorists who tend to be distrustful of ad hoc arguments until the formal properties of the system are worked out.

Describing the Evolution

Traditional Policy

To understand how these general principles were implemented in the early years in the United States, it is important first to understand the policy environment that gave rise to the reform. Some knowledge of that policy framework helps not only to understand the forces for reform but also the shape of that reform once it began to happen.

U.S. air pollution policy was, and is, designed to ensure that people and ecosystems are protected from harmful levels of pollution. It does this by promulgating ambient air quality standards that specify the permissible legal threshold for concentrations of pollutants in the ambient air and by establishing a process for reaching those standards.

The traditional approach for improving air quality typically involved the bureaucratic selection of desirable control technologies, using those technologies as the basis for specifying permissible emission limits, and forcing emitters to stay within those limits.

In the early 1970s, a group of experts from the academic community familiar with emerging literature on property rights suggested that it might be possible to improve upon this system by allowing firms to trade control responsibility among themselves by means of emissions trading. In this way, firms that could control relatively cheaply would voluntarily control more, selling the excess control to those that, for economic reasons, wanted to control less.

In an important sense, emissions trading changes the nature of the regulatory process. The burden of identifying the appropriate control strategies is shifted from the control authority to the polluter. As a result of the flexibility that becomes possible from this shift, many new control strategies can, in principle, emerge. Instead of the traditional focus on end-of-pipe control technologies, pollution prevention is placed on an equal footing by this program. All possible pollution reduction strategies can, for the first time, compete on a level playing field.

Emissions trading also allows more flexibility in the timing of control investments. Under emissions trading, facilities have the ability to time their expenditures so that they coincide with optimal capital replacement schedules and prevailing market conditions. Forcing every emitter to install control equipment at precisely the same time could cause much higher equipment purchase expenditures than would be the case with a schedule that spread deliveries out over a longer period. Demand would be less temporally concentrated with emissions trading.

Reform, however, has its own costs, and the existing policy was likely to persist unless it could be shown that the difference the new policy would make would be sufficiently large to justify the change. Making that case, of course, required empirical analysis that could begin to get at the magnitude of the potential cost savings involved. Were they large enough to justify the effort?

As discussed in more detail in the next chapter, the initial empirical analysis suggested that the command-and-control policy was very cost-ineffective. (Atkinson and Lewis 1974; Tietenberg 1974). Subsequent analyses involving several different pollutants in several different regions find that the initial empirical results were robust—the control costs from command-and-control allocations were estimated to exceed least cost allocations by a substantial margin (Seskin et al. 1983; Roach et al. 1981; Atkinson and Tietenberg 1982; Krupnick, Oates et al. 1983; Maloney and Yandle 1984; McGartland and Oates 1985). Though based on ex ante computer simulations that dealt more with caricatures of command-and-control than actual regulatory allocations, this literature offered the possibility that the increased flexibility made possible by the reform had the potential to meet the environmental targets with substantially lower control costs.

The Evolution of Emissions Trading

The Offset Policy: The Problem Becomes the Solution

The political opportunity to capitalize on that insight came in 1976. By 1976, it had become clear that a number of regions designated as "nonattainment" regions by the Clean Air Act would fail to attain the ambient air quality standards by the deadlines mandated in the act. Because the statute mandated improvements in air quality in these regions, further economic growth appeared to make the air worse, contrary to the intent of the statute. The Environmental Protection Agency (EPA) was faced with the unpleasant prospect of prohibiting many new businesses (those that would emit any of the pollutants responsible for nonattainment in that region) from entering these regions until the air quality came within the ambient standards.

Prohibiting economic growth as a means of resolving air quality problems was politically unpopular among governors, mayors, and many members of Congress. EPA had a potential revolution on its hands. At this point, they began to consider alternatives. Was it possible to solve the air quality problem while allowing further economic growth?

It was possible, as it turns out, and the means for achieving these apparently incompatible objectives involved the creation of an early form of emissions trading. Existing sources of pollution in the nonattainment area were encouraged to voluntarily reduce their emissions levels below their current legal requirements. EPA could then certify these excess reductions as emission reduction credits. Once certified by the control authority, these credits then became transferable to new sources that wished to enter the area; this created the supply of credits.

The demand for credits was created by new sources. New sources were allowed to enter nonattainment regions provided they acquired sufficient emissions reduction credits from other facilities in the region and that total regional emissions would be lower (not just the same) after entry than before. (This was accomplished by requiring new sources to secure credits for 120% of the emissions they would add; the extra 20% would be "retired" as an improvement in air quality.) Known as the offset policy, this approach not only allowed economic growth while improving air quality—it made economic growth the vehicle for improvement. It turned the problem on its head by making the problem part of the solution (Tietenberg 1985; Hahn and Hester 1989b).

The U.S. Emissions Trading Program: Expanding the Scope

It wasn't long before the government began to expand the scope of the program by combining three new policies (the bubble policy, banking, and netting) with the offset policy into what became known as the Emissions Trading Program (ETP).

Whereas the offset policy allowed new sources to acquire credits from existing sources, the bubble policy allowed existing sources to acquire credits from each other. Banking simply allowed the created credits to be saved for subsequent use or sale in the future.

Netting allowed sources undergoing modifications or expansions to escape the burden of meeting the strict requirements imposed on new sources as long as any net increase in emissions (counting emissions reduction credits) fell below an established threshold. By netting out of this review, the facility would not only be exempted from meeting the strict new source technology requirements, but they also would be relieved of the need to secure offsets for the remaining emissions.

Like the offset policy, the emissions trading program was a credit program.[3] A firm could create credits by exceeding its legal reduction requirements and having the excess certified as an emissions reduction credit. In this program, the government not only was required to certify each reduction before it qualified for credit, but credit trades generally were approved by the control authority on a case-by-case basis.

Getting the Lead Out: The Lead Phase-out Program

Following the introduction of the ETP, the government began applying the tradable permit approach more widely. One prominent use involved facilitating the regulatory process for getting lead out of gasoline (Hahn and Hester 1989a; Nussbaum 1992; Kerr and Maré 1997). In this case what was being controlled was not emissions per se, but an input: lead.

Lead was being added to gasoline by a relatively few refineries. Compared to monitoring and enforcing limits on the lead emissions from every gasoline-powered vehicle, it proved more administratively feasible to control the lead problem at the point of gasoline production.

In the mid-1980s, prior to the issuance of new, more stringent regulations on lead in gasoline, EPA announced the results of a cost–benefit analysis of their expected impact. The analysis concluded that the proposed .01 grams per leaded gallon standard would result in $36 billion (1983$) in benefits from reduced adverse health effects at an estimated cost of $2.6 billion to the refining industry.

Although these results suggested that regulation unquestionably was justified on efficiency grounds, EPA wanted to allow flexibility in how the deadlines were met without increasing the amount of lead used. While some refiners could meet early deadlines with ease, others could do so only with a significant increase in cost. Recognizing that meeting the goal did not require every refiner to make the transition at the same time, EPA initiated an artificial market in the rights to use lead in gasoline to provide additional flexibility in meeting the regulations.

Under this program, a fixed amount of lead rights (authorizing the use of a fixed amount of lead over the transition period) was allocated to the various refiners. Refiners who did not need their full share of authorized rights (due to early compliance) could sell their rights to other refiners.

Refiners had an incentive to eliminate the lead quickly because early reduction freed up rights for sale. Acquiring these credits made it possible for other refiners to comply with the deadlines even in the face of equipment failures or acts of God; fighting the deadlines in court, the traditional response, was unnecessary. Designed purely as a means of facilitating the transition to lead-free gasoline, the lead banking program ended as scheduled on December 31, 1987.

Several features of this program are noteworthy because they demonstrate the evolution of emissions trading into new territory. First, the lead program limited an input to emissions, not emissions directly. Second, the lead program was designed to eliminate a pollutant, not merely place an upper limit on its annual use. Third, it resulted in a much earlier phase-out of lead than traditionally would have been possible because of the inter-refinery flexibility it offered. The traditional approach—setting the deadline late enough to allow even refineries facing the most difficult compliance problems to meet it—would have resulted in a great deal more lead being injected into the air.[4] All of these features differentiate the lead program from the offset program.

Reducing Ozone-Depleting Chemicals

Responding to the threat to the stratospheric ozone shield posed by the emission of ozone-depleting gases, 24 nations signed the Montreal Protocol during September 1988. According to this agreement, signatory nations were to restrict their production and consumption of the chief responsible gases to 50% of 1986 levels by June 30, 1998. Soon after the protocol was signed, new evidence suggested that it had not gone far enough; the damage was apparently increasing more rapidly than previously thought. In response, subsequent agreements called for the complete phase-out of halons and CFCs by the end of the twentieth century. Moreover, two other destructive chemicals—carbon tetrachloride and methyl chloroform—were added to the elimination schedule.

The United States chose to use a transferable permit system to implement its responsibilities under the protocols. On August 12, 1988, EPA issued regulations implementing a tradable permit system to achieve the targeted reductions. Under these initial regulations, all major U.S. producers and consumers of the controlled substances were allocated baseline production or consumption allowances using 1986 levels as the basis for their prorated share. Each producer and consumer was initially allowed 100% of this baseline allowance, with smaller allowances being granted after predefined deadlines.

These allowances were transferable within producer and consumer categories and allowances could be transferred across international borders to producers in other signatory nations if the transaction was approved by EPA and resulted in the appropriate adjustments in the buyer or seller allowances in their respective countries.[5]

Production allowances could be augmented by demonstrating the safe destruction of an equivalent amount of controlled substances by approved means. Some inter-pollutant trading was even possible within categories of pollutants. (The categories are defined so as to group pollutants with similar environmental effects.) All information on trades is confidential (known only to the traders and regulators), so it is difficult to know how effective this program has been. One estimate suggests that as of September 1993, the traded amount was roughly 10% of the total permits (Stavins and Hahn 1993).

Since the demand for these allowances was quite price inelastic, the supply restrictions imposed by this program increased revenue from their sale. By allocating allowances to the seven major domestic producers of CFCs and halons, EPA created sizable windfall profits (estimated to be in the billions of dollars) for those producers.

Those profits proved to be short-lived. A revenue-starved U.S. Congress seized the opportunity to impose a tax to soak up the rents created by the regulation-induced scarcity. The Revenue Reconciliation Act of 1989 included an excise tax that was imposed on all ozone-depleting chemicals sold or used by manufacturers, producers, or importers. The tax is imposed at the time the importer sells or uses the affected chemicals. It is computed by multiplying the chemical's weight by the base tax rate and the chemical's ozone-depletion factor. In addition to soaking up some of the regulation-induced scarcity rent, this tax provided an incentive to switch to less harmful (and therefore untaxed) substances. Over time, the tax rate grew high enough that it, not the allowances, was controlling the level of production and use. (In other words, at that point the demand for allowances was lower than the available supply.)

This application also contributed some new features to the evolution of emissions trading. It not only allowed international trading of allowances for the first time, but it involved the simultaneous application of emissions trading and taxes. (Prior to this application, taxes and allowances were considered substitutes, rather than complements.)

Industrial Air Toxics: Emissions Averaging

The 1990 Clean Air Act Amendments required EPA to establish national emissions standards to control major industrial sources of toxic air pollution. In defining its approach, EPA has used emissions averaging as one of several ways to provide compliance leeway in these industry-by-industry standards. Emissions averaging allows facilities some flexibility in choosing the mix of sources used to meet a facility-wide cap; in essence, it involves intra-plant trading. For example, emissions averaging is permitted by national air toxics emissions standards for petroleum refining, synthetic organic chemical manufacturing, polymers and resins manufacturing, aluminum production, wood furniture manufacturing, printing and publishing, and a number of other sectors (Anderson 2001).[6]

Tackling Acid Rain: The Sulfur Allowance Program

The most successful version of emissions trading to date has been its use in the U.S. approach for achieving further reductions in electric utility emissions contributing to acid rain. Under this innovative approach, allowances to emit sulfur oxides were allocated to plants; the number of authorized emissions was reduced in two phases to ensure a reduction of 10 million tons in emissions from 1980 levels by the year 2010 (Kete 1992; Rico 1995; Carlson et al. 2003; Ellerman et al. 2000; Ellerman 2003; Burtraw and Palmer 2004).

Perhaps the most interesting political aspect of this program was the role of trading in the passage of the acid rain bill. Though reductions of acid rain precursors had been sought with a succession of bills over the two decades of Clean Air Act legislation, none had become law. With the inclusion of an emissions trading program for sulfur dioxides in the bill, the compliance cost apparently was reduced sufficiently to make passage politically possible.

Sulfur dioxide allowances form the heart of this emissions trading program. The allowances are allocated to specified utilities on the basis of an allocation formula. Each allowance, which provides a limited authorization to emit one ton of sulfur, is defined for a specific calendar year, but unused allowances can be carried forward into future years. They are fully transferable not only among the affected sources but even to individuals who may wish to "retire" the allowances, thereby denying their use to legitimize emissions.

Emissions in this controlled sector cannot legally exceed the levels permitted by the allowances (allocated plus acquired). An annual year-end audit balances emissions with allowances. Utilities that emit more than authorized by their holdings of allowances must pay a per-ton penalty and are required to forfeit an equivalent number of tons the following year. The amount of the penalty was indexed to inflation from a starting value of $2,000 a ton.

This program has several innovative features, but in the interest of brevity only two are detailed here. The first important innovation in this program was ensuring the availability of allowances by instituting an auction market. Although allowances can be either transferred by private sale or the annual auction, the problem historically with the private sale route was that prices were confidential, so transactors were operating in the dark. Due to a lack of general knowledge not only about potential buyers and sellers but also about prices, transactions costs were high; before the Sulfur Allowance Program, emissions trading markets did not work very well.

EPA solved this problem by instituting an auction market run by the Chicago Board of Trade. In the negotiations, utilities fought the idea of an auction because they knew it would raise their costs significantly. Whereas under the traditional policy utilities would be given the allowances free of charge, under a conventional auction they would have had to buy these allowances at the full market price, a potentially significant additional financial burden.

To gain the advantages an auction offers for improving the efficiency of the market, while not imposing a rather large financial burden on utilities, EPA established what is now known as a zero revenue auction. Each year, EPA withholds from its allocation to utilities somewhat less than 3% of the allocated allowances and auctions them off. In the auction, these allowances are allocated to the highest bidders, with successful buyers paying their actual bid price (not a common market-clearing price). The proceeds from the sale of these allowances are refunded to the utilities from which the allowances were withheld on a proportional basis.

Private allowance holders other than utilities also may offer allowances for sale at these auctions. Potential sellers specify minimum acceptable prices. Once the withheld allowances have been disbursed, EPA then matches the highest remaining bids with the lowest minimum acceptable prices on the private offerings and matches buyers and sellers until all remaining bids are less than the remaining minimum acceptable prices. Although this auction design is not efficient, because it provides incentives for inefficient strategic behavior (Hausker 1992; Cason 1993), the degree of inefficiency is apparently small (Joskow et al. 1998; Ellerman et al. 2000).

A second innovation in this program is that it allows anyone to purchase allowances. This means that environmental groups or private citizens can buy them for the purpose of retiring them. Since retired allowances represent authorized emissions that are never emitted, they result in cleaner air.

RECLAIM: The States Take the Initiative

All of the previous U.S. programs were initiated by the federal government. The states primarily were involved as the enforcement arm of the federal programs. In 1994, states became initiators as well as enforcers. Faced with the need to reduce pollutant concentrations considerably in order to come into compliance with the ambient standards, many states chose to use trading programs as a means of facilitating drastic reductions in emissions.

One of the most ambitious of these programs, and the focus of this section, is California's Regional Clean Air Incentives Market (RECLAIM), established by the South Coast Air Quality Management District, the district responsible for the greater Los Angeles area (Goldenberg 1993; Fromm and Hansjurgens 1996; Hall and Walton 1996; Johnson and Pekelney 1996; Harrison 2004).

Under RECLAIM, each of the almost 400 participating industrial polluters are allocated an annual pollution limit for nitrogen oxides and sulfur. This limit decreases by 5% to 8% each year for a decade. Polluters are allowed great flexibility in meeting these limits, including purchasing RECLAIM tradable credits (RTC) from other firms that have controlled more than their legal requirements.

In part to ensure that the program actually could be implemented, the initial authorization for emission limits was generous. As a result, in the early years of the RECLAIM program (1993–1999) most companies had an excess number of RTC credits because the initial allocation exceeded actual emissions rates.

During the summer of 2000, problems with California's electricity deregulation program spilled over into the RECLAIM market, resulting in a sharp and sudden increase in credit prices (Joskow and Kahn 2002). Specifically, "the average price of NO_x RTCs for compliance year 2000, traded in the year 2000, increased sharply to over $45,000 per ton compared to the average price of $4,284 per ton traded in 1999" (SCAQMD 2001).

The district responded by temporarily pulling power plants out of the program and instituting a mitigation fee as a safety valve. Under the mitigation fee alternative, power-producing facilities contribute $7.50 per credit for any emissions exceeding their allocation. The collected funds are invested in emission reduction projects.

Aside from the fact that this was the first emissions trading program initiated by a state, two other features of this program are of interest. First, trading within this program was restricted spatially by the creation of trading zones for the coastal and interior regions. Furthermore, RECLAIM is the only program to face such significant price increases. As will become clear in subsequent chapters, the experience with both of these features provides some valuable lessons for program design.

The NO_x Budget Program

The next phase in the evolution involved states getting together to cooperate in the development and initiation of a regional cap-and-trade program. States in the Northeastern United States collaborated via the Ozone Transport Commission (OTC) to achieve ozone-season NO_x reductions in several phases.[7] In Phase I, sources were required to reduce their annual rates of NO_x emissions to meet Reasonably Available Control Technology requirements. In Phase II, states initiated a cap-and-trade program, named the OTC NO_x Budget Program (OTCNBP), to achieve additional reductions during the ozone season.

In 2003, the OTCNBP was replaced in Phase III by the geographically more inclusive[8] NO_x Budget Trading Program (NBP). While the Phase III NBP was initiated federally, it essentially ratified and extended the initiative that had already been undertaken by the Northeastern states. Although attainment of the federal ozone ambient standard was the motivation, it was the OTC states that decided to implement a seasonal cap-and-trade program starting in 1999. (Emissions are capped during the ozone season from May 1 to September 30.) It was an outgrowth of the discussions within the OTC set up by the 1990 Clean Air Amendments to facilitate interstate cooperation in the Northeast.

As a result of this earlier state-initiated program, states in the OTC were able to comply with the NBP in 2003, and many other states across the East and Midwest began to reduce emissions in 2004. Twenty-one states and the District of Columbia are participating or will participate in the future.

Based on data reported to EPA, nearly 2,600 affected and operating units are in the NBP states, including states that joined the program in 2004. About 1,000 of these units are in OTC states that complied in 2003, while another 1,600 units are in non-OTC states.

The most unique feature of this program is its focus on seasonal emissions. Whereas most emissions trading programs focus on reducing annual emissions, this program, recognizing the important seasonal component in the formation of ozone in the Northeast, focuses only on those emissions that will directly contribute to the problem.

The Chicago Emissions Reduction Market System

The Chicago area, which was a severe nonattainment area for ozone, was required to come into compliance with the ozone ambient standard by 2007. Concluding that meeting the standard would require substantial reductions in volatile organic matter (VOM) emissions, Illinois adopted the Emissions Reduction Market System (ERMS), an emissions trading program that would reduce overall VOM emissions in the Chicago area.

Similar to the NO_x budget program (because VOM emissions contribute to ozone formation as well), the ERMS program operates from May 1 through September 30. The program allows trading among participating sources to meet a reduced cap on their overall VOM emissions. Each participant is given a number of allotment trading units, corresponding to an overall reduction of 12%, according to what they emitted in previous years.

This was the first program to attempt to use emissions trading to control volatile organic materials. A proposed earlier effort to use a cap-and-trade mechanism in the Los Angeles area to limit VOM emissions had been discussed but not implemented. Implementing a cap-and-trade system for VOM is especially complex because VOM sources not only include a wide array of very different types of emitters, many of them small, but volatile organics represent a class of pollutants, not a single pollutant. To make matters even more complex, VOM contains substances that have been designated as hazardous air pollutants due to the danger they pose to human health. Clearly not all VOM reductions would have the same environmental impact should trading change the mix.

To date, the evidence suggests that this program was superfluous and therefore ineffective. While ex post emissions were far below the cap, findings of unexpectedly large banks, startling permit expirations, and low prices of tradable permits all provide evidence of an ineffective market. Kosobud et al. (2004) find that the market as designed had been constrained from reaching its objectives by the continuance and extension of an underlying layer of traditional regulation and to a lesser extent by over-allotment of tradable permits. The regulations, not emissions trading, largely were responsible for the reductions, and the responses they mandated left little room for emissions trading to play any role.

Emissions Trading in the Kyoto Protocol on Climate Change

The 1992 United Nations Framework Convention on Climate Change (UNFCCC) recognized the principle of the global cost-effectiveness of emissions reduction and opened the way for flexibility in how greenhouse gas targets would be met. Because this early agreement did not fix a binding emissions target for any country, however, the need to invest in emissions reduction at home or abroad was not pressing.

In December 1997, however, industrial countries and countries with economies in transition (primarily the former Soviet Republics) agreed to legally binding emissions targets at the Kyoto Conference and negotiated a legal framework as a protocol to the UNFCCC—the Kyoto Protocol. This protocol became effective in February 2005 once Russia's ratification put the Kyoto Protocol over the 55% threshold.[9]

The Kyoto Protocol defines a five-year commitment period (2008–2012) for meeting the individual country emissions targets, called "assigned amount obligations," set out in Annex B of the protocol. Quantified country targets are defined by multiplying the country's 1990 emissions level by a reduction factor and multiplying that number by five (to cover the five-year commitment period). Collectively, if fulfilled, these targets would represent a 5% reduction in annual average emissions below 1990 levels from this group. The actual compliance target is defined as a weighted average of six greenhouse gases: carbon dioxide, methane, nitrous oxide, HFCs, PFCs, and sulfur hexafluoride. Defining the target in terms of this multi-gas index, rather than only carbon dioxide, has been estimated to reduce compliance costs by some 22% (Reilly et al. 2002).

The Kyoto Protocol authorizes three cooperative implementation mechanisms that involve tradable permits. These include Emission Trading, Joint Implementation, and the Clean Development Mechanism.

- Emissions Trading allows trading as a means of fulfilling the national quotas established by the Kyoto Protocol among countries listed in Annex B of the protocol, primarily industrialized nations and economics in transition. Although in principle trading of emissions reductions could occur among private parties as well as countries, the enabling article, Article 17, is silent on this point.
- Under Joint Implementation, Annex B parties can receive emissions reduction credit when they help to finance specific projects that reduce net emissions in another Annex B party country. This project-based program is designed to exploit opportunities in Annex B countries that have not yet become fully eligible to engage in the Emissions Trading Program described above.
- The Clean Development Mechanism enables Annex B parties to finance emissions reduction projects in non-Annex B parties (primarily developing countries) and to receive certified emission reductions (CERs) for doing so. These CERs could then be used, along with in-country reductions, to fulfill assigned amount obligations.

The European Union Emissions Trading Scheme

The largest and most important emissions trading program has been developed by the European Union to facilitate implementation of the Kyoto Protocol

(Kruger and Pizer 2004). The EU Emissions Trading Scheme (EU ETS) applies to 25 countries, including the 10 accession countries, most of which are former members of the Soviet bloc.[10] The first phase, from 2005 through 2007, is considered to be a trial phase. The second phase coincides with the first Kyoto commitment period, beginning in 2008 and continuing through 2012. Subsequent negotiations will specify the details of future phases.

Initially, the program will cover only carbon dioxide emissions from four broad sectors: iron and steel, minerals, energy, and pulp and paper. All installations in these sectors larger than established thresholds are included in the program. Some 12,000 installations are expected to be included, the largest number of sources covered by any program.

Individual countries determine the initial allocation using a two-step process. First, they must decide how much of the predefined national cap should be allocated to each of these sectors and second, how much of each sector cap should be allocated to each of the installations in that sector. Making these initial allocations has turned out to be a highly controversial process, in part because competitors in different European countries could end up with quite different allocations (and therefore different costs of compliance).

Though this allocation scheme provides installations with the permits for free, auctions of permits may be held in the future. Countries will be allowed the option of auctioning up to 5% of allowances in the first phase of the program and up to 10% in the second phase. Participating countries can use credits acquired from outside the European Union (via the Joint Implementation or Clean Development Mechanisms) to meet their obligations under the emissions trading system.

A couple of other features differentiate this system from U.S. programs. In the EU ETS, new plants in many cases are granted gratis permits, whereas in the U.S. system new firms usually have to buy any permits they need. In addition, plant closures tend to lead to the forfeiture of permits more often in the EU system than the U.S. system (Åhman et al. 2005).

Controlling Particulates in Santiago, Chile

Emissions trading is being implemented in developing counties as well (Montero et al. 2002). In March 1992, a program to control total suspended particulate emissions from stationary sources was established in Santiago, Chile. Sources registered and operating at that time received grandfathered permits, while new sources, which received no permits, must cover or offset all their emissions by buying permits from existing sources.[11]

These permits are denominated not in terms of a source's actual emissions but in terms of its "emissions capacity," which is equal to the maximum emissions that the source could potentially emit in a given period of time.[12] The regulator annually reconciles the estimated emissions capacity with the number of capacity permits held by each source. Firms with actual capacity that falls below the authorized capacity can sell the excess permits, while firms with too few permits can purchase them from other sources. Although permits are traded at a 1:1 ratio, all trades require approval by the regulatory agency.[13]

The Santiago program occupies a significant place in the evolution of emissions trading because it provides experience about the effectiveness of these programs in the environment of a developing country. As such, it provides some important insights into the infrastructure requirements for emissions trading, a subject discussed in more detail in subsequent chapters.

Clean Air Interstate Rule

New, national health-based air quality standards in the United States for ozone and particulate matter (PM2.5) require substantial reductions beyond the existing regulations. On March 10, 2005, EPA announced the Clean Air Interstate Rule, a rule that covers 28 eastern states and the District of Columbia.

States must achieve the required emissions reductions using one of two compliance options: (1) meeting the state's emissions budget by requiring power plants to participate in an EPA-administered interstate cap-and-trade system that caps emissions in two stages; or (2) meeting an individual state emissions budget through measures of the state's choosing.

This reliance on a cap-and-trade approach to securing these reductions is a large step in the evolution of cap-and-trade programs. Normally, state compliance is determined through EPA oversight and approval of state implementation plans. In this case, state actions are deemed adequate if the federally designed model rule of emissions trading is adopted. This EPA dependence on the mechanisms set up by the Clean Air Act Amendments of 1990 would have been unimaginable 20 years ago and may represent the clearest example of the extent to which emissions trading has replaced conventional source-by-source regulation.[14]

The Evolution of Design Features

The evolution of emissions trading over time has resulted in considerable change in some of the programmatic design elements.

Permit Denominations

The original ETP was based on a system of credits that typically were denominated in terms of a pollutant flow such as tons per year. The newer programs are based on allowances defined in discrete terms (e.g., tons rather than tons/year). While the former conferred a continuing entitlement to a flow, the latter provides a one-time entitlement to emit a specific quantity.

Though seemingly a small change, in fact the opportunity for discrete credits has proved to be quite important. One of the original criteria used by EPA for approving credits was that the emissions reduction supporting them should be permanent. Many useful strategies to reduce emissions, such as meeting a deadline early, produce temporary, rather than permanent, reductions. (As noted above, the ability to set an earlier deadline in the Lead Phase-out Program was made possible by the flexibility inherent in an allowance program.) Because allowance programs encourage discrete as well as permanent flow reductions, they facilitate these additional cost reductions with no adverse impact for the environment.

Authorizing future emissions in an allowance system requires the issuance of future allowances. In general, this is done well in advance of the applicable dates according to specific schedules so emitters have reasonable security for pollution control investment planning. Allocating allowances in advance has also facilitated the development of futures markets.[15]

Another major difference is that credits generally have to be certified as excess in advance of any trade by the control authority. In contrast, allowances can be freely traded without any certification step. Since compliance with allowances is ascertained by an end-of-period comparison between actual emissions and surrendered allowances, no certification step is necessary.

Seasonality

For some pollutants, such as ozone, there is a strong seasonal element in the relationship between emissions patterns of precursor pollutants and the resulting ozone concentrations. Another significant characteristic of the evolution of emissions trading is the tendency to tailor programs to take this relationship into account by targeting emissions that occur during the ozone-formation period. This kind of targeting occurs in both the NBP and the Chicago VOM program.

Baseline

Credit trading, the approach taken in the bubble and offset policies, allows emissions reductions above and beyond legal requirements to be certified as tradable credits. The baseline for credits is provided by traditional technology-based standards. Credit trading presumes the preexistence of these standards and it provides a more flexible means of achieving the source-specific goals that the source-based standards were designed to achieve.

Allowance trading, used in the Acid Rain Program and RECLAIM in California, assigns a pre-specified number of allowances to polluters—a number that may or may not have anything to do with the historical, technology-based standards. Typically, the number of issued allowances declines over time, and in most cases the magnitude of the aggregate reductions implied by the allowance allocations exceed those achievable by standards based on currently known technologies.

Despite their apparent similarity, the difference between credit and allowance-based trading baselines should not be overlooked. Credit trading depends upon the existence of a previously determined set of regulatory standards; allowance trading does not. Once the aggregate number of allowances is defined, they can, in principle, be allocated among sources in many different ways. The practical implication is that allowances can be used even in circumstances where a technology-based baseline either has not, or cannot, be established or where the control authority wished to allocate permits in some way other than historical, technology-based standards.[16]

Caps

The tendency for emissions trading systems to move over time from credit systems, such as the U.S. ETP, to allowance systems, such as the NBP and sulfur allowance systems, has another important implication. Allowance systems set a cap on aggregate emissions that is not eroded by the entrance of new emitters. This limit on aggregate emissions is not shared by traditional, technology-based, source-specific emissions standards or, in the absence of other constraints, by an emissions credit system that is linked to technology-based standards. Because emissions standards are source-specific, they exert no control over the aggregate amount of emissions from all sources. As the number of sources increases, the aggregate level of emissions increases. As a consequence, credit trading, which is based on these source-specific standards, will allow aggregate emissions increases unless additional constraints are built into the system.

In the United States, the additional constraint in the ETP was mandating offsets in nonattainment areas. Requiring that all new emitters secure sufficient credits from existing emitters so that air quality would improve as a result of their entering the area provides a cap on aggregate emissions. Since no such constraint was mandatory in attainment areas, credit trading provided no protection from emissions increases as the number of sources increased in those areas.

Shifting the Payoff

The demonstration that traditional regulatory policy was not cost-effective had two mirror-image implications. It either implied that the same air quality could be achieved at lower cost or that better air quality could be achieved at the same cost. While the earlier programs were designed to exploit the first implication, the later programs attempted to produce better air quality and lower costs.[17]

Trading programs were used to produce better air quality in many ways. The lower costs offered by trading were used in initial negotiations to secure somewhat more stringent pollution control targets (as in the Acid Rain Program and RECLAIM) or earlier deadlines (as in the Lead Phase-out Program). Offset ratios for trades in nonattainment areas were set at a ratio greater than 1, implying that a portion of each acquisition would go for better air quality. Environmental groups are allowed to purchase and retire allowances (Acid Rain Program).

This shift toward sharing the benefits between environmental improvement and cost reduction has had two consequences. The cost savings are smaller than they would have been without this benefit sharing, but the public support, and particularly the support from environmental organizations, probably has been increased a great deal.

Substituting for vs. Complementing Traditional Regulation

The earliest use of the tradable permit concept, the ETP, overlaid credit trading on an existing regulatory regime and was designed to facilitate implementation of that program. Trading baselines were determined on the basis of previously determined, technology-based standards and created credits could not be used to satisfy all of these standards. For some, the requisite technology had to be installed.

More recent programs, such as the Acid Rain and RECLAIM programs, replace, rather than complement, traditional regulation. Allowance allocations for these programs were not based on preexisting, technology-based standards. In the case of RECLAIM, the decadal declines were sufficiently large that the control authority (the South Coast Air Quality Management District) could not have based allowances on predetermined standards even if they had been inclined to do so. Defining a complete set of technologies that offered the necessary environmental improvement and yet were feasible in both an economic and engineering sense, proved a formidable, if not impossible, challenge. Traditional regulation was incapable of providing the huge degree of reduction within the deadlines required by the Clean Air Act.

The solution was to define a set of allowances that would meet the environmental objectives, leaving the choice of methods for living within the constraints imposed by those allowances up to the sources covered by the regulations. This approach fundamentally changed the nature of the control process. The historical approach involved making the control authority responsible not only for defining the environmental objectives and performing the monitoring and enforcement activities necessary to ensure compliance with those objectives, but it also was assigned the responsibility for defining the best means for reaching those objectives. Emissions trading transfers the last of these responsibilities to the private sector, while retaining for the public sector both the responsibility for defining the environmental target and monitoring and enforcing compliance with it.

The other major change, seen in the Clean Air Interstate Rule, is substituting a pre-approved cap-and-trade program for state-designed approaches that have to be included in the state implementation plan and ultimately approved on a case-by-case basis by EPA.

An Overview of the Book

Emissions trading certainly did not command an immediate constituency and building one was not easy. In the early days, even industrial sources, the most natural constituents in light of their potential cost savings and the flexibility of the program, were far from unanimous in their enthusiasm.

To some extent, industrial sources feared that this flexibility entailed greater risk. When an EPA-recommended technology failed to live up to standards, the source could claim that it had lived up to its responsibilities, so was blameless. When the control mix was up to the source, however, it would lose this defense. Similarly, by reducing emissions more than was required by law in order to gain emissions reduction credits, plants would alert control authorities to the fact that additional control was possible. Should control authorities use this information to revise the control baseline upward, similar plants under the same ownership would be adversely affected by the creation of the credits. Industrialists feared that they could end up losing more in the long run than they gained in the short run.

Industrialists were not the only constituency to have concerns about emissions trading. State authorities, which in the early U.S. program would bear the brunt of implementation, feared that the new programs would be more difficult to administer and saw them as a threatening departure from their comfortable, customary way of doing business. Environmentalists feared, and no doubt some industrialists hoped, that the program would open a large number of loopholes, leaving a legacy of reduced compliance.

Despite this opposition, emissions trading has now gained a firm foothold in environmental policy and is likely to continue to expand into new arenas for some time. Since so many ideas for policy reform have failed to come to fruition, it is natural to ask what sacrifices were made to place this type of program on the books. Compromise is, after all, the essence of most successful reforms. To what extent were the stated goals of emissions trading programs—increased cost effectiveness and increased speed of compliance—compromised as the price of initiating and maintaining the program?

Equally as important is the question of whether the expectations emanating from theory were unrealistically high when judged in retrospect by actual experience. Were costs minimized? Was the level of environmental protection effective and efficient? Was technical innovation in abatement technologies promoted?

The evidence on which the evaluation in this book is based is drawn from three different sources:

- Economic theory, the first source, is used to derive both market and optimality conditions for various market conditions and pollutant characteristics. It also is used to formalize the incentives present in various permit designs and show whether or not those incentives are compatible with the programmatic objectives.
- Ex ante computer simulations, the second source, flesh out the bare bones of theory. They provide a foundation for an investigation of the magnitude of the control cost differences between the command-and-control and emissions trading allocations, as well as for an identification of the sources of those differences. By incorporating the specific meteorological and source configuration characteristics unique to each region studied, computer simulations bring the general results of theory into sharper focus.
- The final source, actual emissions trading procedures and transactions, allows us to study in some detail how the programs have worked in practice.

The remainder of the book is divided into three parts. The first part, consisting of Chapters 2 and 3, lays the groundwork for the detailed analysis of specific program attributes that follow. Chapter 2 develops the theory behind the emissions trading program, and Chapter 3 estimates the magnitude of potential cost savings revealed by ex ante simulations and the actual results revealed by ex post evaluations.

The next portion of the book is concerned with evaluating the manner in which emissions trading programs have coped with a number of practical implementation problems. Chapters 4 and 5 open this section by examining the spatial and temporal dimensions of emissions trading. Since the initial allocation turns out to be one of the most politically volatile and important aspects of emissions trading, chapter 6 explores this issue in depth. The last two chapters in this section cover the potential for and consequences of market power (Chapter 7) and issues related to the monitoring and enforcement of emissions trading systems (Chapter 8).

The final chapter of the book, Chapter 9, weaves together the insights gained from the individual topic-by-topic examinations of the programs to form a comprehensive evaluation. This final chapter characterizes the state of the art and extracts lessons that might be drawn from this review.

Notes

1. For an extended bibliography of works that describe these various applications see: http://www.colby.edu/~thtieten/trade.html.

2. Setting an efficient goal would, of course, require that information. In practice, governments frequently have been satisfied with "reasonable" goals.

3. This national "credit" version of emissions trading subsequently has been adopted as a model for some state programs. For example, Michigan implemented its own version of this program on March 16, 1996. See that program's Web site at: http://www.michigan.gov/deq/0,1607,7-135-3310_4103_4194-10617—,00.html.

4. Early reductions were especially important in this case because, as the cost–benefit analysis persuasively demonstrated, the health consequences of ambient lead were severe, particularly on children.

5. Note that this approach does not require that both trading countries have implemented a transferable permit system. It does require both countries to adjust their production and consumption quotas assigned under the protocols to ensure that overall global limits on production and consumption are not affected by the trades. The European Union also implemented a tradable permits scheme for ozone-depleting chemicals. See Council Regulation (EEC) No. 594/91 of March 4, 1991, on substances that deplete the ozone layer, Official Journal of the European Communities, 14.3.91.

6. A number of smaller programs also were introduced during this time, including reformulated gasoline, heavy-duty truck emissions averaging, and the hazardous air pollutant early reduction program, among others. For a description of these programs, see Anderson (2001, Chapter 6).

7. The OTC states that participated in this initial trading program were Connecticut, Delaware, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and the District of Columbia.

8. The OTC states were joined in the NO_x State Implementation Plan call by Alabama, Illinois, Indiana, Kentucky, Michigan, North Carolina, Ohio, South Carolina, Tennessee, Virginia, and West Virginia on May 31, 2004.

9. The treaty was scheduled to go into effect only if two conditions were met: (1) at least 55 nations had to ratify the protocol; and (2) the ratifying nations had to account for at least 55% of total carbon equivalent emissions. The first condition proved easy to meet, but due to the failure of the United States, the largest emitter, to ratify the protocol, the second condition was met only when Russia ratified.

10. Details on this program can be obtained from its Web site at: http://europa.eu.int/comm/environment/climat/emission.htm

11. For new sources entering the program during or after 1998, 120% must be offset. This means new sources are required to buy 20% more emissions capacity than they would need. Because the extra 20% remains unused, it is a source of improved air quality.

12. Formally, it was defined as the product of emissions concentration (in mg/m^3) and maximum flow rate (in m^3/hour) of the gas exiting the source's stack.

13. Even a trade between two existing sources sharing common ownership required regulatory approval.

14. I am indebted to Denny Ellerman (MIT) for pointing this out to me.

15. In a futures market, buyers can acquire allowances for a specified future date (say five years hence) at a current market-determined price. Enabling sources to plan ahead by fixing the future allowance price now reduces the risk of price fluctuations and uncertainty about the effects of abatement investments.

16. This was an important source of flexibility for the initial allocation under the Sulfur Allowance Program, as Raymond (2003) points out.

17. One interesting analysis examines the cost and emissions savings from implementing an emissions trading system for light-duty vehicles in California. In that study, Kling (1994a) finds that although the cost savings from implementing an emissions trading program (holding emissions constant) would be modest (on the order of 1% to 10%), the emissions savings possibilities (holding costs constant) would be much larger (ranging from 7% to 65%).

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