Chapter 2

Markets for Tradable Carbon Dioxide Emission Quotas: Principles and Practice

Graciela Chichilnisky
Geoffrey Heal

2.1 Introduction

This chapter reviews a range of issues relating to tradable carbon dioxide (CO_2) emission quotas (TEQs). It considers the economic principles on which they are based, compares them with alternative carbon abatement policies, and reviews many aspects of how tradable quotas would be implemented in practice.

Section 2.2 sets the scene, explaining why these issues are on the agenda and how they relate to current issues, such as joint implementation.

The principal alternative to a TEQ regime is the adoption of carbon taxes. Section 2.3 compares salient aspects of the two policy approaches. It also analyzes how they can be combined. Section 2.4 studies a particular and very important aspect of a TEQ regime: the allocation of TEQs among participating countries. These two sections present the key theoretical perspectives on tradable quotas and their main alternative: carbon taxes. Section 2.5 addresses issues connected with the implementation of TEQs, analyzing questions associated with the design and management of a TEQ market.

2.2 The Context of the OECD Discussion

The 1992 Earth Summit in Rio de Janeiro set important goals for the control of the planet's greenhouse gas emissions. Annex 1 countries[1] agreed to roll

[1] Annex 1 countries include the main industrial countries, including the OECD, the former Soviet Union, and the Eastern European members of the former Soviet bloc.

back their emissions to their 1990 levels by the year 2000. Certain institutions share the responsibility for devising policies to implement these goals. These institutions include the Global Environment Facility and primarily the UN Framework Conventions on Climate Change (FCCC), on Biodiversity, and more recently on Desertification.

Industrial and developing countries have rather different perceptions of the issues involved, and these differences are to a certain extent limiting progress in international negotiations. Developing countries fear the imposition of limits to their growth in the form of restrictions on emissions, and therefore on energy use, and more generally on the use of their own resources. They feel that most environmental damage originates currently, and has originated historically, in the industrial countries, whose use of energy and patterns of development are at the root of the environmental dilemmas we face today.

Industrial countries have a different set of concerns. They fear excessive population growth in developing countries and the environmental damage that this could bring about. While recognizing their historical responsibility for excessive environmental use, industrial nations focus on a long-term future in which environmental problems could originate mostly in the developing countries.

In addition to differences in perceptions, scientific understanding of some of the main issues has emerged only recently. Newly found science makes its way slowly into the political decision process because by nature science is highly specialized and is often tentative in its conclusions. The differences in perceptions and the failure to communicate recent scientific findings have hampered the international decision-making process.

2.3 The Economics of the Global Environment

The implementation of the Rio goals of stabilizing emissions at levels not harmful to the climate requires substantial conceptual advances in our understanding of some of the main issues as well as the development of a consensus about the possible policy instruments for tackling these issues. This is not an easy task because the problems of climate change, sustainable development, and protection of biodiversity are all rather new, global in nature, and complex. The economics of climate change involves challenging issues related to economic principles and policies, including the following:

1. The connections among energy use, energy prices, trade, and growth
2. The optimal distribution of quotas to emit greenhouse gases between

countries (As we argue here, the distribution of quotas is not a matter to be judged only on the grounds of equity but can have substantial implications for efficiency.)

3. The conditions that are necessary for carbon taxes to act efficiently
4. The connections among levels of income, optimal property rights, and trading practices in such markets
5. The design of cooperative international policies for the abatement of emissions of greenhouse gases as provided by Clause 4 of the Rio convention

In addition to requiring extensive technical work,[2] implementing the Rio targets requires a deliberate effort on the part of all parties involved to communicate and to understand one another's concerns, to address in depth and critically the problems and the possible solutions, and to reach consensus.

2.3.1 The Present Practice — Joint implementation is a term that is frequently used to describe a cooperative venture between two or more countries to decrease the sum total of their emissions of greenhouse gases. Its origins can be traced to Clause 4 of the Rio convention, which specifically contemplates this possibility. The experience to date has been of relatively small projects involving five countries. One is an agreement involving Norway and Mexico, funded mostly by the Global Environment Facility (GEF). Mexico initiated an effort to replace small electric appliances, such as light bulbs, in a manner that diminishes energy use and carbon emissions. A second project involves the Netherlands in cooperation with Poland and India. Here Poland aims at replacing its use of coal in energy production by natural gas, thereby decreasing its carbon emissions.

In both of these examples, the nature of the cooperation is a bargain between an industrialized country and one or two less developed countries (members of Annex 2 of the Rio protocol), by which the former, in cooperation with the GEF, "purchases" its right to continue its current emission practices through ensuring decreased emissions from the developing countries. The Annex 1 country is credited with an emission reduction that it brought about even though this did not occur on its territory. The experience to date suggests several policy issues that have been the subject of discussion in the FCCC.

[2]These are issues on which recent research at Columbia University and at Stanford University has made much progress (Chichilnisky [3–5], Heal [12–14], Chichilnisky and Heal [2,7], and Chichilnisky, Heal, and Starrett [10]), reflected in the chapters of this book.

2.3.2 The Potential of Joint Implementation — The first, most obvious issue is the effectiveness of joint implementation if taken to its natural conclusion: the purchase by industrialized countries (Annex 1 countries) of rights to continue present emission practices by ensuring decreased emissions from developing countries (Annex 2 countries). Developing countries currently emit at most 30% of the world carbon emissions. Therefore if the aim is to decrease world emissions by, for example, 60% of long-run future emissions, as is often proposed, then even a complete cessation of carbon emissions by all developing countries would at best barely attain this goal. Thus abatement of the type contemplated at present requires active decreases in carbon emissions by industrial countries, which are the main emitters. Joint implementation of the type described here cannot be a substitute.

An argument in favor of joint implementation is that it can lead to improvements in the positions of all the countries engaged in the bargain. This argument is supported by the evidence that the bargain is freely agreed among the countries involved. If countries do not stand to gain, why would they enter the deal? These arguments are correct within a restricted institutional framework but fail to provide a thorough analysis of the situation. What is chosen depends on the alternatives available. A bargain might be better than no bargain at all, but it could be worse than other, alternative bargains that were not within the scope of discussion. With more information about the alternatives available, a country can typically improve its trading position. Indeed the most frequently voiced concern about joint implementation is that a few countries could "steal the march" on others by taking advantage of a thin market with little information. All this is simply a restatement of a well-known fact: Efficient trading requires well-distributed information among all the traders. It also requires competitive trading, which in turn is a function of the number of traders. Two traders typically do not make a competitive market. These two principles, market information and market depth, are widely applied in most well-organized markets across the world and are associated with market efficiency. This leads us naturally to consider a multilateral extension of joint implementation, a framework in which trading is conducted with well-distributed information flows and in which market depth can be achieved through the simultaneous participation of all countries.

2.3.3 A Migration Path to Multilateral Trading? — From the previous remarks emerges another argument in favor of joint implementation. The joint ventures, or "bilateral trading" practices, that characterize joint implementation so far can be viewed as the first step in the development of a well-organized, multilateral market. It is often the case that bilateral trading precedes and leads to multilateral trading. Examples are provided by the Chicago commodity markets and by the Lloyds of London insurance market, both of which started with informal bilateral trading among a few parties. Thus, the challenge is to build a well-defined institutional structure of which joint implementation represents a first developmental step. This requires the construction of a multilateral organization with the clear understanding that today's bilateral joint implementation ventures are to provide data and knowledge about how the multilateral organization will work. The eventual aim is to develop an organization in which countries can achieve an efficient allocation of their resources through decentralized trading by means of well-organized and efficient mechanisms.

2.3.4 Tradable Quotas — A natural multilateral trading organization is a market in which entitlements or quotas to emit greenhouse gases are traded. Such a market has a venerable tradition in economics. At present there are three examples of similar markets in the United States. A sulfur dioxide (SO_2) entitlement market has been trading since the early 1990s on the Chicago Board of Trade. For trading to be possible, property rights must be established. In this case the property rights were established by the Clean Air Act, which restricted the emission rights of the major utilities in the United States. At present trading is conducted mostly between these utilities. Recently, new markets have opened up, as futures and swaps on these quotas have been introduced. These markets are called *derivative* because they trade contracts whose values depend on (are derived from) the value of an underlying asset, in this case quotas to emit. Thus, the prices on these contracts and the gains and losses from trade are derived from the expected prices of the quotas. An electric utility company trades futures because it wants to plan effectively the costs of a projected expansion or reduction of its output, and this will require different quotas from those it holds at present. The next section explains how such markets work to correct externalities and how they can be used to induce a reduction of greenhouse gas emissions domestically and globally.

2.4 Tradable Quotas and Emission Taxes

2.4.1 The Pigou and Coase Traditions — The problem of global climate change addressed by the Rio convention is a classic case of large-scale negative external effects, that is, harmful effects of one party on another that are external to and thus not mediated by the market mechanism. By the emission of CO_2, a country increases the risk faced by all countries, itself included, of a harmful change in climate, thus the existence of a negative external effect. There are two principal approaches to the control and correction of external effects: control and correction through taxes and subsidies, in the tradition established by Pigou [16], and control and correction through the introduction of property rights, as suggested by Coase [3].

Pigou described externalities as stemming from differences between the private and the social costs of an activity. In his vision these differences between private and social costs were to be corrected by taxes or subsidies that alter the private cost of the activity until it equals the social cost. After correction one has the relationship

$$\text{private cost} + \text{tax} = \text{social cost.}$$

Thus, in the case of CO_2 emission, there is a private cost given by the costs of the fuel burned. The social costs include, in addition to the fuel costs, the costs of an increased likelihood of harmful climate change. A Pigovian corrective tax, when added to the private cost, will bring it into line with the social cost.

On the other hand, Coase focused on the fact that goods and services can only be bought and sold and thus brought within the orbit of the market mechanism if they can be owned. Ownership of a good or service means that people can have property rights in these. Coase then saw externalities as arising from an absence of property rights, and, as a consequence, certain economically important goods and services could not be bought or sold and their provision regulated by the market. Thus, in particular the market could not ensure their provision at an efficient level. The natural policy prescription from this perspective is the introduction of property rights for the goods for which they are missing, so that these goods can be traded and their provision regulated by the market. The application of this view to climate change indicates that the services of the atmosphere are being used in the combustion of carbon-based fuels as a depository for CO_2. This happens in a legal framework in which there are no property rights in the atmosphere and thus no opportunity for people to register a demand for it to be left unaltered. In contrast there are property rights over the ground, so that this cannot be used as a depository for waste without permission from the owner, which normally requires payment. Coase's insight is that we need to mimic this situation with respect to access to the atmosphere.

Pigou's insight has given rise to the dominant European policy approach in this field, namely, the use of corrective taxes and subsidies: Coase's has inspired the American approach of tradable permits and quotas, as used in the United States for sulfur dioxide, lead additives, and water discharge rights. The key point in this approach is that before emitting a pollutant into the atmosphere, a firm must own the right to effect such an emission, and such a right is conveyed by the purchase of a TEQ. The creation of these quotas establishes property rights in the atmosphere. If a firm is forced to buy a quota before emitting a pollutant, then, in Pigovian terms, this also raises the private cost of pollution, in this case by the cost of the quota. Once again marginal private costs are changed so that they approach marginal social costs. In fact, in a competitive quota market they will be equated exactly to marginal social costs by the inclusion of the costs of buying quotas.

The two approaches are formally equivalent in important ways, although not in all ways. A tradable quota system requires a polluter to buy a permit before polluting, and this raises the private cost of pollution by an amount equal to the price of the permit. In this respect it appears to the polluter like a tax, as it imposes a tax equal to the price of a permit. Both approaches are consistent with the "polluter pays" principle, which has been adopted by the OECD. Compliance with this is widely viewed as a prerequisite for fairness in the management of pollution. However, from the perspective of the policymaker, there are differences associated with where the main policy uncertainties arise, and we explore these here. There are also differences in the role of the government in each system, as government plays a more central role and of course raises revenue under a tax regime.

2.4.2 Historical Experience and Intellectual Traditions — The different intellectual traditions noted previously lead to different policy regimes, and it is clear that these different intellectual traditions have colored in different ways the policy choices of Europe and the United States.

The Coasian tradition emerged from the University of Chicago, an institution whose influence on economic policy formulation in the United States in the last 20 years has been profound and far-reaching. Thus, the United States has experimented extensively with TEQs in several areas, including the management of SO_2 emissions, management of the distribution of lead additives to vehicle fuels, and management of various emissions in the urban areas of northern and southern California. The United States finds this approach consistent with the prevailing market-oriented approach to economic policy. By the same token tax-based policies have been anathema to a political climate strongly predisposed against taxes, as illustrated by the rapid demise of the Clinton Administration's BTU tax proposal.

In Europe the tradition is quite different. The Pigovian tradition emerged from Cambridge University and is also fully consistent with the French tradition in public economics and economic policy. At the same time most European governments have historically had no natural affinity for market-based approaches to pollution management, having perceived markets as part of the problem rather than as part of the solution. Thus, the concept of a tradable emission quota regime has been less familiar in Europe; rather, the approach that has risen naturally to the top of the agenda is a policy based on carbon taxes.

2.4.3 Uncertainty about Cost-Benefit Relations — One of the main differences between tradable quotas and emission taxes is in the degree of assurance that they offer to the policymaker about the aggregate level of pollution. The point here is simple yet important. It is as follows. With a system of tradable quotas, the aggregate level of pollution is determined to be the total number of quotas issued. If quotas are issued for the emission of, for example, 6 billion tons of carbon dioxide, then, if the system is enforced, the total of emissions will not exceed 6 billion tons. This much the policymaker can be sure of in advance: The total amount of pollution is predictable. However, there is an important aspect of the policy that is not known to her, namely, the cost to polluters of the regulation of emissions to the specified level as measured by the price of an emission quota. This price will be determined by the forces of supply and demand and cannot in general be predicted with any accuracy.

Contrast this with the situation with a pollution tax in which the cost to the polluter is now known with certainty and is of course given by the tax. However, the aggregate amount of pollution cannot be predicted. This will now be determined in the market by the forces of supply and demand. To be precise it will be determined for each firm at the level at which the marginal abatement cost equals the tax on pollution.

With quotas the policymaker is sure in advance of the aggregate amount of pollution that will result from her intervention but is unsure of the resulting costs to industry and commerce. With taxes matters are exactly the opposite: The costs to polluters of policy are known, but the results, in terms of pollution levels, are not. This is a key difference, a key duality,[3] in that in situations of great political sensitivity, knowing the cost of policy intervention to industry and commerce might be essential. This is an argument for taxes. In situations of great sensitivity of the environment to pollution, knowing the aggregate

---

[3]This duality was first studied by Weitzman [19]. See also Dasgupta and Heal, chapter 13 [11].

level of pollution that will result from a policy might be essential. This is an argument for TEQs.

Threshold Effects

Consider a situation in which the effect of a pollutant on the environment is reversible up to a certain threshold level of pollution that we denote L and is irreversible after that. One can think of many examples. Water bodies can cleanse themselves, provided that they are not "too polluted," but they cannot cleanse themselves if pollution exceeds a certain level. Threatened species can reestablish themselves, provided that their stock is not "too low," but if their stock falls below this level, they are doomed to extinction. Ocean currents and the climates that depend on them remain essentially the same provided that changes in atmospheric temperatures are not "too large," but they can change in a major way if the temperature change exceeds a critical amount.

In each of these cases, there is a level of pollution below which the consequences of pollution are reversible and above which they are not and there is a permanent loss of an environmental asset. It is this threshold level that L denotes. In such situations there is a premium on not exceeding L: The costs of pollution increase sharply beyond L. In such situations there is a strong argument in favor of TEQs, for these can provide the assurance that the aggregate level of pollution will not exceed L. One does this simply by issuing a total of permits that does not exceed L. The only way to reach such assurances with pollution taxes would be to consider the range of all possible marginal emission costs and to pick a tax level that ensures pollution of less than L for any possible marginal emission abatement costs.[4] If the uncertainty about possible marginal abatement cost schedules is great, such a tax might be far greater than is actually needed. In contrast the tax implied by tradable quotas—the price of a quota when the total number of quotas is L—will be exactly the least needed to ensure aggregate pollution less than L.

In many contexts this might be an important consideration in favor of TEQs, as they guarantee that pollution will be within some predetermined limit. There is considerable scientific evidence of threshold effects in the damage that results from many pollutants. All of the previous examples have a real scientific basis.

[4] High marginal abatement costs imply high pollution levels for any given pollution tax, as the alternative to paying the tax is cutting back pollution and paying the marginal abatement cost.

Although there are believed to be threshold effects in the relationship between atmospheric CO_2 concentration and climate change, these thresholds are a function of the *stock,* not of the *flow,* of CO_2 into the atmosphere. This means that they depend on cumulative emissions to date and not on the current level of emissions. Cumulative emissions change only rather slowly, and this reduces the importance of the threshold argument in the case of greenhouse gases.

2.4.4 Option Values — The capacity to implement abatement policies in a manner that respects thresholds and so avoids irreversible changes in the physical environment of human societies is an important one in the context of environmental problems in which threshold effects matter. The nature of this importance bears further examination. A key issue here is that we often, indeed usually, do not know how important it is to avoid a change in the environment. For example, we do not know the importance of avoiding major climate changes, nor do we know the importance of preserving certain types of species. Of course we have some ideas, but they are not at all precise, and often they are the subject of disagreement and dispute. Presumably, we will learn more about these as time passes. A quarter of a century hence, our research and experience might have led us to a much better grasp of these issues. In this case it is intuitive that there is a lot to be said for keeping matters as they are until we do know the consequences of a change.

This intuitive point can be formalized in the concept of an "option value" associated with preserving environments as they are.[5] Preserving an environment, say, for 10 years gives us the right and the ability but not of course the obligation to continue preserving it for longer after that. If in 10 years we understand better the consequences of a change, then at that time we can reconsider the preservation issue in the light of better information. Not preserving the environment, irreversibly altering it now, takes away this possibility, the possibility of reviewing our choice in the light of better information. Thus, if we are going to learn more about the importance of environment to society in the future, preserving environments until we have done that learning gives us the possibility of making better-informed long-run preservation decisions. Preservation lets us make a choice when we know more about the possible consequences, and clearly there is a value to this.

The term *option value* is used to refer to this phenomenon because there is the same structure here as is associated with buying an option to purchase

---

[5] These issues were formalized by Arrow and Fisher [1] and by Henry [15]. This literature is reviewed in Dasgupta and Heal [11] and Chichilnisky and Heal [8].

a security. That option gives you the right, but not the obligation, to buy the security in the future when you have more information about its value. Any policy that maintains the environment, and specifically the climate regime, in its present status quo has to be credited with the corresponding option value. Thus, the existence of the option value is an argument in favor of a conservative environmental policy. In the climate context two conditions are necessary for the option value to be significant: first, that more information about the value of avoiding climate change should become available over time and, second, that climate changes should be irreversible. Both of these conditions appear to be satisfied.

2.4.5 Uncertainty about Future Regulations — A key aspect of CO_2 emission and global climate change is that scientific understanding of this phenomenon is continuously evolving. More is known now than 10 years ago, and the next 10 to 20 years will unquestionably bring even bigger changes. The problems of global climate change might come to be seen as much more or much less threatening than currently. As a consequence of such changes in scientific understanding, the tightness of CO_2 emission regulations will change, becoming more restrictive if the consequences of CO_2 emission are found to be more serious and vice versa.

It follows that there is inevitably uncertainty about the tightness of future regulatory policies with respect to CO_2 emissions. This uncertainty has a cost to firms. For example, when deciding whether to select a technology less intensive in CO_2, a firm will base its decision on the expected costs of CO_2 emission over the life of the project. A utility choosing between oil, gas, and nuclear will make a forecast of the costs of CO_2 emission over the 20- to 30-year life of the project as measured by the costs of tradable CO_2 emission permits or the likely level of CO_2 taxes. In doing so it will recognize the risk of anticipating incorrectly the costs of CO_2 emission and will want to hedge or insure the attendant risk of making the wrong technological choice. An example of such a risk is the risk of selecting a non-carbon-based energy source on the assumption that restrictive emission policies will force up the costs of CO_2 emissions and then finding that in fact a carbon-based energy source is the least expensive and that competitors who have chosen that alternative have lower costs.

An advantage of TEQs relative to carbon taxes is that they can naturally be developed in a way that facilitates hedging this kind of risk. Hedging could occur through the trading of derivatives, such as futures or options on TEQs, a possibility mentioned in previous sections. To elaborate, if a utility anticipates a sharp increase in the costs of CO_2 emission, it will choose the energy source that is least intensive in CO_2 emissions. This exposes it to the risk that scientific research will reveal CO_2 accumulation in the atmosphere to be less threatening than previously believed, with a consequent increase in the number of TEQs issued by regulators and a drop in their price. To offset the risk of being "wrong footed" in this way, the utility would either sell TEQs forward, or buy put options on them. In either event it would profit from a drop in quota prices, and this profit would in some degree offset the costs incurred unnecessarily by the selection of the least CO_2-intensive technology. In the Chicago market for SO_2 emission quotas, utilities have already demonstrated their ability to use such strategies.

2.4.6 Taxes and Quotas: Alternatives or Complements? — Although tradable permits and carbon taxes are generally viewed as the main alternatives in the management of global CO_2 emissions, they are in fact not antithetical. They can be combined in several ways.

Mixed Domestic Policy Regimes

In certain cases a country could find it attractive to employ a mixture of the two approaches. It could have a regime of tradable CO_2 emission quotas but allow firms to emit more than the CO_2 quotas that they hold in exchange for the payment of a tax on each unit of emission in excess of the quotas owned by the firm. For example, if a firm owned quotas to emit 100,000 tons of CO_2 and in fact produces 120,000, then it might be allowed to pay a tax on the 20,000 units by which its emission of CO_2 exceeds the quotas in its possession. In such a regime a firm finding its quota allocation too restrictive would have three options:

1. Reduce emissions
2. Buy more quotas
3. Pay a tax on emission in excess of the quotas possessed

It would choose the least costly option. This clearly implies that the market price of a quota would never exceed the tax rate, for if it did there would be no demand for quotas. One could always achieve the same effect as buying a quota by paying a tax, so that at quota prices above the tax rate there would be no buyers. Thus, the tax rate sets an upper bound on the market price of a TEQ. By setting a tax rate, the regulator bounds the costs to firms of its regulatory policies. This could reduce one of the main disadvantages of a tradable quota regime, namely, the unpredictability of the costs to firms, but at the cost reducing its main advantage, namely, the predictability of the total level of CO_2 emissions. To the extent that a firm can supplement its TEQs by paying taxes, it can in effect create new quotas, making total emissions less predictable.

In a situation in which there is a need for a cap on the cost to industry of a regulatory policy and in which there is also a need for some predictability of the total level of emissions, this mixed system might have a valuable role to play.

Quotas Internationally, Taxes Domestically

Another possible combination of the two approaches is to allocate tradable quotas to countries that can trade them internationally to alter their total allocations of emission quotas and then have countries enforce the given total emission levels domestically either by tax or by command-and-control regimes. In such a system a country that is allocated quotas to allow it to emit 500 million tons of CO_2 might purchase additional emission quotas to bring its total allocation up to 550 million and then implement the national target of 550 million tons domestically by any means it chooses. Of course the commitment to emit no more than 550 million tons would, as already discussed, probably be implemented most accurately by a domestic tradable quota regime, but in principle any domestic policy regime is possible.

2.5 Quotas: Distribution and Efficiency

To introduce a regime of TEQs, we have to create property rights where none previously existed. These property rights must then be allocated to countries participating in the CO_2 abatement program in the form of TEQs. Such quotas have a market value, perhaps a very great one. Thus, the creation and distribution of quotas is potentially a major redistribution of wealth internationally. This of course means that it is economically and politically important, and it is important to understand fully the issues that underlie an evaluation of alternative ways of distributing emission quotas. A clear precedent for this redistributive effect of the introduction of property rights at the international level can be seen in the Law of the Sea conference and the introduction of 200-mile territorial limits in the waters off a nation's coast. The introduction of 200-mile limits established national property rights where none previously existed, and these rights could be and frequently were distributed by governments to domestic firms. The introduction of these property rights in offshore waters effected a very substantial redistribution of wealth internationally.

Clearly, the aim of a TEQ regime is to alter consumption and production patterns internationally. Any policy that is designed to alter global consumption patterns will affect the levels and distribution of consumption. This is especially true in the case of carbon taxes and in the assignment and trading of emission quotas, as both aim at restricting the use of energy, and energy is essential in the production of all goods and services. There is no way to restrict countries' emissions without altering their energy use and so without altering their production and consumption patterns. Thus, the implementation of measures to decrease carbon emissions will have a significant impact on the ability of different groups and countries to produce goods and services for their own consumption and for trade, and the distributional impact of such policy is a matter of major import. This makes their analysis especially difficult because distributional considerations are typically the ones on which consensus is often most difficult to achieve.

The allocation of the world's finite resources among individuals or groups is a central issue in economics, and indeed by itself it practically defines the subject. Market allocations are often recommended on the basis of their efficiency. This means that it is not possible to reallocate resources away from a market-clearing allocation without making someone worse off: There is no slack in the system. Market efficiency requires three key properties of markets:

1. Markets must be competitive.
2. There must be no external effects; that is, in the Pigovian terminology private and social costs must be equal, and in the Coasian there must be property rights in the environment.
3. The goods produced and traded must be private goods, namely, goods whose consumption is rival in the sense that what one person consumes cannot also be consumed by others.

In such markets the outcome is efficient no matter who owns what; that is, the efficiency of a market allocation is independent of the assignment of property rights. Ownership patterns are of great interest for welfare reasons, and different ownership patterns lead to different efficient allocations at which traders achieve different levels of consumption and which are characterized by different distributions of income. However, ownership patterns are of no interest for market efficiency as defined here. The efficiency of the market under these conditions, independently of distribution, is a crucial property that underlies the organizations of most modern societies.

Yet the efficiency properties that make the market so valuable for the allocation of private goods may fail when the goods are public in nature. With such goods it is not possible to separate efficiency from distribution. A good is called *public* when its consumption is not rival, that is, when, to the contrary, what one person consumes is necessarily the same as what all others consume. The atmospheric concentration of CO_2 is a quintessential public good in that it is the same for all of us—we all consume the same amount.[6] Classic examples of public goods are law and order and defense. If these are provided for one member of a community, then they are provided for all.

The public good nature of the atmospheric CO_2 is a physical fact that is derived from the tendency of CO_2 to mix thoroughly and stably. This fact is completely independent of any economic or legal institutions. We can tax emissions or assign rights to emit gases and decide how these can be traded, but nothing changes the physical fact that the atmosphere is a public good. This simple physical fact has profound implications for the efficiency of market allocations. It changes matters to the extent that efficiency and distribution are no longer divorced as they are in economies with private goods. They are in fact closely associated. In economies with public goods, market solutions are efficient only with the appropriate distributions of initial property rights. Why?

It seems useful to argue by analogy, thinking of the market with a public good as far as possible as a market with private goods and checking where the analogy breaks down. This gives us a good idea of the connection between efficiency and distribution in economies with public goods.

A market's operation requires that each trader have a well-defined initial endowments of goods: the traders' *property rights*. This is the same with or without public goods. For example, the property rights in the atmosphere are the trader's assigned rights to use it as a sink for the emission of greenhouse gases. Traders produce and trade goods freely so as to maximize the utility of consumption; the trading activity continues until a market-clearing allocation is reached. Up to this point the analogy between markets with private and those with public goods holds in every sense. However, it breaks down at a crucial point, as market-clearing allocations with public goods can be shown to have very different properties from their private counterparts. This can be seen as follows.

When all goods are private, one expects that different traders will typically end up with different amounts of goods at a market-clearing equilibrium on

---

[6] Atmospheric CO_2 is an unusual public good in that it is produced privately, unlike centrally produced services, such as defense and law and order. Carbon dioxide is produced by the actions of individuals and firms in choosing the fuels that they use and the amounts that they use. Although we all consume the same atmospheric concentration of CO_2, the implications of this concentration differ from country to country, depending on exposure to the harmful effects of climate change. This does not mean that CO_2 concentrations is not a public good; rather, it means that different countries value this public good differently.

account of their different tastes and endowments. This is indeed the case, and the flexibility of the market in assigning different bundles of goods to different traders is crucial in its ability to reach efficient solutions because, for efficiency, traders with different preferences should nevertheless reach consumption levels at which relative prices between any two goods equal the marginal rate of substitution between those goods *for every trader* and also equal the rate of transformation between the two goods *for every producer.* This is an enormous task to achieve, and it is the decentralized power of markets that must be credited with this coincidence of values at a market-clearing allocation.

However, when one good is public, a physical constraint emerges. All traders, no matter how different, must consume the same quantity of this good, not by choice but by physical laws. It is not possible for traders to consume different atmospheric qualities, even if they want to and even if our economic and legal institutions would allow it. The quality of the planet's atmosphere is one and the same for all traders. This imposes an additional constraint, a restriction that does not exist in markets in which all goods are private. Because of this restriction, some of the adjustments needed to reach an efficient equilibrium are no longer available in markets with public goods.

The number of instruments used by the market to reach an efficient solution, namely, the goods' prices and the quantities consumed by all traders, are the same with private or public goods. However, with a public good these instruments must now perform an additional task. At a market equilibrium the quantities of the public good demanded independently by each trader must be the same no matter how different the traders are. In addition to equalizing prices to every trader's marginal rates of substitution and transformation, one more condition must now be met: The sum of the marginal rates of substitution between the public good and all private goods across all traders must equal the rate of transformation. This condition emerges from the simple observation that one additional unit of the public good produced benefits each and every trader simultaneously. Thus, the physical requirement of equal consumption by all introduces a fundamental difference between efficiency with public goods and efficiency with private goods. All this must be achieved by the market in a decentralized fashion. Traders must still be able to choose freely, maximizing their individual utilities. In other words, with public goods the market must perform one more task.[7]

An additional task calls for additional instruments. Because the market with

---

[7] Afficionados of economic theory will note that a Lindahl equilibrium provides extra instruments for this task, namely, extra prices, by considering "personalized prices" for public goods. Redistribution of endowments can substitute for the extra prices in a Lindahl equilibrium, as is shown in chapter 3 of this book.

private goods has precisely as many instruments as tasks, with public goods new instruments must be enlisted. Some of the economy's characteristics can now be adjusted to meet the new goals. The traders' property rights on the public good, or their rights to emit gases into the atmosphere, are a natural instrument for this purpose because they are in principle free and undefined until the environmental policy is considered. By treating the allocations of the atmosphere's quotas as an instrument (i.e., by varying the distribution of property rights on the atmosphere), it is generally possible to achieve not only a market-clearing solution but also one by which traders choose freely to consume exactly the same amount of the public good. With public goods market efficiency can be achieved, but only with the appropriate distribution of property rights.

2.5.1 Quota Allocations: North-South Aspects — The physical constraint imposed by the public good is felt most acutely when traders have rather different tastes and endowments. Tastes are often difficult to measure, but differences in endowments are measured readily, as national accounts provide often an adequate approximation. Income differences are very pronounced in the world economy, so that one might expect that the public good problem will have a major effect on market efficiency.

For simplicity one can divide the world into a North and a South, the industrial and the developing countries, respectively. It is fairly obvious that endowments of private goods are much larger in the North than they are in the South; in a competitive market with private goods, this naturally leads to very different patterns of consumption and is likely to emphasize the importance of distributional considerations. Thus, the North-South dimension of CO_2 abatement is likely to be an important aspect in the evaluation of environmental policy. Although this point is widely understood in the context of political negotiations between industrial and developing countries, it has not been clear until recently that the political arguments have in fact an analytical underpinning. Not only are distributional issues fundamental to achieving political goodwill and to building consensus, but, because of the properties of markets with public goods, distributional issues are also fundamental in the design of policies that aim at market efficiency. Market efficiency is crucial in reaching political consensus, as negotiations often advance by producing solutions that are potentially favorable to all. Proposing an inefficient solution means neglecting potential avenues to consensus. This can be a strategic mistake in negotiations in which the achievement of consensus is key.

2.5.2 The Distribution of Quotas among Countries — From the previous arguments it follows that a judicious allocation of quotas among countries must not be viewed solely as a politically expedient measure designed to facilitate consensus. Nor should it be viewed as an attempt to reach fair outcomes at the expense of efficiency or, at least, independently of efficiency. The appropriate allocation of quotas within a given world total of emissions is an instrument for ensuring that competitive markets can reach efficient allocations. The fact that it plays this role derives from the physical constraints that a public good imposes on market functioning. However, what remains to be determined is the particular distribution of quotas that is needed to ensure that the market solution will be efficient. Distributional issues are delicate points in any negotiation and the fact that market efficiency is involved makes the point apparently more complex. However, in reality it can be seen to improve the dynamics of the negotiation process. The reason is that the connection between distribution and efficiency means that an argument about distribution is not a zero sum game, as it would be if all that were involved were the division of a fixed total between competing parties. Because some distributions of quotas are efficient and others are not, some lead to a greater total welfare than others and thus an opportunity for all to gain relative to the other, inefficient distributions.[8] Here we give a conceptual overview of the problem: For applications one needs in additions an analytical framework for computing solutions in each specific case. The latter requires further scientific studies.

Under certain minimal conditions a general recommendation can be reached. We will work under the assumption that all countries have generally similar preferences for private goods and for environmental assets if they have comparable levels of income.[9] This is of course consistent with different trade-offs between private and environmental consumption in countries that are at different levels of income. A second standard assumption is that the marginal utility of consumption decreases with the level of income. This simply means that an additional unit of consumption increases utility less at higher levels of consumption than it does at lower levels: Adding one dollar's worth of consumption to a person with meager resources increases the person's well-being more than adding one dollar's worth to the consumption of a wealthy individual. We assume also that all countries have access to similar technologies and that their productive capacities differ only as a consequence of differences in capital

---

[8]Although we cannot develop this point here, this is true even in a strictly second-best context in which the total emission level being distributed between countries is not one associated with an efficient pattern of resource use overall. In fact, of course, the connection between efficiency and distribution has long been known to be close in the context of second-best policy choices. See chapter 4.

[9]By this we mean only that their income and price elasticities of demand are of the same order of magnitude. We are ruling out radically different valuations of private goods and the environment.

stocks. Under these assumptions an efficient allocation of tradable quotas will require that poor countries be given quotas in excess of their current emission and that rich countries get quotas less than their current emissions.

The previous remarks imply that the allocation of quotas might have to favor developing countries proportionately more than industrial countries if we seek market efficiency. This holds true for any total target level of emissions. However, it seems reasonable to inquire more generally if there is a connection between the distribution of income and the efficient level of emissions reached. To answer this question one must consider one more fact about preferences between private and public goods: that environmental assets are *normal* goods. This is entirely reasonable, as it means that the amount that one is willing to spend on environmental amenities or assets increases with the level of one's income: The more we earn, the more we spend on every normal good, including of course on environmental goods.

The final general condition invoked by our analysis requires perhaps more thought. It is that environmental assets are *necessary* goods. This simply means that whereas the total amount spent on environmental assets increases with the level of income, the *proportion* of income a person is willing to spend on environmental assets increases as the income level drops. This assumption has been corroborated empirically in every known study in the United States, Europe, and Africa, although such studies typically involve contingent valuation techniques, which can have weaknesses.[10] The assumption can be theoretically justified on the grounds that lower-income people are more vulnerable to their environment than are higher-income people. The latter can afford to choose or modify their environment, whereas the former cannot. For example, public parks or access to potable water are environmental assets that have relatively more value to lower-income people than they do to those who can afford to build their own parks or arrange their own water access. Humans in lower-income countries are known to be more vulnerable to the effects of global warming than those in higher-income countries. Thus, we propose a plausible formulation of a fact that has been established with remarkable regularity in all known empirical studies, namely, that the income elasticity of demand for environmental assets is between zero and one.

From these facts it is possible to establish that a redistribution of income toward lower-income individuals or countries will generally lead to an improvement in the world's emission levels and in the world's level of environ-

[10]This has now been documented in a large number of studies in many different countries. A good reference is a paper by Kristrom [16].

mental preservation. This is because when preferences are similar and the income elasticity of demand is less than one, a redistribution of income in favor of lower-income groups implies that relatively more income will be allocated to the environmental asset. If traders choose freely, they will choose more preservation. In our case higher abatement levels are to be expected when more resources are assigned to the lower-income groups of countries.

However, there is another factor that must be considered. Developing countries could be less efficient in terms of energy use and thus lead to more emissions as they grow. This is certainly an important concern for the long-run future, that is, 50 years or so. Indeed it seems that such concerns should drive environmental policy today. Every effort must be made to help prevent developing countries from adopting the patterns of environmental overuse of industrial countries as they grow.

2.6 The Design of the Market

2.6.1. Transaction and Implementation Costs — Any policy has certain implementation costs associated with it. These are rather different in nature for the two policy alternatives under review here. For a tradable quota regime, the costs are as follows:

1. The costs of establishing and maintaining a market
2. The costs of transacting in the market
3. The costs of monitoring and ensuring compliance with the policy

For a carbon tax regime, one has the following as cost categories:

1. The costs of collection
2. The costs of monitoring and ensuring compliance with the policy

Costs of a Tradable Quota System

The costs of establishing and maintaining a market are fixed costs, that is, costs that are largely independent of the size of the market and the volume of business conducted in it. An effective market requires a legal and contractual framework that defines the commodity to be traded, establishes the contractual obligations of the parties to a trade, and sets out payment and settlement mechanisms. The costs of establishing such a framework are likely to be large in the first place. Because they are independent of the volume of transactions, they will be substantial on a per trade basis for low trading volumes but will become quite acceptable per trade if, as seems likely, the volume of transactions eventually rises to several $U.S. billion per year. Thus, they are probably not a major factor in the choice of policy regime, although it must be emphasized that a successful market does require regulation and a good legal infrastructure.[11]

The costs of transacting in the market, of buying and selling, depend on the nature of the market and on its liquidity. In some tradable quota markets, these have been quite high: Stavins [17] cites a figure in some cases as high as $25,000 per transaction (on transactions that are valued at millions of dollars). Such high figures occurred because prior to the development of the Chicago SO_2 quota market, markets were decentralized and operated through brokers acting as intermediaries. The role of the brokers was to bring together buyers and sellers, so that they claimed an introduction fee as well as a buy-sell spread. The transaction costs on the Chicago market are now very much less and are of the same order as transaction costs in organized financial markets. Such costs are low enough not to be a major factor in the evaluation of a tradable quota regime.

There is one important general observation about the costs of TEQ regimes: There is a trade-off between the size of transactions costs in the market and the level of the initial investment in market infrastructure. The point here is that the larger is the initial investment in establishing a transparent well-run market open to all would-be traders, the smaller are the per transaction costs when the market is operating. The reason is that a well-run centralized market obviates the need to pay brokers and other intermediaries to find counterparties to a transaction. It also greatly reduces the costs of settling a transaction and, by providing a standard legal framework and establishing contractual relationships between trading parties and the market, reduces the risks associated with possible failure of a counterparty to a trade to perform their part of the deal. In informal markets characterized by bilateral bargains, these risks have historically been considerable. A well-run market provides a supply of traders, a contractual framework that minimizes nonpayment and nondelivery risks, and an organized payment-and-settlement system.

The costs of monitoring and verifying compliance are much the same under either policy regime. These are the costs of verifying that a quota is opened or a tax paid for each unit of CO_2 emitted. As discussed in the following, this will typically not require the measurement and recording of each unit of CO_2

[11] The securities markets of the United States, by general agreement the most active and open in the world, are heavily regulated and managed by the Securities and Exchanges Commission.

emitted. A compliance system will typically require quotas to be purchased or taxes paid at the wholesale level. It will require producers of gas, coal, and refined petroleum products to comply with the provisions of a tradable quota or tax regime on the principle that the overwhelming majority of carbon-based fuels to reach end users will pass through these channels. Such an approach will limit the number of sources to be monitored to a number in the hundreds or, at most, thousands.

The Costs of a Tax Regime

The infrastructure needed to implement a regime of carbon taxes is quite conventional relative to that required for a tradable quota regime and is of a type already possessed by almost every government. It is essentially the administrative apparatus need to administer a fuel tax, which is already in place in many countries. The costs of monitoring compliance with a tax regime are the same as those of monitoring compliance with a tradable quota regime and have already been discussed.

Private Sector Involvement in Implementation

The governments of most countries will probably find it easier to implement carbon taxes than tradable quotas. However, it is possible that private-sector financial institutions will be willing to organize and provide much of the institutional framework needed for a tradable quota regime in exchange for the right to participate as brokers and market makers in the resulting markets. In financial markets such rights to participate are valuable, as in many cases the markets are financed by charging membership fees to the financial institutions who subsequently become the key participants. Several major private-sector international financial institutions have already indicated interest in becoming participants in a global CO_2 TEQ market.

2.6.2 The Organization of Quota Markets — For the full economic potential of a regime of TEQs to be realized, the market for tradable quotas must be competitive and free of manipulation and should give all would-be traders equal access to information. It must also provide mechanisms for hedging price uncertainty. The issue of hedging mechanisms is addressed in section 2.5.6 and in Chichilnisky [6].This section focuses on issues associated with the nature of competition in quota markets and the organization of access to these markets.

A key issue is whether the number of traders in these markets will be large enough to ensure competition and whether any of the traders will have the power to dominate the market. These issues are in turn linked to the question of who participates in the tradable quota markets. There are several possibilities here, and mixtures of them are possible as well:

1. International quota markets will be intergovernment markets, purely for the redistribution of quotas between countries. Participation would be open only to designated government agencies.
2. International quota markets will be open to all firms in all countries, establishing a truly global market for CO_2 emission quotas.
3. The international market will be open only to governments but will be supplemented by domestic quota markets within which firms in a country trade the quotas that have been issued to or purchased by its government.

In terms of establishing a truly competitive market, the second option here—international markets open to all comers—would be the best. However, such an approach would raise questions about the ability of governments to implement national policies, as it would allow the transfer of permits between countries without any government approval.

The issue of whether firms in a country should be freely able to export or import tradable quotas is a complex one. Many governments will have an instinctive reaction to restrict this ability and retain control of the total number of quotas in their country. There would in fact be no reason for restrictions on the export or import of quotas if and only if it were clear that market prices reflected fully the social value of a tradable CO_2 quota to a country. In this case the export of an emission quota from a country would give it an amount of cash that fully compensated for the loss of the quota.

Unfortunately, there are likely to be many circumstances in which this condition is not fulfilled. For example, a developing country's government might feel that the current market price of an emission quota does not reflect the value to it of that quota at some future date when its industrialization strategy is further advanced and its emissions of CO_2 consequently much greater, and thus it might want to accumulate quotas not currently needed for future use. An alternative strategy, feasible if there is a liquid futures market for quotas, would be for the country in such a position to allow the sale of current quotas and at the same time to make forward purchases to cover anticipated future needs.

In an active market one would expect to see "maturity swaps" developed to provide precisely this service. Equivalent swaps are routine in government debt markets and are also available in the Chicago market for SO_2 quotas, in which a utility with a surplus of quotas for the near future and a deficit for the longer term may swap the surplus near-term permits for permits of future validity.

There are several possible models of what might ultimately emerge if a global tradable quota policy is adopted. One is a two-tier market system. In this case one might see regional markets in such areas as North America, western Europe, and South America, with all firms and governments in a region free to trade on the regional market, and then a global market in which only governments or regional authorities trade to alter the distribution of quotas between regions.

An alternative would be a global market in which some governments allow domestic firms to trade directly on the global markets and export or import quotas freely and in which other governments restrict the right to trade on the global market. In such a case the major industrial countries might be expected to permit any domestic firms to trade on the global quota market, whereas developing countries' governments might exercise more control over the import and export of quotas. For example, they could impose tariffs on trade in quotas, requiring exporting firms to pay a fraction of the revenues from exports into a national tradable quota bank, or require export licenses.

From the perspective of ensuring a competitive market with incentives for brokers to innovate in the production of instruments such as swaps, futures, and options, the last regime is clearly the best.

2.6.3 Design of the Tradable Quota — What exactly is the object to be traded in a market for tradable emissions permits? The fundamental source of possible climate change is the stock of CO_2 in the earth's atmosphere. The larger this is, the larger is the chance of a significant change in the climate. Thus, the ultimate objective of economic policies is first to stabilize and then to reduce the stock of CO_2 in the atmosphere. There is a natural CO_2 cycle in the environment by which human activity emits CO_2, which is removed from the atmosphere either by solution in the oceans or by photosynthesis by green plants or by microorganisms in the ocean. This process turns CO_2 into energy for plants and microorganisms and into oxygen, which is emitted into the air. Thus, to stabilize and then reduce the stock of CO_2 in the atmosphere, the emission of CO_2 has to be reduced below the rate at which it is removed from the atmosphere by solution in the oceans and photosynthesis. One part of a policy strategy might be to increase the rate of removal by photosynthesis, which can be affected by the preservation and extension of forests. In principle, then, a policy has to discourage the emission of CO_2 and encourage its absorption.

What are the implications of this for the nature of tradable quotas? Damage inflicted depends on the stock of CO_2 in the atmosphere and not on the flow of CO_2 into the atmosphere. The rate of emission of a given total is much less important than the size of the total. It is of limited concern whether a given amount of CO_2 is emitted at a great rate over one month or much more slowly over a year or more. Thus, quotas should govern the total amount of CO_2 to be emitted over some interval, not the rate of emission. This means that a five-year quota for, say, 100,000 tons of CO_2 entitles the holder to emit a total of 100,000 tons in any time pattern whatsoever over the five-year validity of the quota. It is not a right to emit 20,000 tons annually for five years. The 100,000 could all be emitted in the first month, or in the last month. The timing of emission might matter only in one respect, namely, that the social costs imposed on the global community by an incremental unit of emission might be less when the stock of CO_2 in the atmosphere is less. In the limit, if the stock in the atmosphere were to return to preindustrial levels, there would be no social costs of emission not reflected in the private costs. However, within the foreseeable future this is likely to be an insignificant effect, and it seems safe to assume that within 5- to 10-year intervals the timing of emission is irrelevant to the economic significance of the emission.

However, from the perspective of a firm, there are important issues related to the timing of the emissions allowed by a quota and the duration of the quota. A firm seeks to choose the least-cost technology for a certain purpose. Suppose, for example, that a utility selects oil as the least-cost energy source on the basis of present and anticipated energy prices and prices of CO_2 emissions permits. Then, by constructing an oil-fired power station, it will be making a 20- to 30-year commitment on the basis of these prices and will want to "lock in" these prices to the greatest degree possible. In the case of emission quotas, this could be facilitated by the regulatory regime in one of two ways. One way is to give quotas a 20- to 30-year life, so that quotas purchased now by the utility at current prices will remain valid over the life of the power stations that it intends to build. An alternative way is to give shorter life spans to the quotas, perhaps 5 to 10 years, but establish futures markets in quotas so that the utility can lock in a supply of quotas for the life of its power station today at known prices.

From the regulatory perspective, there is a difference between these two approaches, that is, between giving long-lived quotas or establishing futures markets in shorter-lived quotas. The latter approach gives more flexibility. In particular it allows changes in the distribution of quotas. As discussed in chapters 3, 6, 7, 8, 11, and 13 of this volume, the allocation of CO_2 emission quotas between countries is a politically complex and important issue, and it is quite possible that it might be appropriate to alter this allocation over time, for example, by shifting the distribution of quotas over time toward the developing countries. If quotas have a life of 20 years, a distribution cannot be changed within this time span. If they have a 10-year life, then after 10 years a new set of quotas can be distributed according to different rules. One remark that should be made about this possibility is that if there are short-lived quotas and uncertainty about the future distribution of quotas, this would lead to uncertainty about the future prices of quotas. Countries uncertain of their future allocations would not know whether they would be net buyers or sellers, so that future prices could not be established. Thus, if quota distributions were to be altered over time, it should ideally be according to a preannounced strategy.

2.6.4 Enforcement Framework

Monitoring Compliance

There are two aspects to an enforcement framework. One is the monitoring of compliance with the regulatory framework and detecting violations. The other is responding to violations in a way that ensures that it is always in the interests of participants to comply.

The first of these aspects is by far the more straightforward of the two. Arrangements for monitoring compliance have been mentioned several times. In particular, we have made the point that to monitor overall compliance it is not necessary to monitor every possible industrial source of CO_2. It will be sufficient to monitor the sales of the major distributors of carbon-based fuels (i.e., the major distributors of gas, oil, and coal). These are limited in number and fairly prominent. Provided that the sales of fossil fuels by these agents are within a country's quota, the total use of such fuels must also be within the quota. These distributors are of course not the ultimate users of fossil fuels and so are not responsible for burning them and emitting CO_2. Thus, they would not be required to hold permits, but nevertheless their outputs would provide a good guide to the total emissions of CO_2. The TEQs would be needed and traded by their customers. In fact, estimates of the consumption of the various carbon-based fuels in each country are already available from data on production, import, export, and inventories. Such data are available to international agencies and would be difficult to falsify to a significant degree.

It is also possible to monitor fairly readily the preservation of carbon dioxide sinks, such as forests and other large areas of vegetation. The extent of these can be observed and measured from satellite pictures. In fact these are the main sources of internationally agreed data in this area today.

Thus, there is the capacity to monitor annual emissions and absorptions of CO_2 by countries. However, as noted in the previous section, emission quotas should not in general specify an annual emission rate; rather, they should specify a total of emissions over a multiyear life. If all the quotas in a country have the same validity dates—for example, all are valid from 1995 to 2005—then this does not complicate matters, as it is decadal rather than annual emissions that are monitored.

If the lives of quotas are not synchronized, matters could be more difficult. Consider, for example, a country with two utilities using quotas. One has a quota valid from 1995 to 2000 for a total emission of 0.5 million tons and a quota valid from 2000 to 2010 for 1 million tons. The other utility has a 1-million-ton quota from 1995 to 2005 and a 0.5-million-ton quota from 2005 to 2010. In this case emission from 1995 to 2000 could legitimately be anywhere in the range from 0.5 million tons to 1.5 million tons. The upper end of the range would occur if the second utility used all of its quota for 1995 to 2005 in the first five years of its life. It is probable that with large numbers of quota-using firms, such effects would be less significant in the aggregate. It is also likely to be the case that the lives of quotas will be synchronized.

Enforcing Compliance

The enforcement of an international agreement clearly poses serious problems, although there are many precedents for multinational agreements that have been respected by their signatories. These include the Montreal Protocol on Substances that Deplete the Ozone Layer and the Nuclear Non-Proliferation Treaty, both of which limit either environmental emissions or national sovereignty over power sources and thus have some element in common with a treaty on global warming. However, a global warming treaty would be much more far-reaching than either of these.

Ultimately, enforcement could be achieved only by a combination of enlightened self-interest and diplomatic and economic pressures, as the international community has no effective legal sanctions that could be used to ensure compliance. Economic pressures would be exerted through international agencies and patterns of international trade and diplomatic pressures through the usual diplomatic sources. The successful implementation of a broad-based global warming treaty would unquestionably pose new challenges to the international community and set an important precedent for planetary cooperation on environmental matters. Successful implementation is related to the nature of the countries that agree to participate in the treaty. In the next section we argue that the incentives to comply increase with the number of participants, and indeed that with sufficient participation compliance, will be in each country's self interest.

2.6.5 Participating Countries — How many countries, and which countries, have to ratify a global warming treaty for it to be worth implementing in the sense that it will make a real difference to the threat of climate change? Perhaps more important, how many countries have to ratify such a treaty for all the signatories to feel that they will gain from the treaty and that it justifies their support and commitment? This is closely related to the issue of enforcement discussed in the previous section.

There are several analytical issues behind these questions. A global warming treaty is unlikely to have the participation of all countries as soon as it starts; rather, it is likely to begin with limited participation and to gain support over time. Thus, the group of countries that starts the treaty must be such that they all feel that the group is durable and that the group will continue to abide by the treaty for long enough for widespread support to build up. Whether this condition is met depends very much on the size and composition of the initial group.

A key issue here is that the gains to all countries from participation in a global warming treaty depend on and increase with the number and size of the participating countries. The costs to each country of participation also fall as the number of participants increases. There is a sense in which there are economies of scale in the formation of such agreements. There are two key points here.

One is that when a country cuts back its emission of CO_2, it alone pays the costs of this abatement; however, benefits accrue to all other countries that would be negatively affected by climate change, because climate change, if it occurs, will be worldwide. It follows that if one country abates CO_2 emission on its own, it will clearly be a net loser from this, as it will meet all the costs, and many other countries will share the benefits with it. Suppose, however, that a group of countries agree jointly to abate carbon emissions. The costs of each country's abatement, as before, are borne by that country, but each country now gains not only from its own abatement but also from that of all the other participating countries. The ratio of benefits to costs is now much more favorable. The costs to each country are unchanged, and the benefits to each country are multiplied by the number of participating countries.

In fact, and this is the second point leading to scale effects in the formation of abatement agreements, countries' costs might actually be reduced if the abatement is part of a simultaneous policy move by several countries. One of the main costs of CO_2 abatement is the development of new technologies, and if this is done collaboratively by several countries, each might face a lower individual abatement cost. There is clear evidence of this in the case of unleaded vehicle fuels. Once refining practices and engine designs to cope with these had been developed in the United States (at considerable costs), these technologies could be deployed by the companies that developed them in other countries at little or no incremental cost.

It follows from this that there is a "critical mass" issue in forming the initial group of signatories of a CO_2 abatement treaty.[12] The group has to be big enough (size here is measured in terms of the fraction of global CO_2 emissions controlled) that the gains to each country from participation of the others are sufficient to outweigh the costs that each country incurs. Once such an abatement configuration is in place, problems of deliberate noncompliance at the national level should be greatly reduced.

Another analytical issue in evaluating the adequacy of a group of signatories to a global warming treaty is the phenomenon of "carbon leakage." This refers to the fact that if there is agreement by a group of countries that are major energy consumers to cut back the use of fossil fuels as part of a CO_2 abatement policy, then the consequent decrease in their demand for these fuels will decrease their prices on world markets and so encourage other nonparticipating countries to consume more. This could partially offset the policies implemented by the signatories of the global warming treaty. There is as yet little agreement about the possible magnitude of the phenomenon of carbon leakage,[13] and indeed there are several other mechanisms through which leakage can occur.

What are the implications of these issues for the group that should be targeted as the initial signatories of a CO_2-abatement agreement? Such a group has to be sufficiently broad based to meet two conditions:

1. It has to form a critical mass in the sense of being large enough to ensure that all members gain from membership and so have incentives to remain in compliance.
2. It has to be large enough that the carbon leakage phenomenon does not detract from its efficacy.

However, it need not contain initially all the countries that will ultimately have to join to make it a complete success. It should certainly contain the major industrial countries—the members of the OECD. The additional groups who will ultimately have to join for complete success are the economies of eastern Europe and the former Soviet Union and the major developing countries, such as India and China. It is probably not necessary for all these additional countries to be full members of a global warming treaty as soon as it starts, as long as two conditions are fulfilled:

[12] This point is developed in Heal [2,3].

[13] A more detailed discussion of these effects can be found in OECD Economic Studies, No. 19.

1. They will not pursue policies that will undo the efforts of the signatories of a global warming treaty; that is, they will not increase their emissions of CO_2 to offset, fully or partially, the measures taken by signatories. In particular, they will neutralize carbon leakage.
2. They express an intent to participate fully within a specified period of, say, 10 years.

In fact these aims could easily be achieved by all countries joining a TEQ regime if the OECD countries were allocated quotas that forced them either to reduce emissions or to buy from other countries and if the developing countries were allocated quotas sufficiently in excess of their current needs that they would not constrain their economic development in the near future. In effect the developing countries would then be sleeping members of the treaty for a period but during this period would be able to benefit from the sale or loan of their excess quotas to industrial countries, providing them with an incentive to keep carbon emissions low and maximize the revenues obtainable from quotas. Such a distribution of quotas is, as already noted, consistent with their efficient allocation.

2.6.6 Market Management

Instruments for the Trading of Emissions Quotas

What instruments, apart from the basic tradable quotas, should be traded on the markets that form a part of a tradable quota regime? The role of derivatives such as futures and options in facilitating hedging price risks has been mentioned several times and clearly is important. These instruments, plus various maturity swaps, are already traded in association with the SO_2 quota market on the Chicago Board of Trade, where experience to date confirms the importance of these instruments in hedging.

There is an additional argument for the introduction of such products, namely, that derivatives help achieve market depth and liquidity and so improve market functioning. In the market they serve two important functions. They reallocate risks, as do all financial instruments, and they function as substitute credit markets, allowing traders with limited liquid assets to trade extensively. For example, trading options on oil futures requires less cash than trading oil futures. Thus, market liquidity is increased with options.

Borrowing and Lending versus Buying and Selling

So far we have spoken entirely in terms of the purchase and sale of emission quotas: sale by countries with a surplus over their immediate requirements and purchase by those whose emissions exceed their allocation of quotas. It is clear that some countries feel an unease at selling, parting permanently with their rights to emit greenhouse gases, rights that they might need in the future at a different stage of economic development. In principle they can of course buy these rights back in the future when they are needed, although there is a risk that the price will then be excessive. This risk can, as already mentioned, be reduced by the use of futures contracts or maturity swaps. Nevertheless, there might remain a residual unease about the sale of emission rights. There is a rationale for this, as no one can predict the liquidity of the TEQ market or the prices in that market several decades hence.

An alternative approach is to allow countries to lend or borrow emission rights rather than buying and selling them or indeed to allow both. We can conceive of a central bank[14] at which quotas are deposited when not needed and from which deficit countries borrow quotas. A country with a surplus of permits that it anticipated continuing for, say, five years would make a five-year deposit in the bank and be paid interest on this deposit. After five years it could withdraw its permits or roll over the deposit. Through this system a country's total emission rights never change: It never gives them up permanently but simply lends them while they are not needed.

The interest rate payable on permits would of course depend on the balance of supply and demand for permit loans. A large number of would-be borrowers with few lenders would force up the interest rate and vice versa. The interest rate would be affected strongly by the initial distribution of permits.

Such a system not only bypasses the reluctance that countries might feel with respect to selling emission quotas but also reduces the risks in the market because each party would be dealing with an international institution—an international environmental bank—which would have a credit status similar to that of the International Monetary Fund (IMF) and the World Bank. This arrangement would remove any counterparty risks linked to trading with countries of uncertain credit worthiness.

References

1. Arrow, K. J., and A. C. Fisher. "Preservation, Uncertainty and Irreversibility." *Quarterly Journal of Economics* 87 (1974): 312–19.
2. Coase, R. H. "The Problem of Social Costs." *Journal of Law and Economics* 3 (1960): 1–44.

---

[14]Elsewhere, Chichilnisky has written on the case for a "Bank for Environmental Settlement" that could play this role. See chapter 11.

3. Chichilnisky, G. "A Comment on Implementing a Global Abatement Policy: The Role of Transfers." Paper presented at the OECD Conference on the Economics of Climate Change, Paris, June 1993. In *OECD: The Economics of Climate Change,* T. Jones, ed. (Paris: OECD, 1994).
4. Chichilnisky, G. "North-South Trade and the Global Environment." *American Economic Review* 84, no. 4 (September 1994): 851–74.
5. Chichilnisky, G. "What Is Sustainable Development?" *Land Economics* 73, no. 4 (November 1997): 467–91.
6. Chichilnisky, G. "Markets with Endogenous Uncertainty Theory and Policy." *Theory and Decision* 41 (1996): 99–131.
7. Chichilnisky, G., and G. M. Heal. "Who Should Abate Carbon Emissions: An International Perspective." *Economics Letters* (Spring 1994): 443–49.
8. Chichilnisky, G., and G. M. Heal. "Global Environmental Risks." *Journal of Economic Literature* (fall 1993): 65–86.
9. Chichilnisky, G., and G. M. Heal. "Markets for Tradable CO_2 Emission Quotas: Principles and Practice," Economics Department Working Paper No. 153, OECD, Paris, 1995. Also published as chapter 10 in *Topics in Environmental Economics,* ed. M. Boman et al. (Amsterdam: Kluwer Academic Publishers, 1999).
10. Chichilnisky, G., G. M. Heal, and D. A. Starrett. "Equity and Efficiency in International Permit Markets." Working paper, Stanford Institute for Theoretical Economics, Stanford University, fall 1993.
11. Dasgupta, P. S., and G. M. Heal. *Economic Theory and Exhaustible Resources.* Cambridge: Cambridge University Press, 1979.
12. Heal, G. M. "International Negotiations on Emission Control." *Economic Dynamics and Structural Change* 3, no. 2 (1993): 223–40.
13. Heal, G. M. "Markets and Biodiversity." Paper presented at a conference on Biological Diversity: Exploring the Complexities, Tucson, Arizona, June 1994.
14. Heal, G. M. "Valuing the Very Long Run: Environment and Discounting." Working paper, Columbia Business School, Columbia University, fall 1993.
15. Henry, C. "Option Values in the Economics of Irreplaceable Assets." *Review of Economic Studies* (1974).
16. Kristrom, B. "Is the Elasticity of Demand for Environmental Goods Less Than One? Evidence from International Studies." Paper presented at the Second Ullvon Conference on the Environment, June 1994.
17. Pigou, A.C. *The Economics of Welfare.* London: Macmillan, 1932.

18. Stavins, R. "Transactions Costs and the Performance of Markets for Pollution Control." Working paper, Kennedy School of Government, Harvard University, fall 1993.
19. Weitzman, M. L. "Prices vs. Quantities," *Review of Economics Studies* 41, no. 4 (1974): 477–91.