

Conf-911184--6

TRADEABLE CO₂ EMISSION PERMITS FOR
COST-EFFECTIVE CONTROL OF GLOBAL WARMING

ANL/CP--74713

DE92 003519

by

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Received

NOV 25 1991

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presented at
13th Annual North American Conference
International Association for Energy Economics
Chicago, Illinois
November 18-20, 1991

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ABSTRACT

Many current global warming mitigation policy proposals call for large, near-term reductions in CO₂ emissions, thereby entailing high initial carbon emission tax rates or permit prices. This paper claims that these high initial tax rates or permit prices are not cost-effective in achieving the desired degree of climate change control. A cost-effective permit system is proposed and described that, under certain assumptions, would allow markets to optimally lead permit prices along a gradually increasing trajectory over time. This price path represents the Hotelling result and would ease the abrupt, inefficient, and costly adjustments imposed on the fossil fuel and other industries in current proposals. This finding is demonstrated using the Argonne Model, a linear programming energy-environmental-economic model that allows for intertemporal optimization of consumer energy well-being.

INTRODUCTION

This paper investigates the cost-effectiveness of time paths of policy limitations on CO₂ emissions, and the associated reduction in future fossil fuel production and consumption. It argues that many current proposals to stabilize or reduce current CO₂ emissions would require high initial carbon tax rates or emission permit prices that are not cost effective in terms of their objective, mitigating potential global climate change. By their design, the current proposals impose large near-term adjustment costs on the fossil fuel and other industries.

The paper constructs alternate time paths of policy control that are more effective and are welfare superior. In the scenarios examined, the climate change control policy establishes a long-run CO₂ atmospheric concentration that is consistent with the desired future climate, while allowing markets to determine the appropriate carbon emissions permit price and optimal CO₂ emissions time path. Permit prices start low and rise as the rate of interest over time; consequently, near-term emission time paths deviate only marginally from business-as-usual or no-policy levels.

If it is determined that the threat of global warming warrants action and greenhouse effect control policy becomes part of a domestic/international agenda, then the choice of

market-based approaches, and specifically tradeable emission permits, has attractive features. Such an approach has been endorsed by the Intergovernmental Panel on Climate Change (IPCC, 1990) which concluded that a permit system would create "... economic incentives ... for ...new technologies, sink enhancement, and resource use efficiency." The IPCC, however, expressed concern about the limited experience with a market-based approach, and about the appropriate design of permit markets; in particular, their scope, size, and expected performance.

The focus of this paper is on the latter concern: how to design permit markets so they create incentives for cost-effective behavior. A number of important issues about permit markets are not addressed in this paper: for example, the degree of climate change mitigation desired; how to allocate permits fairly among nations and regions (see references in Grubb, 1989); how to incorporate trace gases other than CO₂ (see references in Victor, 1990); and how to develop workable monitoring and enforcement procedures (see references in Smith et al., 1991).

A mental laboratory must be set up for this investigation since market data are nonexistent. The Argonne energy-environmental-economic model is well suited for this purpose since it can simulate efficient market determination of permit prices under alternate policy scenarios.

SUMMARY OF RESULTS

Proposals to curb or reduce current CO₂ emissions, if successfully negotiated, would set annual limitations which, if the policy instrument chosen were tradeable permits, would require the issuance of dated (annual) entitlements. A negotiated policy would determine emission time paths by making available each year, or time period, a particular quantity of permits that would be canceled on extraction of a given unit of fuel; markets would determine permit prices given the prespecified time path and quantity of permits in the market. Simulation of this policy in the Argonne model produces very high initial permit prices that require major adjustments in the fossil fuel industries. This result is consistent with the high initial carbon tax rates predicted by others -- Manne and Richels (1991) and EMF (1990), for example.

Taking as an objective a particular long-run (e.g., year 2100) CO₂ atmospheric concentration level, an alternate cumulative emission permit policy can be simulated in which the total volume of undated permits are issued immediately commensurate with the desired long-run level. A domestic/international climate change policy would establish this long-run concentration limitation, but the markets would determine both the permit price and emissions time path.

Under such a scenario, permit prices start low in efficient markets and rise exponentially as the rate of interest: permits are seen by forward-looking traders as an exhaustible resource and the Hotelling price path effect (i.e., exponentially increasing as the long-run real interest rate [5%]) is reproduced. In addition, cost-minimizing emitters would equate marginal abatement costs over time, a requirement of longitudinal cost-effectiveness. Under such a scenario, emissions are relatively unchanged from the no-policy case in the short-run, but during the next century fall below that level, as well as below the annual control policy level.

THE GREENHOUSE EFFECT AND POLICY

Concern about global climate change has grown in the last several years as some scientists have attributed changes in global temperature to increased GHG concentrations; i.e., the greenhouse effect (IPCC, 1990). These same scientists believe that continued emission of anthropogenic greenhouse gases will lead to atmospheric concentration densities in the next century that could produce discernible changes in climate. Some of these changes could be: elevation of average global temperature with larger regional variations -- average global temperature elevations of about 0.3 degrees C per decade are expected within a range from 0.2 to 0.5 degrees C (IPCC, 1990); altered precipitation patterns; increased frequencies and intensities of storms; decreased large fresh water system levels; and increased ocean levels. The precise timing, regional location, and magnitude of these effects is not now discernible and subject to considerable scientific uncertainty (for a review of these uncertainties see Fernau and South, 1991).

There are many greenhouse gases: CO₂ accounts for 55% of the anthropogenic contribution to global warming at present, CFCs a little less than 25%, CH₄ about 15%, and N₂O about 6% (IPCC, 1990). The sources, chemical and physical atmospheric transformations, and sinks of these trace gases are not well understood, and even the most studied, CO₂, has information gaps.

While CO₂ is only one greenhouse gas, and on a molecular basis is the least radiatively potent (Kane, Fernau, and South, 1991), it is the one most studied due to its large current atmospheric concentration. Since a permit system will require careful monitoring of GHG cycles, and enforcement can only be developed on a quantitative assessment of each phase, it has been suggested that a CO₂ emissions permit system be developed first, and extended to the other GHGs when better information becomes available (Goulder, 1990). Consequently, in this paper, a CO₂ emissions permit market will be examined for illustrative purposes.

Examination of a marketable permit system for GHGs is appropriate at this time because, although considerable scientific uncertainties still exist, there have been calls for precautionary policy measures to control/stabilize CO₂ emissions that are not cost-effective and could induce substantial economic costs on the fossil fuel industry. To examine the potential benefits of a market-based tradeable permit approach, the following assumptions are made -- some of which are under investigation at Argonne regarding the promises and problems of emissions trading:

- a) International agreement has been reached on either targeted levels of annual CO₂ emissions or on a targeted CO₂ concentration at some future date (e.g, 2100);
- b) International agreement has been reached in each policy scenario on the initial allocation of permits among countries (any allocation that does not destroy a competitive market does not theoretically affect the results);
- c) A well defined permit has been designed which is canceled when a unit of fossil fuel is extracted. Permits set aside for sinks such as reforestation or reduced deforestation are not a large share of the total;
- d) Enforcement and monitoring procedures are credible;

- e) Spot and futures permit markets are efficient and inhabited by traders with forward-looking expectations that are consistent with each policy scenario. Each policy is fully implemented as announced;
- f) Convexity/concavity of production and consumption sets enables smooth substitutions away from fossil fuels as their prices rise.

MENTAL TESTING LABORATORY: HOW THE ARGONNE MODEL MIMICS PERMIT MARKETS

The test scenarios are carried out in a representative consumer, dynamic optimization, partial equilibrium-type linear programming model that has been developed at Argonne from pioneering work by W.D. Nordhaus (1979). It is a global model with two sectors: the U. S. and rest-of-the world (for a model description see Daly et al., 1986).

A key feature of the model is its price sensitivity. On the supply side, fossil fuel resources and solar and nuclear technologies are represented by supply curves based on reserves, extraction, and processing costs. CO₂ emission coefficients for each fossil fuel translate limitations on emissions into higher prices of fossil fuels.

On the demand side, four final energy commodities are specified that enter consumer's utility functions from which demand curves are derived. The price and income elasticities of demand are based on econometric evidence.

Consumer energy well-being is maximized, subject to supply and demand constraints, yielding for every set of input values (exogenous variable and parameter settings) market-clearing time paths of energy prices and quantities, and time paths of CO₂ emissions and concentrations. Alternate scenarios can be simulated by changing variables such as income growth rates or energy technology costs, imposing carbon tax rates, or by constraining CO₂ emissions or concentrations. Each variation produces a long-run trajectory of prices and quantities that simulates efficient market equating of demand and supply.

In the BAU scenario, energy prices rise because fossil fuels, and nuclear fuels, are exhaustible. Substitutions occur as prices rise, leading in the very long-run to increased dependence on inexhaustible but expensive energy "backstop" technologies; however, fossil fuels and especially coal remain the dominant fuels throughout the next century. As a result, CO₂ concentrations increase and more than double by 2100.

In the policy scenarios, the precise means by which policy is introduced as a constraint in the model, and in the markets, is of importance in determining cost-effective paths of permit price. A policy to curb or reduce annual emissions is introduced into the model as a constraint on annual emissions, and hence a constraint on annual use of fossil fuels. The resulting shadow price per metric ton of carbon is interpreted to be the price an efficient market would place on a permit to emit a metric ton of carbon. Curbing CO₂ emissions immediately means issuing few permits initially, leading to high permit prices and increased prices of primary fossil fuels. These high prices impose on the industry drastic reductions in fossil fuel demand and substitution away from these fuels. Such

a permit price path, and required adjustment of marginal abatement costs to it, are not cost-effective, as will be shown.

A policy to achieve the same degree of long-run climate change control as in the above scenario, but which allows markets to determine not only permit prices but also annual emissions, may be introduced into the model as follows. A future period, say the year 2100, is chosen as the date at which anthropogenic climate change is to be stabilized, or reduced to an acceptable rate (by stabilizing the CO₂ concentration or reducing its growth rate). In this test, the year 2100 CO₂ atmospheric concentration generated by the stream of annual emissions allowed under the annual control policy scenario (described above), was used as the long-run climate change stabilization goal. The model was permitted to reach that concentration level but no greater by 2100. Total permits for this ultimate concentration level, to be canceled on use, are placed on the market immediately in this scenario.

This constraint on total atmospheric concentration yields an annual shadow price on CO₂, which is interpreted to be the permit price path determined by efficient markets for the exhaustible stock of permits. This price path has as its dual (or its counterpart) the quantity of permits used up each year or its equivalent, the annual flow of CO₂ emissions. These paths of prices and emissions are cost-effective in reaching the environmental goal, as will be shown.

The resulting permit price path, with the atmospheric concentration constraint, starts low and rises as the rate of interest rises, permitting emitters in the fossil fuel industry to equate marginal abatement costs over time, a requirement of intertemporal cost-effectiveness. Implicit in this interpretation are the responses of traders -- energy enterprises and speculators in the world permit markets -- who recognize the exhaustible nature of the stock of permits and bid for them in terms of their expected future value.

RESULTS OF COST-EFFECTIVE ANALYSIS

Three policy scenarios were chosen for cost-effective analysis, each being representative of proposals to take precautionary measures against the uncertain but potentially threatening aspects of global climate change. The policy scenarios, summarized in Table 1, are consistent with those being examined by the Energy Modeling Forum in their study, *Global Climate Change: Energy Sector Impacts of Greenhouse Gas Emission Control Strategies* (EMF-12, 1991).

Scenarios A, B, and C are the proposals to reduce annual emissions in the near- or medium-term future. Scenarios A', B', and C' (examined only in this paper) are designed to achieve the same degree of climate control as A, B, and C, respectively, but allow permit markets to determine the annual consumption of permits, and hence annual flow of emissions. It is important to precisely define how these scenarios are constructed, and how the same degree of climate control is achieved.

The second column of Table 1 explains that scenario A stabilizes emissions by 2000 at 1990 levels, B calls for a 20% reduction by 2010 from 1990 levels, and C calls for the same reduction as scenario B by 2010 but a further reduction to 50% of 1990 levels by

Table 1: Global Policy Scenario Descriptions

Scenario Label ¹	CO ₂ Annual Emissions Path ²	CO ₂ Concentration at 2095 ²	Welfare Gain: billions of \$1980 ³
Business-As-Usual	No controls	No controls (reaches an increase of 668 billion tons by 2095 over 1980 volume)	
A	Stabilize by 2000 at 1990 annual levels	No controls (reaches an increase of 346 billion tons by 2095 over 1980 volume)	
A'	No controls	Increase limited to 346 billion tons by 2095 over 1980 volume	900
B	20% reduction by 2010 from 1990 levels	No controls (reaches an increase of 277 billion tons by 2095 over 1980 volume)	
B'	No controls	Increase limited to 277 billion tons by 2095 over 1980 volume	2,300
C	20% reduction by 2010 and a 50% reduction by 2050	No controls (reaches an increase of 229 billion tons by 2095 over 1980 volume)	
C'	No controls	Increase limited to 229 billion tons by 2095 over 1980 volume	2,200

Notes:

¹ In the A, B, and C scenarios, CO₂ concentrations continue to increase throughout the next century and beyond, leading to continuing, though slowed, climate change. In the A', B', and C' scenarios, CO₂ concentrations are stabilized at 2095 and anthropogenic climate change from fossil fuel use ceases after that point in time.

² CO₂ emissions in billions of metric tons of CO₂ by Carbon weight (CWT). CO₂ concentrations in 1980 are estimated to be about 600 billion tons by C wt.

³ Welfare gain in billions of discounted 1980 dollars measures the gain in consumer well-being associated with scenarios A', B', and C' over scenarios A, B, and C. Recall that this is a global objective or welfare function that is being maximized.

2050. None of these reductions stabilize CO₂ concentrations, which increase by the amounts shown in column 3 by the year 2095, and continue to grow thereafter. Hence, anthropogenic climate change would likely increase, although more slowly than in the no-policy case.

The second column reveals that scenario A' imposes no controls on annual emissions, but does limit the atmospheric CO₂ concentration to an increase of 346 billion tons over the 1980 volume by 2095, (column 3), the same volume recorded by scenario A. Data for the other scenarios are displayed in Table 1.

In a mathematical programming context, the introduction of emissions constraints on an annual basis represent dated permits being issued year by year, and are either used or lost, with no carry-over permitted from one year to the next. Thus, in scenarios A, B, and C, the shadow prices resulting from the annual constraints are interpreted as market-determined permit prices.

In scenarios A', B', and C', total permits for the concentration volume in 2095 are placed on the market, and traders price them as an exhaustible resource so that prices start low and rise over time at the rate of interest (5%). Emitters attempting to minimize costs must acquire permits and adjust marginal abatement costs to permit prices, which implies equating these costs over time. The resulting emissions paths should differ markedly from those of scenarios A, B, and C.

Figure 1 displays the time paths for scenarios A and A'. In panel (a) of Figure 1, the CO₂ concentration time paths for each scenario are depicted. Both scenarios reduce concentrations by about 50% from the business-as-usual (BAU) scenario, but A' stabilizes concentrations at the year 2095. Panel (a) enables precision to be used in controlling climate change through changes in concentrations. Both scenarios A and A' achieve the same degree of control in 2095 since they both reduce concentrations by 50% from the BAU case. However, if climate change is driven by the rate of change of atmospheric concentrations (the slopes of the curves), or by the areas under the curves (total damage borne), the conclusions that can be drawn would be ambiguous. A high-priority task for atmospheric scientists is to clarify, for policy purposes, the relationships of global climate change to the different characteristics of atmospheric trace gas concentrations.

Panel (b) of Figure 1 displays the emission paths of scenarios A and A'. It can be seen that the stabilization of emissions by policy scenario A requires large short-term reductions from the BAU scenario. Scenario A' allows emissions to parallel those of the BAU scenario through 2030, then decline gradually to zero in 2100. The path of scenario A' lies between the paths of the other two scenarios considered (BAU and A) over the medium-term future, and falls below scenario A thereafter. Fossil fuel usage is implicit in these curves.

Panel (c) is the dual of panel (b); it reveals the sharp rise in permit price required under scenario A to bring about the required emission reductions. Scenario A' permit prices reveal the Hotelling effect, rising with the rate of interest up to the backstop technology constant cost, at which point the backstop technology provides the necessary energy.

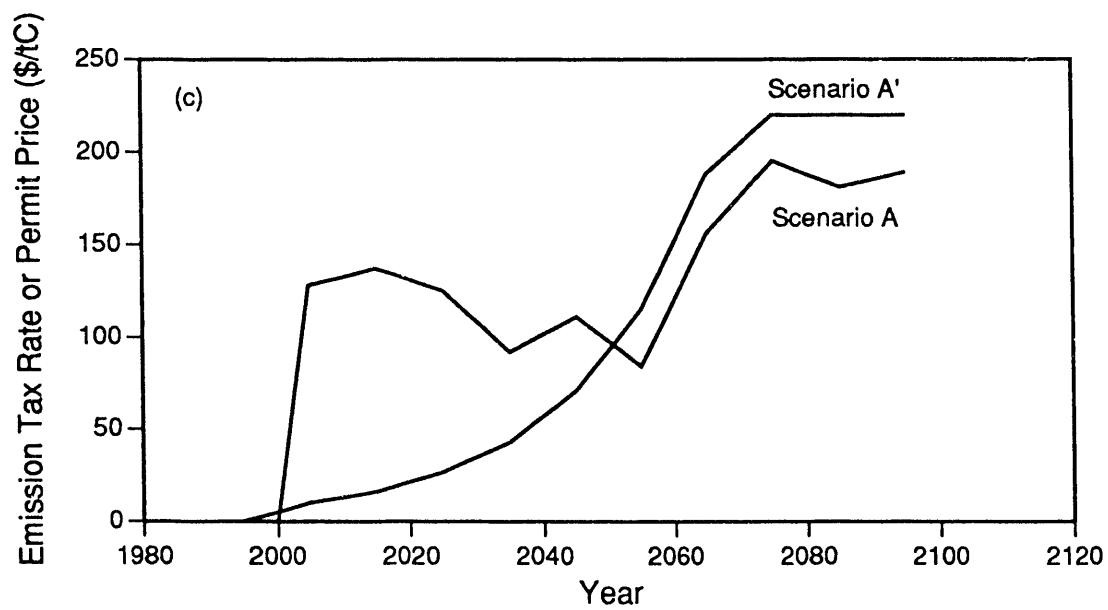
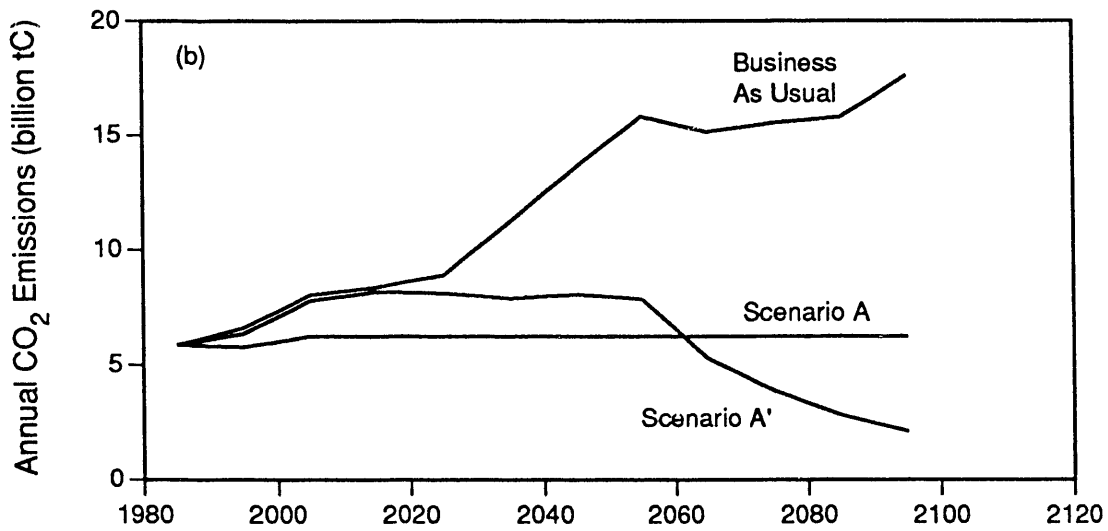
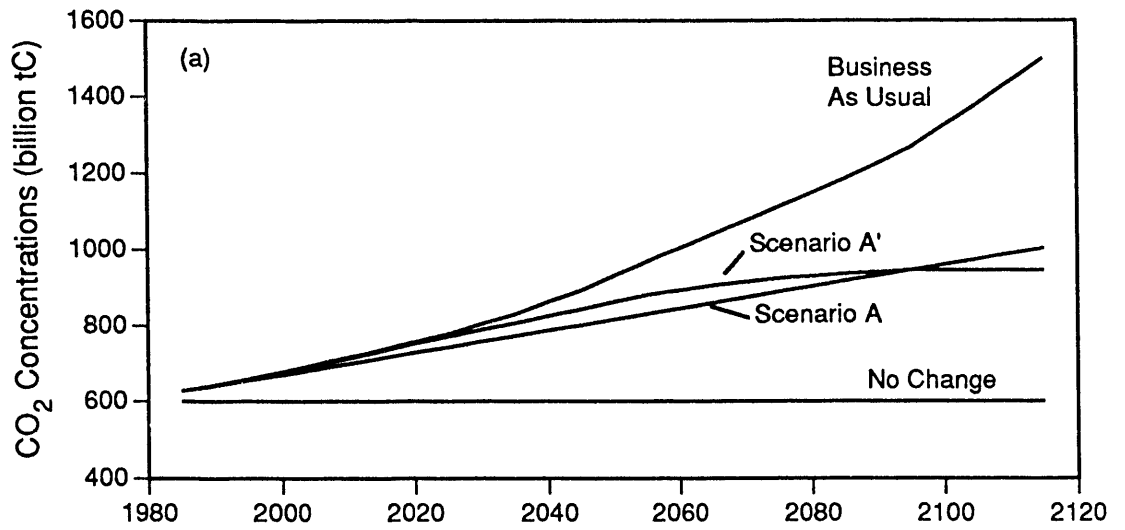


Fig. 1 Policy Scenarios A and A'

The objective function solution value for scenario A', consumer well-being, shows a discounted constant (1980) gain of \$900 billion over scenario A. This value is used as a measure of a more cost-effective way of achieving the targeted goal of reducing CO₂ concentrations by 50% (from baseline) by 2095.

Figure 2 illustrates two ways of limiting CO₂ concentrations to an increase of 277 billion tons by 2095, about a 60% decrease from BAU concentrations. Achieving this concentration level through scenario B -- reducing emissions by 20% by 2010 and holding them there -- yields immediately lowered emission and higher permit price paths depicted in panels (b) and (c) compared with doing it through scenario B'. The welfare gain of scenario B' over B is increased to \$2.3 trillion. The more drastic reduction in concentration levels required by scenario B over A enables the more cost-effective path to achieve greater economic gains.

Figure 3 depicts yet a greater limitation on the growth in CO₂ concentrations, to an increase of 229 billion tons by 2095, about a two-thirds decrease from BAU concentrations. The deeper emission reductions of scenario C require higher initial permit prices. The welfare gains of scenario C' are again large, reaching \$2.2 trillion.

One feature to bring out in these comparisons is the tilting of the game against the cost-effective trajectories: stabilizing concentrations by 2095 as in scenarios A', B', and C' is a more stringent climate change control policy than the one embodied in scenarios A, B, and C that aims for corresponding concentrations by 2095 but allows concentrations to increase beyond that date. Despite this tilt, the trajectories of scenarios A', B', and C' are welfare superior as measured here.

SUMMARY AND CONCLUSIONS

This paper has described a permit system that would lessen the near-term costs borne by the fossil fuel and other industries of potential climate change mitigation. This is accomplished by constructing the marketable permit system so as to treat the allowable increases in atmospheric CO₂ concentrations as a depletable resource. The permit price, as determined by efficient markets, rises per the Hotelling effect, i.e., exponentially increasing as the long-run real interest rate (5%).

Key assumptions made preparatory to this analysis about international negotiations on targets, permit allocations, enforcement, and monitoring require additional research if the attractive features of marketable CO₂ entitlements are to be taken seriously. Some of this research is underway at Argonne and elsewhere.

Initial results indicate the cost-effectiveness of schemes to allow the market to determine both permit price and emission paths by issuing total permits immediately. Utilizing the market fully, to determine both emission and permit price paths, has been demonstrated in this study to have desirable properties. Some of the most interesting questions that can be raised deal with further design features of the permit contract and the market institutions that would make this scheme workable: What kinds of permits and markets appear most promising? Where should markets be located, and how many?

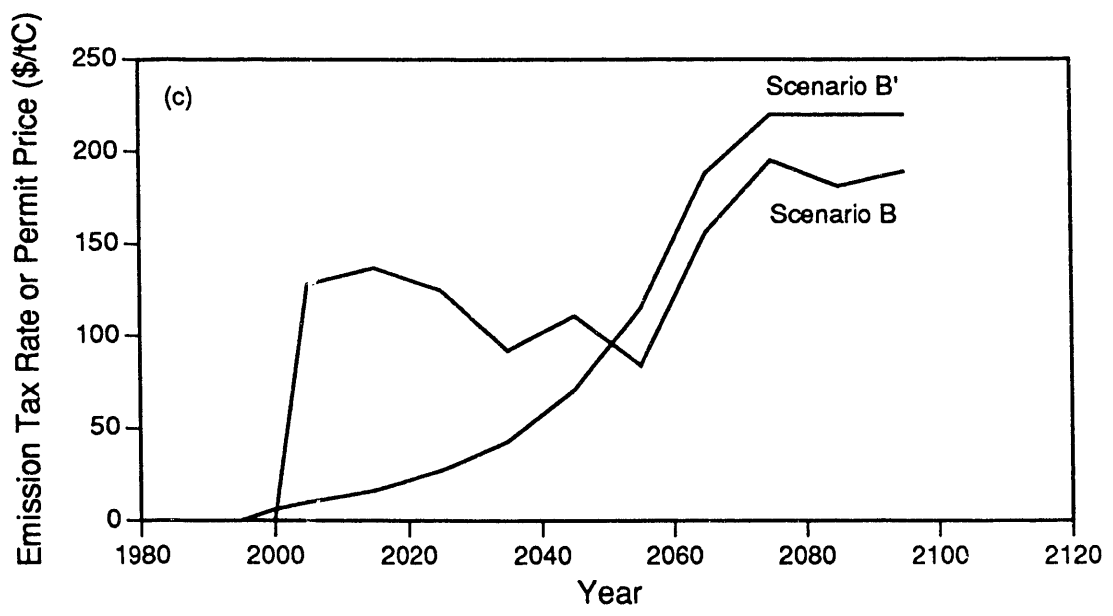
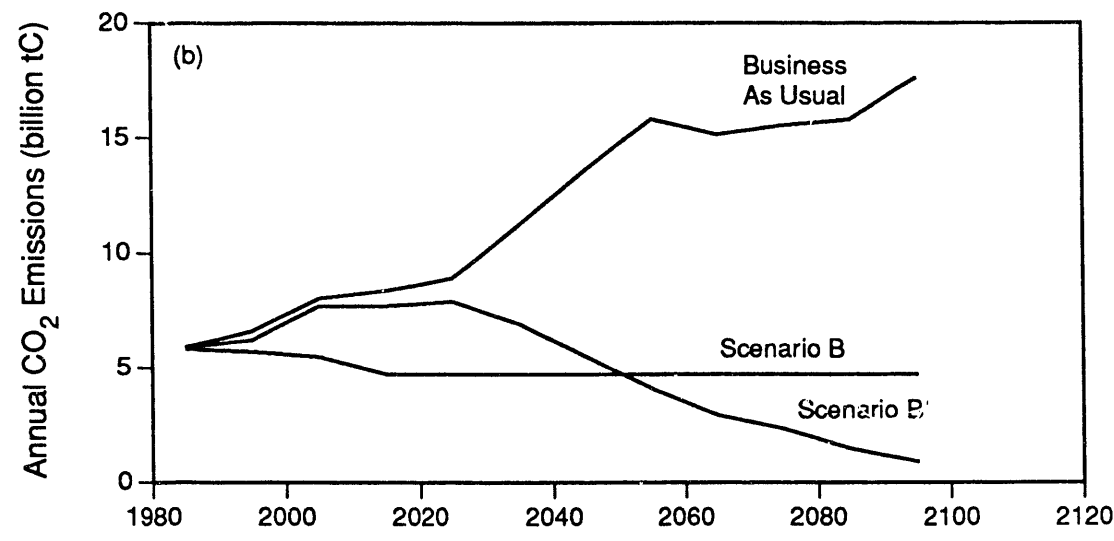
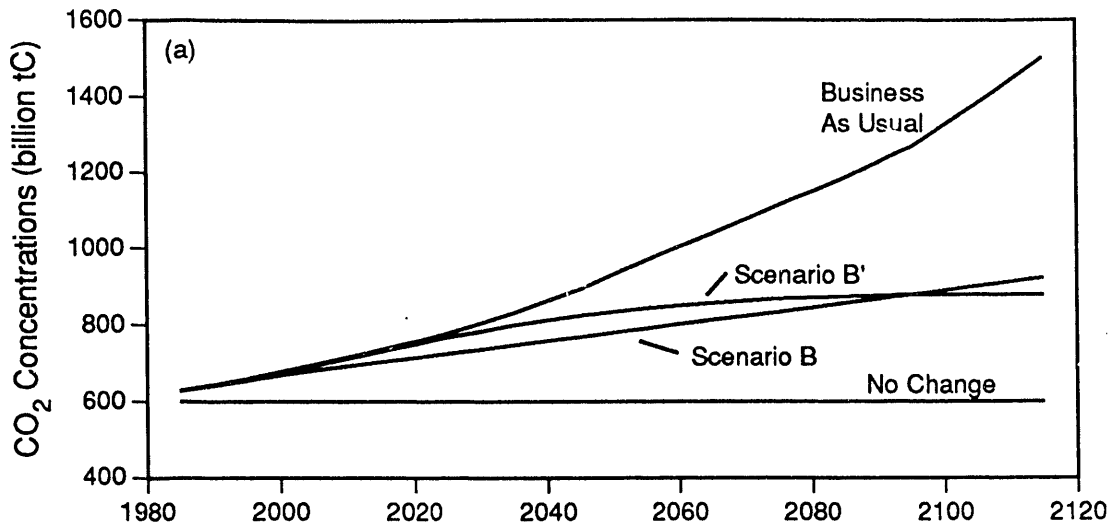


Fig. 2 Policy Scenarios B and B'

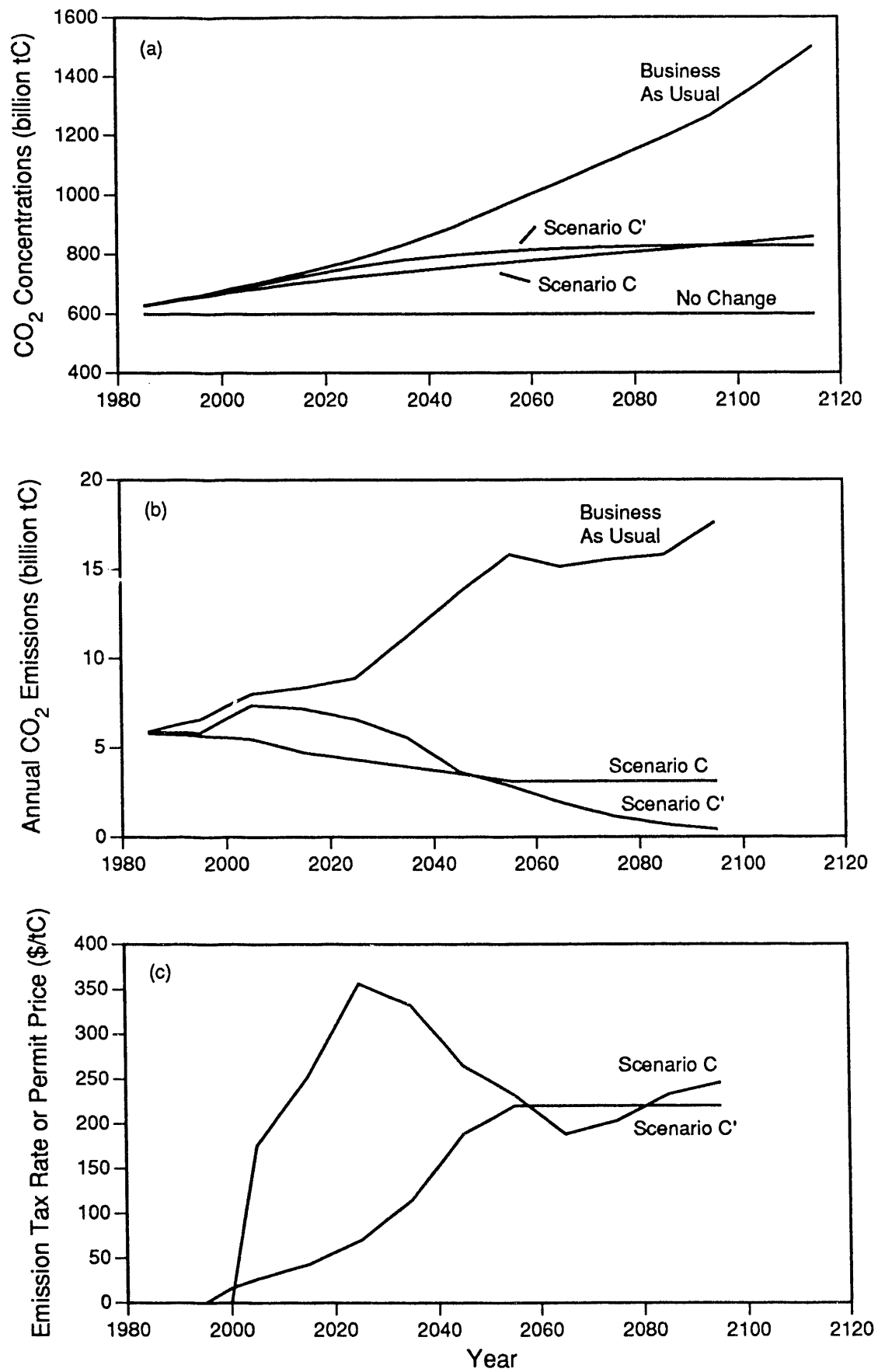


Fig. 3 Policy Scenarios C and C'

Issuing all the permits immediately for a long-run climate control goal may raise complicated questions of their allocation. Blocks of permits for periods up to 20 or 30 years ahead could be issued with the additional information that a given amount was set aside for later allocation. Expectations of a clear policy by traders would then facilitate rational bidding.

A central permit bank that issues and buys permits could operate much as a central bank that manages the money supply in nations around the world. Efforts to prevent market manipulation could be one of the tasks assigned to the bank. The fact that the bank could take policy action creates some uncertainty in the permit market. Such uncertainty could lead to trader losses and could be a welfare cost of policy discretion but, as in the case of managing the money supply, there are offsetting welfare gains.

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ACKNOWLEDGEMENTS

Work sponsored by U.S. Department of Energy, Assistant Secretary of Fossil Energy under contract W-31-109-Eng-38.

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