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Global Environmental Resources: The Ozone Problem

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ALLOKATION IM MARKTWIRTSCHAFTLICHEN SYSTEM

HORST SIEBERT (ed.)

**GLOBAL
ENVIRONMENTAL
RESOURCES**



PETER LANG

HORST SIEBERT (ed.)

GLOBAL ENVIRONMENTAL RESOURCES

This volume contains two papers which use the ozone problem as the empirical starting point of their analysis. Gladwin/Ugelow/Walter survey empirically the sector of the economy which produces fluorocarbons. The regional origin of fluorocarbons in the world and possible international ozone management strategies (e.g. interactions between the USA and Europe) are discussed. Pethig attacks the issue of ozone management from a theoretical aspect and uses game theory in order to discuss potential solutions.

Global Environmental Resources

STAATLICHE ALLOKATIONSPOLITIK IM MARKTWIRTSCHAFTLICHEN SYSTEM

Herausgegeben von
Heinz König, Hans-Heinrich Nachtkamp,
Rüdiger Pethig, Horst Siebert, Eberhard Wille

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HORST SIEBERT (ed.)

**GLOBAL
ENVIRONMENTAL
RESOURCES**

The Ozone Problem



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Preface

This volume analyses the ozone layer of the earth as a global environmental resource. The ozone layer can be interpreted as the prototype of a public good that is used in equal amounts by all. No one can be excluded from its protecting services, and its depletion would affect everyone. Simultaneously, the ozone layer can be understood as a common property resource being characterized by free access, the absence of property rights or rules of use and by a zero price.

The paper "Approaches to International Negotiations on the Chlorofluorcarbon Problem" (Gladwin, Ugelow, Walter) surveys the sector of the economy which produce fluorocarbons. An empirical picture of the sectors in Europe and the United States is given. The regional origin of fluorocarbons in the world is discussed. The paper also analyses possible European reactions to the fluorocarbon policy of the United States. Starting from this empirical description of the given situation, the paper proceeds to discuss possible approaches to shared ozone management. The basic elements of a bargaining solution are developed.

The paper "Reciprocal Transfrontier Pollution" (Pethig) attacks the issue of ozone management from a theoretical aspect and uses game theory in order to discuss potential solutions. The paper addresses non-cooperative behavior of polluters, unilateral regulations and international bargaining. The Nash-solution, optimal threat strategies and strategic manipulation of information are discussed.

Both papers use the ozone problem as the empirical starting point of their analysis. The results can be easily applied to other global environmental resources such as the acid rain issue in the Northern Hemisphere. The basic concepts may also be applied to other public goods such as natural environments, i.e. the water quality of the oceans of the world.

The ozone problem represents an interesting contrast with the issue of regional environmental use discussed in the first book in this series. In the case of regional environmental systems such as a river system or an air shed it may be easier to find institutional arrangements for environmental quality management. (Water associations). Furthermore, it may be likely that individuals truly reveal their preferences by voting with their feet (Tiebout-theorem) either by interregional migration or by commuting. Finally, voting procedures are more easily implemented in a regional setting. In the case of global environmental goods, all these aspects disappear and a solution becomes much more complicated.

I would like to thank Maria Bednarek for typing the manuscript with grate care. Manfred Schnepf has prepared the diagrams and Wolfgang Vogt has been helpful in editing the book.

Horst Siebert

Global Environmental Resources: The Ozone Problem

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Approaches to International Negotiations
on the Chlorofluorcarbon Problem

by

Thomas N. Gladwin
Judith L. Ugelow
and
Ingo Walter

In the early 1980's the international dimensions of the chlorofluorocarbon problem will assume top priority in the United States. The reasons are obvious. By banning the use of CFCs in non-essential aerosols in April 1979, the U.S. cut its share of global emissions from about 50% to roughly 20%. Ongoing damage to stratospheric ozone to a large extent therefore involves predominantly non-U.S. sources. By acting unilaterally, the U.S. has presented the rest of the world with a "free ride"--albeit at relatively modest cost--and may have seriously eroded its bargaining leverage in obtaining an international solution to the problem. Essentially, the U.S. has by its own actions turned the CFC issue from a largely reciprocal or "bi-directional" problem of transfrontier pollution to one that is substantially more "uni-directional," with the American role undergoing change by degrees from polluter to victim. As the theory of transfrontier pollution clearly shows, this changes the nature

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of the U.S. role as initiator in the search for a global ozone management policy. Regardless of the intrinsic merits of the U.S. action on CFCs in non-essential aerosols, the challenge facing the United States in the years ahead may have become more difficult.

From a purely national interest point of view as well, the nature of the problem has changed. Given its own perceptions of risk, damage functions, and degree of risk-aversion, U.S. policy thus far has achieved some benefits at relatively modest cost--a substantial reduction of CFC emissions and presumed damage to global stratospheric ozone with relatively low-cost adjustment to replacement materials and applications. In the next phase, the costs to the U.S. of further unilateral action will be enormous, but the benefits without coordinated action abroad will be small. Again depending on risk, damage and cost issues, such action by the U.S. simply may not make sense.

This paper examines the international dimensions of the CFC problem from a number of perspectives. We begin with an assessment of CFC policy outside the U.S., with emphasis on Western Europe, based on extensive interviews with individuals from industry, governments, and international organizations. This discussion is designed to describe the environment the U.S. faces in any further initiatives to move global ozone management ahead. The final section of the paper applies some principles of conflict management to the CFC problem and suggests a number of alternatives that appear reasonable the early 1980's.

It should be noted that, even prior to the U.S. ban on non-essential aerosol CFC use, world production was declining, as Exhibit 1 shows. From 1977 to 1978, fillings in North America declined 6.4%, in Europe 0.2% and in Oceania 12.7%. At the same time, fillings rose by 16.6% in South America, 15.9% in Asia, and 11.8% in Africa. On balance, world fillings declined by 1.2%. The U.S. share in 1977 was 39% of the total. In 1974, the contribution of aerosols to CFC usage was 65.9% in the OECD countries. Hence it seems unlikely that the reduction in CFC emissions brought about by the U.S. will quickly be replaced by emissions elsewhere, allowing adequate time for the international initiatives that will ultimately be required to cope with the problem.

European Reactions to U.S. CFC Policy

Although most European governments have not yet enacted legislation or imposed regulations altering fluorocarbon use, it seems that some manufacturers and users have either ceased use of fluorocarbon or are preparing for such in response to the ozone controversy. This type of behavior tends to enhance the benefits of existing and proposed U.S. CFC measures.

The collection of information for this study relied on interviews using a structured questionnaire. For the most part, the interviews were held with marketing and technical executives of fluorocarbon producers and related firms in the

air conditioning and refrigeration, polyurethane, aerosol, and auto air conditioning sectors. Although the names of these companies will not be disclosed, by agreement, each is a large contributor in its field. In addition, interviews were held with (a) the British Aerosol Manufacturers' Association (BAMA), (2) the British Refrigeration and Air Conditioning Association (BRACA), and (3) the Federation of European Manufacturers, (FEA), as well as representatives of (4) the Commission of the European Communities, and (5) the Organization for Economic Cooperation and Development in Paris. Less structured interviews were appropriate in these cases, although discussions followed the general lines established in a questionnaire, specifically designed for the study. The questionnaire sought the following information: (a) company description, (b) industry description--national and international, (c) importance of fluorocarbons to the product, (d) effects to date from the fluorocarobon-ozone controversy, (e) expected or potential regulations, and (f) effects of U.S. regulation. Additional information was obtained through trade reports and magazines, and government documentation. A general finding is that Europe, with the exception of West Germany, remains in a pre-regulatory state in terms of the use of fluorocarbons in aerosols. Much like the United States aerosol industry in 1976, the European aerosol industry is preparing for and moving toward its own version of the alternative aerosol propellant--a fluorocarbon-hydrocarbon mixture. Exhibit 2

indicates the European usage of CFCs in various product categories for 1976 and 1977.

The European Aerosol Industry

England, France and Belgium experienced an increase in aerosol production in 1977 by 7%, 4% and 5% respectively. West Germany, the Netherlands, Denmark, and Italy experienced decreases by 0.1%, 0.2%, 4.0%, and 35.0%, respectively.^{1/} Most countries are finding that hairspray, antiperspirant and deodorant, and other personal product sales relating to aerosols are dropping--slowing growth in overall aerosol use. This drop is being offset by increases in sales of insecticides, household products and other non-personal products.^{2/} The product change is significant because it potentially reduces the demand for CFCs. The former group of products requires CFCs as a propellant almost exclusively, while CFC-use in the latter group of products is generally much less and more easily substitutable.

There are several other factors, all very much interconnected, that are influencing the use of fluorocarbons in aerosols in Europe. The first is current U.S. CFC regulation. European industry feels pressure mounting from the U.S. by way of the activities of the Environmental Protection Agency, the National Resources Defense Council, and other organizations. Europe has in the past tended to adopt U.S. regulations in various areas, so there appears to be some anxiety over the eventual adoption of U.S. rules of CFCs.

^{1/} Metra Report, Tables 4.3 and 4.4, pp. 120 and 125.
^{2/} Ibid. See also Kinglake, "British Production."

A second factor is the U.S. aerosol industry. Manufacturers of "non-essential" aerosol products appear to have successfully converted a variety of products to non-CFC aerosols. The consumer has been educated about the lighter weight of the can, and product sales have been increasing significantly.^{3/} Producers' confidence in these new aerosol products is exhibited, for example, by Alberto Culver's switch in its advertising emphasis from hair spray pump to hair spray aerosol.^{4/} An additional influence is the availability of U.S. products for laboratory analysis. European conversion efforts do not have to start with the research phase.

A third influencing factor is the European Economic Community's Commission proposal, specifically Article 2, which calls for a 30% reduction in the use of chlorofluorocarbons in aerosols in relation to 1976 use levels.^{5/} As accepted by the Council of Ministers--a decision was reached in 1980-- it will go into effect by 31 December 1981. European CFC producers and users are carefully monitoring this development.

Fourth, hydrocarbon propellant producers are strongly influencing the aerosol industry. They have traditionally been dominated in the market by the CFC producers, who have developed a paternalistic attitude toward the aerosol and other CFC-related industries. Hydrocarbon producers are making a considerable effort to advise fillers on the proper conversion and safety needs of their products and facilities,

^{3/} Aerosol sales increase.

^{4/} San Giovanni, pp. 23-32.

^{5/} EEC Commission document, 14 May 1979.

and on the available grades of hydrocarbon for use in aerosol products. Though present U.S. use of hydrocarbons for aerosols only amounts to 1% of the production of propane and butane, it is a growing market.^{6/}

Fifth, because of their desire to maintain the value of their investment in the industry, fluoro-carbon producers have not given up their search for a fluoro-carbon-related aerosol propellant. They are still considering FC-22, -142b and -152a, all of which contain hydrogen and are therefore likely to break down more easily than FC-11 and -12.

The sixth factor involves economics. Hydrocarbons are cheaper than fluoro-carbons. They do not in themselves have the characteristics that make use of fluoro-carbons so attractive. Yet with the proper formulation, the final product is a good substitute. Hence there are savings to the consumer and savings to the aerosol producer in the use of hydrocarbons. The balance of such savings, and their implications for costs, prices and profits after considering costs of conversion, is not well documented.

Finally, there are a number of items which may well serve to inhibit voluntary conversion to non-fluoro-carbon aerosols. These include taxes on alcohol, odors in hydrocarbons, and safety at the workplace and at the time of use. Competing aerosol producers will not share their product secrets, but there has been a considerable effort to educate each other on the safety features required in the manufacture and use of hydrocarbon propellants. Although there are no regulations

^{6/} See Aerosol Age, "Commentary," p. 5.

against the use of hydrocarbons in Europe, they do exist in Turkey and undoubtedly in other countries as well. Indeed, one American executive expressed a fear of such regulation in the U.S. which would add significantly to the costs of conversion. These risks must be added to the uncertainty that remains in the ozone depletion hypothesis.

These seven factors have, all or in part, elicited various kinds of reactions at the industry level in the European countries. Almost without exception, they all feel that the U.S. Environmental Protection Agency was entirely too impulsive about regulation. Yet this has not prevented the British, French, Dutch, or German aerosol industries from pursuing product changes consistent with those in the U.S.

British industry representatives voiced their opposition to the U.S. CFC regulations quite clearly. Some of this reaction certainly stems from the belief that the ozone-depletion hypothesis is inherently faulty. Indeed, one executive went so far as to say that removing CFCs from the stratosphere might deny the CFCs' offsetting properties to other chemicals which are thought to play a role in an ozone depletion process. There are also two economic factors which contribute to the British reluctance to switch aerosol formulations. First, British aerosol sales are significantly on the rise, particularly exports.^{7/} Though the relative product strengths are changing, and those with only some or no CFCs are gaining, the American experience of "all are guilty" threatens the present trend of growth. The second is the experience of S.C. Johnson Company. In 1976, after the company 7/ Kinglake, "British Production."

switched to non-CFC aerosol formulations company-wide, its market share dropped from 8% to 7% in 1977, a significant decline.

Despite these apparent short-term problems, the British feel there are some gains to be made by altering aerosol formulations to include hydrocarbons. There is a trade-off here--a loss in performance versus the savings from using a less expensive propellant. This has facilitated an agreement made by industry with the British government to reduce CFC use wherever possible. And, the industry is anticipating adoption of the EEC program, so that all manufacturers are preparing for different formulations.^{8/} At least one company has begun marketing one of its new products in Europe, but outside of Britain--it is waiting for consumer acceptance before bringing the product back to the U.K., since timing is of critical importance to the commercial viability of a new product.

This effort to change away from CFCs in aerosols is dampened by two technical problems: the problem of plant safety, which is shared by everyone in the aerosol industry, and the problem of odors in hydrocarbons. The first has already been mentioned. The second, which may be specific to Britain alone, stems from a law that requires household-grade hydrocarbons to be identifiable by smell. In the U.S., hydrocarbons for aerosols can be made odorless, or "sweet," by scrubbing and repeated molecular sieving. This is not an option for the British. Consequently, U.K. manufacturers feel that perfume products cannot be adequately reformulated without
^{8/} Personal interview.

fluorocarbons--many would even include all personal products in this category.

The French aerosol industry is in a similar situation to the British in terms of sales growth, but the strongest product category remains perfumes/colognes. Despite the repeated statements that the French woman would never accept inferior products--meaning those reformulated with hydrocarbons--it is rumored that the largest aerosol producer in France is already prepared for reformulation. However the product savings might not be comparable with those in Britain, U.S. and other countries because of a heavy tax on alcohol which drives up the cost of the product. Alcohol is required with hydrocarbon propellants to reduce product flammability.

The German aerosol industry has already undergone a substantial change. In 1977 the industry made an agreement with the German government to reduce CFC use in aerosols by 30% from 1975 levels effective 31 December 1979. Because CFC use was higher in 1975 than in 1976, the Germans face a relatively tougher reduction requirement than that called for by the EEC. It is not known how the German industry protects itself against the competition from imports containing CFC propellants. The reformulated German cans are labeled "environmentally friendly," and this may provide enough of a competitive edge for products marketed in a socially-minded environment.

In the Netherlands aerosol products containing CFC's are labeled with a warning so stating, a regulation effective

1 April 1979. Reformulated products are being marketed there, but the degree of success has not yet been measured. The situations in Spain and Italy are unpredictable--"politics are always interfering," one observer noted. But the speculation is that there are internal changes being made in the industry in preparation for the adoption of the EEC regulation.

The general conclusion from interviews is that the European aerosol industry has already taken a major step toward accommodating CFC use-reduction.^{9/} How much of this is manifest in actual measures and how much as yet shows up only in company plans is difficult to assess. It may be that a majority were waiting for the EEC directive and for new scientific findings--another part of the EEC program asks for review of the first round of directives in light of new scientific evidence.^{10/} This would require two costly steps toward complete elimination of CFC's in the use of non-essential aerosols.

The European Refrigeration and Air Conditioning Industry

Refrigeration and air conditioning in Europe at present employs only 11% of R-11 and R-12 production. This number is considerably less than that in the U.S. The climate in Europe requires far less air conditioning than in the U.S., although much of the equipment manufactured in Europe is used industrially throughout the world. Refrigeration is of course in widespread use in Europe and elsewhere. In Britain alone, total 1979 sales and installations by this industry were ^{9/} Kinglake, "Toiletries and Cosmetics," pp. 35-36. ^{10/} Hartford, pp. 21-23.

valued at £2 billion. Statistics for other countries are not available, although they should clearly be comparable for West Germany and France, as well as Italy--one of the major producers and exporters of household refrigerators.

The European market is dominated by the affiliates of three U.S. companies--Carrier, Trane, York, and the Swiss firm, Sulzer, as well as various local suppliers like Bosch, AEG, Siemens, etc., that sell both nationally and internationally. However, product changes often come through the first four of these suppliers. It is interesting to note that while affiliated European companies of U.S. firms provide essentially the same product, one executive felt that there was greater flexibility in his European operations, and that Europe could more easily tolerate a system utilizing ammonia than could the U.S.

In designing refrigeration and air conditioning systems for industry, companies are often specifically requested to utilize either ammonia or a CFC. One installation in Poland, for instance, was build for use with CFC because the customer insisted it was easier to operate and required fewer engineers. Another executive, however, said that one country in the Middle East requested an installation requiring ammonia for the same reason. This contradiction is explained by the fact that many technical variables and the mix of service conditions will determine the ideal choice.

Although only the U.S. is explicitly considering CFC regulation in the air conditioning and refrigeration

sector, the repercussions are widely felt due to corporate ties especially in Europe. The refrigeration and air conditioning industry has always stressed the need to avoid CFC leakages--which result in equipment breakdowns. But this point has been strongly reiterated in the past few years by an industry which is threatened by potential regulation. The EEC Council Resolution of 30 May 1978 states that "Immediate steps should be taken to encourage the manufacturers and users of equipment containing chlorofluorocarbons F-11 and F-12 to eliminate the discharge of these compounds."^{11/}

The British refrigeration industry recently reported to their Department of the Environment, as its request, on technical improvements and a possible code of practice which would reduce or eliminate CFC leakage. The report is classified, but it apparently estimated that such practice could reduce fluorocarbon consumption by 25-30%. One problem now seems to be quality control--assembly of parts results in some mismatch. An improvement would be to prepack and make one manufacturer responsible for all parts of a particular assembly.

There are no other obvious developments in the European refrigeration and air conditioning industry in terms of reacting to the ozone depletion thesis. The European fluorocarbon industry is reportedly researching the use of fluorocarbons other than R-11 and R-12 in refrigeration and air conditioning equipment. Some conversion was made a few years ago to R-22 and R-502, although these modifications 11/ EEC Commission document, 14 May 1979.

only affect new equipment. These kind of changes, however, are viewed as requiring a great deal of time to work through.

There may be some R&D on the part of the European fluorocarbon industry devoted to developing a recycling and purification system for CFCs but there was no explicit discussion of such among manufacturers. That kind of investment is extremely expensive, one executive noted, and refused to speculate about future possibilities. He noted that technical improvements were the best bet for significant emissions reductions in an industry that does not use a great quantity of CFCs in the first place.

The European Polyurethane Foam Industry

The polyurethane foam sector represents an expanding industry in Europe, with flexible foam demand growing at 3% a year, and rigid foam demand growing at 8% a year.^{12/} The markets in Europe are largely based on strength in basic construction and automotive demand. Big export markets are North America, Japan and Eastern Europe is evidencing a growing interest in shoe manufacturing, especially jogging shoes. Iran was a large and rapidly growing market until the revolution in 1978-79.

The polyurethane chemical industry is an oligopoly, selling to numerous foam manufacturers. The relationship between the chemical producers and foam manufacturers is similar to that of the fluorocarbon producers and aerosol manufacturers. The chemical producers perform an advising function as well as ^{12/} Metra Report, pp. XVII-XVIII.

development of formulations. The larger polyurethane chemical producers in Europe are BASF, Bayer, ICI, Montedison and Upjohn, with a smaller input from DuPont, RhônePoulenc and Shell.

There are four factors influencing change in the polyurethane foam industry. The first factor is U.S. fluorocarbon regulations. This has been the only source of particular pressure on urethane products resulting from the fluorocarbon-ozone controversy. However, aerosol foam systems in Sweden were also threatened by the Swedish regulation banning CFCs in non-essential aerosols, although it is thought that the final Swedish assessment released these systems from regulation.

Another factor is the proposed second phase of U.S. fluorocarbon regulations, which includes foam products in its domain. The possible content of this development is not yet fully known, but the European polyurethane industry is aware of and concerned with the possibility of further regulatory moves in the U.S.

The third factor is the EEC Council Resolution of 30 May 1978, which stated that "Immediate steps should be taken to encourage all the aerosol and plastic foam industries using chlorofluorocarbons F-11 (CCl₃F) and F-12 (CCl₂F) to intensify research into alternative products and to promote the development of alternative methods of application."^{13/}

A fourth consideration is Dow Chemical Corporation and other firms that market methylene chloride, a close substitute for F-11 in flexible foam manufacture. There was some 13/ EEC Commission document, 14 May 1979.

question about the toxicity of methylene chloride, a question which Dow promptly investigated. Although Dow gave it a clean bill of health, there is at least in Germany a toxicity limiting value (TLV) of 100 ppm because methylene chloride metabolizes to carbon monoxide.^{14/}

The changes that have occurred in the European foam industry are not yet visible in terms of a changed product. Price, employment and production have not yet been affected. There is change, however, in R&D expenditures. Companies are actively looking for alternative formulations. Executives state that flexible foam will be made less soft if CFC's are used more sparingly and more water is used, but they concede that the product would eventually be accepted by the market. Rigid foam, however, cannot at present be manufactured any other way, and to remove CFCs from the formulation is to kill a product vital to energy conservation.

Proposals have been made to cut fluorocarbons released during flexible foam manufacture, but R&D emphasis has not been given to this issue as yet. Recycling might be considered in the longer term but the process at present is uneconomical. In addition, the amount of air required to vent manufacturing areas makes the fluorocarbon-air mixture so dilute that recapturing fluorocarbons is close to a technical impossibility.^{15/}

European executives, in anticipating regulation of flexible foam in the U.S. and the possibility of subsequent

14/ Personal interview.

15/ Personal interview.

regulation in Europe, are concerned with harmonization of laws in order to avert massive reorganization in competitive structures. Since regulation would be on production rather than consumption, foreign manufacturers could market in areas where manufacturing is banned. Harmonization of policies in this area throughout the EEC is viewed as a necessity.

The European Auto Air Conditioning Sector

The automobile air conditioning industry in Europe is quite small. Its largest markets are outside Europe.^{16/} Only 10% to 15% of the cars in Europe are equipped with air conditioning units, whereas in the U.S. the percentage is around 80. One interviewee foresees air conditioning use eventually reaching 25%, but not anytime soon since it is used on the larger, more expensive cars which also use more fuel and are not likely to be in great demand in the foreseeable future. The auto air conditioning market is supplied by Behr of Germany, Sofica of France and Ipra of Italy, and there are units supplied by various U.S. companies. The market is in large part split between Behr and Sofica.

The auto air conditioning firms do not seem to have been influenced by the ongoing fluorocarbon-ozone controversy.^{17/} Indeed, one interviewee was quite perplexed as to why he was being included in the study. His view was that, if there were any changes to be made, they would probably come from the fluorocarbon suppliers themselves.

^{16/} Personal interview.

^{17/} Personal interview.

Summary

Our assessment of European reactions to U.S. CFC policy revealed that there are major changes occurring in the European aerosol industry, while there are more subtle movements, if any, in the air conditioning and refrigeration, polyurethane, and automotive air conditioning sectors. The European aerosol producers have, for the most part, prepared reformulations of products reducing the amount of, or eliminating, CFC propellants per unit in light of anticipated EEC regulatory directives and in response to perceived economic advantages. These products have appeared in West Germany, the Netherlands and Belgium. Their appearance in the remaining European countries depends on the resolution of uncertainties in the ozone depletion theory, in the passing of the EEC regulation directive, and in determining the strength of market share for a new product.

Product change or adaptation has not occurred in the other three CFC related industries. The air conditioning and refrigeration, and the polyurethane industries are each devoting additional R&D efforts to technical improvements and alternative refrigerants, in the first case, and to alternative blowing agents and reformulation in the second case. Representatives of the air conditioning and refrigeration industry foresee substantial savings in CFC use coming from these technical improvements and from the institution of a code of practice which would charge one manufacturer with the production of entire assemblies. The polyurethane industry representatives could accommodate the reduction, and possibly elimination of

CFCs in their flexible foams, but only if there were to be identical requirements, at the least, throughout Europe and the U.S. Changes in the formulation for rigid foams would obliterate this product's advantage, and, therefore, its market. Hence, producers are firm in their request for its release from regulation. The automotive air conditioning industry has felt no impact from either U.S. CFC policy or the ozone controversy as a whole as yet.

Shared Ozone Management

We have now discussed, in some detail, the degree to which ozone management policies in major CFC source countries differs from that in the U.S., and the way these differences are likely to unfold in the years ahead. Our conclusion is that there is a problem, stemming from differences in perceptions of scientific evidence, damage functions, costs of control, and attitudes toward risk. Whereas these differences are perhaps not as strong as they once were, particularly with recent initiatives in the EEC, there remains a significant problem of international coordination to be resolved. The second part of this paper develops the nature of options from unilateral and multilateral initiatives--concentrating particularly on constraints facing unilateral measures.

The stratospheric ozone layer clearly represents an international common property resource--a natural asset providing man with an indivisible and valuable flow of services. Because no one can control access to the flow of services, and any individual can feasibly take advantage of

them, the ozone layer cannot be reduced to private ownership and effectively exchanged in markets. As with other common property resources, open and complete access to the services of stratosphere ozone appears to be leading to overuse, misuse and quality degradation. The ozone layer is, the addition, a public or collective good--its stream of services can be used by one person without diminishing its availability to another. Its improvement or depletion affects everyone. The outcomes of management efforts to protect it from CFC-induced degradation also represent public goods. As such, we can perceive that a "free rider" problem exists--nations may see few incentives to contribute to a CFC abatement effort given that they can have free access to the benefits other nations generate by their abatement actions. Incentives exists for countries to falsely report their benefits and costs in order to profit from the actions of others.

International action aimed at the ozone problem is obviously desirable to avert a possible "tragedy of the commons" given that CFCs are used worldwide, that stratospheric CFC pollution does not recognize national boundaries, and that any depletion of the ozone layer is expected to impose damages around the globe. For idealists, the only answer to this kind of problem is to create a sort of international environmental protection agency that would design and apply worldwide international controls. But in a world where national sovereignty is still jealously guarded, the call for a global EPA remains a utopian, impractical notion. And so the ozone

management problem can be solved only through voluntary behavior on the part of CFC producing and/or consuming nations--realistically, compulsion is simply not possible.

Here we shall attempt to add to the insights already provided by our survey by theoretical approaches. We shall first examine the ozone depletion problem from the point of view of some simple theory, and then develop a framework for assessing the probable success of an effort aimed at bringing about a coordinated international approach.

An Elementary Model

A simple model, adapted from the work of Charles Pearson on ocean management, can be used to suggest some principles for the shared management of stratospheric ozone.^{18/} The model highlights problems in negotiation of international controls in the absence of a supranational authority, the inherent linkage between concerns of allocative efficiency and distributional consequences in dealing with international common property resources, and the apparent need for international transfer payments (i.e., bribes) between nations in order to obtain optimal agreements. The basic question addressed is whether globally optimal reductions in CFC emission levels can be approximated via independent, parochial national abatement efforts. Assume for simplicity the following:

1. A world composed of two actors: the United States (us) and the rest of the world (rw). Each pollute the commonly shared ozone layer, using it for CFC waste disposal services.

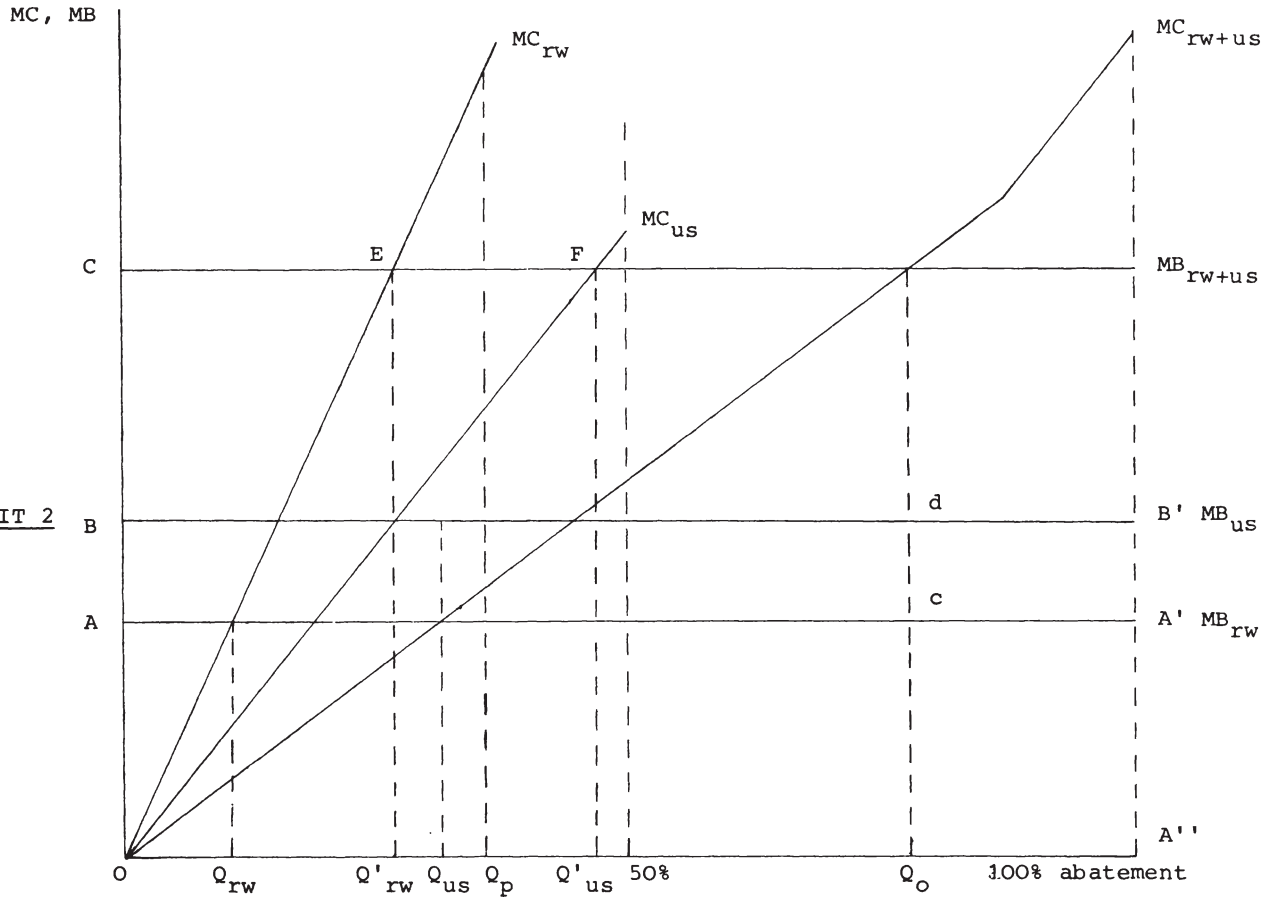
^{18/} See Pearson, in Walter (ed.), 1976. See also Pearson and Pryor.

2. Each actor contributes an identical amount of CFC emissions (such as was approximately the case prior to U.S. action on nonessential aerosols).
3. Marginal damages from CFC emissions are constant.
4. CFC emissions once rising to the stratosphere cause identical damages, regardless of whether they emanate from the United States or the rest of the world.
5. Marginal costs for CFC abatement are independent and rising.
6. Marginal costs of CFC abatement are higher in the rest of the world than in the U.S. (reflecting, for example, greater difficulties in finding alternative propellant and refrigeration technologies, and the like).
7. Marginal benefits from CFC abatement are independent and constant (this is the implication of assumed constant marginal damage from CFC emissions).
8. Marginal damage (i.e., abatement benefit) from CFC emissions is at a higher level of the United States than for the rest of the world (as a consequence, for example, of skin pigmentation, altitude, latitude, agricultural production, and risk-cost perceptions).
9. Neither actor, in the absence of compulsion, will undertake CFC abatement beyond the point where it is made worse off by doing so.

This situation is depicted in Exhibit 2. The horizontal axis measures CFC emissions abatement by both actors. At 100%, therefore, neither party is depleting stratospheric ozone. The vertical axis measures marginal costs (MC) and marginal benefits (MB). Marginal costs of CFC abatement are MC_{us} for the United States and MC_{rw} for the rest of the world. The constant marginal benefits from CFC abatement are indicated by MB_{us} for the United States and MB_{rw} for the rest of the world.

The global marginal costs of CFC abatement--assuming that the responsibility for reducing CFC emissions is efficiently

EXHIBIT 2



Adapted from Pearson and Prior.

allocated between the United States and the rest of the world-- is the horizontal sum of MC_{rw} and MC_{us} , or $MC_{rw + us}$. This represents the minimum global marginal CFC abatement cost curve. Leaving aside the distributional consequences for the two parties, Exhibit 2 shows that the incremental real resource costs of CFC abatement will be equal to the incremental damages avoided only at level Q_0 . To achieve that level the rest of the world would undertake CFC emissions reduction at the level Q'_{rw} , while the United States would undertake abatement at the level Q'_{us} . At Q_C resources would be allocated in an optimal fashion from a global perspective. Dual optimality criteria would exist: $MC_{rw + us}$ would equal $MB_{rw + us}$ and marginal CFC abatement costs from all emitting sources would be equalized, that is, MC_{rw} would equal MC_{us} .

Exhibit 2 provides various insights regarding potential international negotiations over CFC emission reductions. If no CFC abatement were undertaken by either party, for example, the United States (under our assumptions) would suffer greater total damages than the rest of the world (OBB'A" is greater than QAA'A"). Even though both would be contributing equal quantities of CFC emissions, the United States because of its damage assessment would suffer a greater welfare loss.

Another point is that unilateral action, taken independently and from a purely national perspective (i.e., exclusively a function of local CFC abatement cost and damage functions), could improve each party's welfare. Unilateral action, however, would result in suboptimal CFC abatement from

a global perspective. The reason is that the rest of the world would equate its marginal costs and benefits ($MC_{rw} = MB_{rw}$) and pursue an abatement level Q_{rw} . The United States would similarly choose $MC_{us} = MB_{us}$ or abatement level Q_{us} . As shown, the sum of the unilateral CFC abatement efforts (OQ_{rw} and OQ_{us}) would add to less than the optimal OQ_o . This simply reflects the essential character of externalities imposed on international common property resources--national decisions to undertake CFC abatement, in the absence of compulsion, would not take into account incidental damage caused to other nations.

It follows that the prospects that an international agreement among the parties on reducing CFC emissions will select the globally optimum CFC abatement level (Q_o) are poor unless compensatory payments can be made between the parties. The globally optimal CFC abatement level, under our assumptions, would require a greater relative and absolute CFC abatement effort by the United States than the rest of the world (Q'_{us} is greater than Q'_{rw}). If the outcome of negotiations is a requirement of equal CFC abatement, the optimal level Q_o would be reached in each party undertook Q_p . But at Q_p the marginal cost for the rest of the world exceeds the marginal cost for the United States, and the allocation of CFC abatement effort would therefore be inefficient. The implication for global CFC policy is as follows: If CFC abatement cost and damage functions differ markedly from nation to nation, then optimal environmental policy for

managing the shared ozone layer will generally require disproportionate cost burdens. Countries having relatively low-cost alternatives (and/or greater damage or benefit perceptions) would need to undertake greater CFC abatement in order to approach the globally optimum abatement level. One can easily predict resistance on equity grounds, especially if no compensatory payments could be made.

But another feature in our example should be noted. If the optimum global level of CFC abatement were chosen, both the United States and the rest of the world could be better off than if there were no CFC abatement. The global optimum is thus not ruled out. This can be seen in Exhibit 2 comparing the area under the marginal benefit curves for the rest of the world and the United States. Net benefits for the United States would be $OBDQ_0$ less OFQ'_{us} . The rest of the world would receive net benefits equal to $OACQ_0$ less OEQ'_{rw} --that is, gross benefits less CFC abatement costs.

What conclusions can be drawn from this simple conceptual analysis? One is that unilateral action by CFC producing and consuming nations to reduce CFC emissions based on their narrow cost-benefit calculus will go some distance toward protection the stratospheric ozone layer--but the abatement level achieved is likely to be suboptimal from a global perspective. The chances of the optimum being attained will be greater, the more local the damages caused by ozone depletion, that is, the smaller the external costs passed among nations. In any case, the United States should be able to encourage other nations to

take protective measures of stratospheric ozone by showing that those efforts are in their own self-interest. The key will rest in influencing the substance and process of cost-benefit analysis in those nations. In terms of our analysis, efforts should be directed at raising perceived marginal benefit (damage) functions and lowering perceived marginal cost functions.

As we have already noted, in the absence of a supranational authority that could compel compliance, a reasonable working assumption is that nations will voluntarily join an agreement to limit CFC emissions only if they are made no worse off by so doing. Our model implies, however, that a voluntary agreement among nations to limit CFC-induced ozone depletion could possibly encourage each to go beyond its parochially determined abatement levels. This is because the potential for each being made better off may exist. There may be benefits associated with joint reduction efforts, therefore, which can be used to motivate nations into going further in CFC abatement than if they were left alone. This, once again, simply reflects the common property/public good nature of the ozone layer--nations benefit themselves as well as others when abatement efforts are undertaken.

Attaining the true, global optimal CFC abatement level, however, will probably require use of some international compensatory system. Those nations with lower marginal abatement costs (in our example, the United States) may find it necessary to compensate those nations confronting higher

marginal costs (or perceiving lower marginal benefits), in return for those nations undertaking abatement efforts beyond those called for in purely local optimization terms. If no compensation payments--side deals such as trade concessions, foreign aid, troop levels and the like--can be made, or if the only "currency" for making payments is in units of CFC abatement, it is unlikely that the globally optimum level of CFC abatement will be attained. The rationale for compensation paid by the "victim" (the United States in our example) is simple--as long as the amount of the bribe needed to induce the other nations to reduce CFC emissions is less than the damage inflicted on the bribing nation, then that nation will be better off by paying the bribe. More in the way of compensation payments may be necessary as a result of the unilateral action of the United States banning CFC use in nonessential aerosols. The argument can be made that the United States gave away units of CFC abatement in return for very few concessions by other producing nations. With fewer and only terribly more expensive units of CFC abatement available to trade, the United States may have to turn to other forms of compensation.

Applications of Shared Management Principles

Stratospheric ozone is not the first international common property resource problem confronted by the world's nations. Useful lessons for U.S. ozone policy, therefore, can be drawn from examining previous experience with attempts at managing

shared natural resources (oceans, lakes, rivers, fisheries, airsheds, and the like). An extensive review of the theoretical and empirical literature concerning these efforts at shared resource management indicates many factors or conditions bearing on the likelihood of successful international cooperation.^{19/} Exhibit 3 provides a listing of these factors and also suggests the attributes of each which have generally been found to either facilitate or impede the process of developing international agreement and coordination regarding constructive management of a shared common property resource. The factors are classified into four interrelated categories: characteristics of the environmental or resource problem at stake, the parties (nations) involved, the problem-solving capabilities available, and the wider negotiating context in existence.

Exhibit 3 can be interpreted in a probabilistic fashion. Examine, for example, the nine characteristics associated with the type of environmental problem at stake (Section A). Some kinds of international environmental problems are more likely to motivate or facilitate joint management action among nations than others. Successful cooperation, according to our literature review, appears most likely when transfrontier pollution damages are reciprocal, when scientific consensus has been achieved internationally, when the underlying theory (e.g., chemical, physical, biological) and associated risks involved are relatively certain, and when the problem is

^{19/} Among others, see Barros and Johnston, Caldwell, Hargrove, Kay and Skolnifokk, and Young.

Exhibit 3

Factors Bearing Upon Successful Joining Management of a
Shared International Common Property Resource

Factor	<u>Attributes which tend to:</u>	
	Facilitate Cooperative, Coordinated Management	Impede Cooperative, Coordinated Management
A. <u>Characteristics of Environmental Problem at Stake:</u>		
1. Transfrontier pollution flow	reciprocal	one-way
2. International scientific consensus	present	not present
3. Uncertainty of underlying theory	low	high
4. Uncertainty of associated risks	low	high
5. Problem urgency	immediate	distant
6. Problem scale/scope	small	large
7. Problem gravity/severity	serious	trivial
8. Problem clarity	distant	fuzzy
9. Problem reversibility	irreversible	reversible
B. <u>Characteristics of Parties (Nations) Involved:</u>		
1. Number of parties	small	large
2. Perceived damage functions	similar	dissimilar
3. Perceived abatement cost functions	similar	dissimilar
4. Risk-cost tradeoffs	similar	dissimilar
5. Desires for national sovereignty	weak	strong
6. Business-government relations	similar	dissimilar
7. Environmental political pressures	similar	dissimilar
8. Technologies employed	similar	dissimilar
9. Economic development levels	similar	dissimilar
C. <u>Characteristics of Problem-Solving Capabilities Available:</u>		
1. Supranational enforcement authority	existing	not existing
2. Quality of experts involved	high	low
3. International organization involvement	strong	weak
4. International scientific involvement	strong	weak
5. Financial resources available	abundant	scarce
6. Availability of alternative technologies	available	not available
7. Solution complexity/difficulty	easy	difficult
8. Economic costs of solution	low	high
9. Leadership role assumed	assumed	not assumed

Exhibit 3 continued

Factor	<u>Attributes which tend to:</u>	
	Facilitate Cooperative, Coordinated Management	Impede Cooperative, Coordinated Management
D. <u>Characteristics of Negotiating Context in Existence:</u>		
1. Number of issues	few	many
2. Volume of transnational relations	high	low
3. Availability of precedents	available	unavailable
4. International legal foundations	developed	undeveloped
5. Precedent setting	will not set	will set
6. International payments network	developed	undeveloped
7. Transactions costs	low	high
8. Third party pressure	present	not present
9. Dispute resolution machinery	existing	not existing
10. Quality of diplomatic relations	high	low
11. Kind of firms involved	multinational	domestic
12. Equity vs. efficiency balance	efficiency	equity
13. Reversibility of regulatory action	reversible	irreversible

Exhibit 4 continued

	Likely to greatly facilitate cooperation	Likely to partly facilitate cooperation	Likely to partly impede cooperation	Likely to greatly impede cooperation
7. Solution complexity/difficulty				(X)
8. Economic costs of solution			(X)	
9. Leadership role assumed	(X)			
D. <u>Characteristics of Negotiating Context in Existence:</u>				
1. Number of issues	←←←←←←←←←←X			
2. Volume of transnational relations	(X)			
3. Availability of precedents				(X)
4. International legal foundations		(X)		
5. Precedent setting		X→→→→→→→→→→		
6. International payments network		(X)		
7. Transactions costs	←←←←←←←←←←X			
8. Third party pressure		(X)		
9. Dispute resolution machinery		(X)		
10. Quality of diplomatic relations	(X)			
11. Kind of firms involved	(X)			
12. Equity vs. efficiency balance		X→→→→→→→→→→		
13. Reversibility of regulatory action		X→→→→→→→→→→		

brackets around some of the X's indicate that no significant movement in either direction is expected. A summary of the logic employed in reaching these points and trends judgements follows.

Characteristics of the CFC problem. The ozone depletion problem is currently marked by a range of features which probably makes international cooperation difficult to achieve. One critical factor working in favor of cooperation, however, is the mutuality of the CFC emissions damage flows--"reciprocal transfrontier pollution is in some ways as easier problem to solve than simple one-way transfrontier pollution. The reason is, of course, that the polluting country itself feels the direct consequences of its own action, which diminishes the cost-benefit gap between it and the victim country with respect to the pollution-control process. There is at least partial coincidence of both rights and damages. As a result, the bargaining conflicts are less, and the likelihood of compromise solutions is correspondingly greater."^{20/} We must note, however, that the United States--via its frontrunner unilateral actions in banning CFC use in nonessential aerosols--has greatly reduced its contribution of global CFC emissions (from a share of about one-half down to about one-fourth).

Despite the fact that damages are still reciprocal (but less so now than a few years ago), most other features of the ozone-depletion problem appear biased against collaborative international CFC controls. Although there is growing

^{20/} See Walter, 1975.

scientific agreement (more so in the United States than overseas) that CFCs do deplete stratospheric ozone, there is still sharp disagreement over the rate of depletion and whether it is rapid enough to warrant further restrictions. The degree of international scientific acceptance of the full ozone-depletion theory and its consequences will fundamentally affect the pace at which control measures are adopted. But proof of the theory and an accurate pinpointing of the depletion rate are years away, and no near-term results are likely to settle the uncertainties of the ozone-depletion hypothesis. In addition, many doubts still exist about the risks of continued CFC use. The risk of skin cancer in humans, possible damage to crops and wildlife, and particularly long term changes in climate, all continue to be widely debated--for some, the risks are reason for hysteria; for others, they are trivial. These uncertainties in large measure explain the staunch wait-and-see attitude of various foreign governments (e.g., Britain, France). Research programs currently underway, however, may help to reduce these uncertainties over the next years, at least in part, and thereby facilitate the formation of international scientific consensus.

Still other features of the problem appear biased against quick and cooperative international action. One is a divergence of opinion regarding the urgency of the ozone-depletion problem. No immediate hazard to life is at stake and adverse effects predicted to appear thirty to fifty years from now are

heavily discounted. The problem is also global in its dimensions, on a scale that is very difficult to solve. And even given the worst possible interpretation of the ozone threat, such as eventual losses of up to 20% of the stratosphere's ozone, some experts have concluded that the adverse effects (e.g., in the form of incremental cases of skin cancer per 100,000 light-skinned population living at high altitudes) would be relatively minor. Still other scientists claim that anthropogenic generation of prodigious amounts of CO₂ is both speeding up the generation of stratospheric ozone and slowing down those reactions which may act to deplete it. The implication is that the insertion of CFCs into the environment may perhaps be beneficial in helping to limit the degree of eventual ozone proliferation. In any case, the nature of the total ozone layer problem is still unclear, particularly with respect to combined or synergistic effects of atmospheric pollutants--more research may help to reduce these uncertainties in the years ahead.

Finally, not all are convinced that we are dealing with a problem which nature cannot correct. In some quarters the view is emerging that the ozone layer is a durable, rugged system that possesses a remarkable ability to recover from perturbations and restore the ultraviolet shield. In sum, current perceptions of the CFC-ozone depletion problem appear heavily biased against the development of international consensus and synchronous or tandem emissions control action.

Progress hinges critically on the reduction of many types of scientific uncertainty.^{21/}

Characteristics of the parties involved. Many characteristics of the nations involved in CFC production and consumption also militate against effective international action. Perhaps the two most negative factors are the large number of "relevant" countries involved and deeply imbedded notions of "national sovereignty." The large number of parties involved translates into difficult communication, coordination and implementation problems on goals and means of CFC control. Involvement of relatively disinterested or "coerced" parties would tend to reduce outcomes to the "lowest common denominator." For this reason, it may be wise to seek coordinated action only on the part of the primary producer nations--substantial improvements could result even in the absence of countries such as the Soviet Union, India, Argentina, South Africa, or those of Eastern Europe. But even among the OECD nations, most will remain unwilling to give up their freedom of action in favor of international constraints.

If the communist and developing nations are set aside, then problems associated with different types of technology and levels of economic development should not represent major stumbling blocks in achieving international cooperation. Most of the OECD nations involved should be able to more or less equally bear the costs of reducing CFC emissions. But ^{21/} See Fox.

a range of other variations among the primary producer nations may constrain development of a cooperative approach. Even if the objective uncertainties regarding the CFC-ozone depletion are reduced, subjective assessments of the risks and costs involved would surely continue to differ among nations. Most societies are less risk-averse than the United States--few are willing to go as far in implementing policy using the "better-safe-than-sorry" philosophy. On both objective and subjective grounds, perceived damage and abatement cost functions are likely to remain varied among the producing nations involved. Convergence will depend on the attainment of better scientific understanding and consensus internationally.

We should also note that the power of CFC industries and environmental lobbies to influence the shape of government policy of CFCs varies among nations. The industry point of view is generally given greater weight on environmental questions in countries such as France, the United Kingdom, Italy and Japan than in the United States. And environmental groups which in the United States have helped to keep the ozone depletion issue in the public spotlight, are generally much less powerful in most other CFC producing nations. Furthermore, within most environmental group communities overseas, the ozone-depletion issue has not rated as high a priority as in the United States. The issue has also not received the equivalent amount of attention from the press. Indigenous political pressures for CFC control, in fact, have yet to develop at all in some of the nations involved.

Characteristics of the available problem-solving capabilities. Of the four categories of factors profiled in Exhibit 4, the brightest outlook for international cooperation appears to rest with the problem-solving capabilities available. The CFC-ozone depletion problem has attracted high quality scientific expertise (particularly in the U.S.) and financial resources for atmospheric research and economic evaluation have been abundant. International organizations such as OECD and various bodies of the United Nations have become involved (perhaps thus far not to the extent necessary) and a leadership role has been assumed by the United States. Leadership, of course, entails both benefits and risks. The U.S., by bringing the issue to the world's attention and in initiating remedial action by banning nonessential uses of CFCs, has hopefully set the stage for a powerful "demonstration effect." The road ahead has been paved. With time and careful diplomacy, others will hopefully follow. Coercive pressure tactics to induce the "bandwagon," however--given the uncertainties and national viewpoints reviewed about--could easily backfire.

On the negative side, the foremost obstacles to international cooperation in this capability sector relate to the difficulty, complexity and feasibility of technological solutions. Finding substitutes for CFC use in aerosols, of course, has proved to be quite feasible and rather painless. The real problems center on the availability of substitutes

for nonaerosol CFC applications--ready substitutes have reportedly not yet been found for CFCs as refrigerants and foaming, cleaning and fire extinguishing agents. Much resistance can be expected unless and until the technology for replacing CFCs develops further (which may indeed occur over the next few years). Until then, the perceived economic costs of CFC controls will remain high--aggregate abatement costs will naturally be highest in large CFC producing and using nations such as the United States, West Germany and the United Kingdom.

Although certain segments of the foreign scientific community have exhibited considerable interest in the CFC-ozone-depletion problem, still deeper and more widespread involvement is necessary. The reason is that international scientific consensus is not likely to develop rapidly unless such expanded involvement is attained. No supranational authority having the power to compel compliance currently exists, and none is likely to emerge soon. Without such compulsion, international cooperation can be obtained only through voluntary means. Local scientific support for CFC control measures would seem to represent a necessary condition for such voluntary behavior to come about.

Characteristics of the negotiating context. The broader context surrounding international negotiations over CFC emissions consists of an assortment of institutional factors bearing upon bargaining incentives and processes.

In general, that context currently appears to be midly unfavorable. We do see, however, a large volume of transnational relations among the OCED CFC-producing member countries. Flows of influence and communications are multifarious. Economic, political, military, and cultural ties are close and diplomatic relations are generally of a high quality. Bargaining is thus among "friends" (assuming Communist and developing nations are not involved). Another potentially favorable factor is that some CFC-related industries involve multinational companies. Flows of technology, information and policy from the U.S. or European parents to their foreign affiliates in regard to CFC substitutes may represent an important mechanism for bringing about CFC emissions reductions overseas. Home-country governments may be able to shape the incentives guiding managers at the headquarters level of these firms such that global emission reduction policies are adopted. In certain cases, of course, the involvement of multinationals in the CFC problem may inhibit cooperation among governments, particularly if the firms choose or threaten to escape to "CFC pollution havens." Such behavior may not occur, however, given that the CFC emissions issue is mainly a consumption rather than production related environmental problem--what good would it do to switch production of CFCs or CFC-using goods to a "pollution haven" if the flow of such goods into major markets could easily be stopped via import barriers.

The basic institutional problem is the fact that international efforts to manage common property resources is a rather new endeavor on the world scene. Few tried and tested precedents are available, experience with large scale international negotiations is sparse, international law in the area is quite embryonic and not definitive, impartial dispute resolution machinery for such issues does not yet exist, third party roles and pressures are undeveloped, and perhaps most importantly, international compensation networks are highly imperfect. We saw earlier that prospects for optimal or adequate international environmental safeguards may critically depend on flows of compensation between victims and polluters. More efficient mechanisms for such international transfers remain to be developed.

The number of issues at stake in the CFC-ozone-depletion problem, and the transactions costs entailed in the bargaining process, are likely to decline over time as uncertainties are reduced and experience with negotiations develops. But other factors may still serve to impede progress. Regulators in some nations may grow increasingly concerned about the risks involved in taking actions that "wipe out an industry" and are thus perceived as irreversible. Bargaining has the chance of becoming highly politicized, that is, becoming obsessed with emotional equity rather than hard-headed efficiency issues. And finally, great caution may emerge if the nations involved come to see the CFC issue as a pathbreaking, precedent-setting

matter that would set the ground rules for other common property resource problems. Such a view would raise the stakes involved.

Summary of characteristics. The outlook for successful international cooperation in reducing CFC-emissions, in our view, has not been very bright. But with patience and diplomacy, the chances for success may significantly improve. The key barriers currently lie with the inherent nature of the CFC-ozone-depletion problem and with the nature of the parties involved. Problem-solving capabilities, on the other hand, appear adequate to the task. And the institutional context surrounding international bargaining, while at the moment highly imperfect and full of impediments, can with skillful, sincere and creative diplomacy probably be overcome.

Toward International Coordination

Given the foregoing discussion, what concrete actions are available to the U.S. to deal with the global ozone management problem. A potentially useful way to organize a national strategy is presented in Exhibit 5. This is a conflict management model that has been successfully applied to a variety of disputes that fall outside the confines of the marketplace.^{22/}

When one party is in a conflict with one or more others, its behavior can be defined in terms of two dimensions, assertiveness and cooperativeness. Observed conflict behavior is a product of these two dimensions. A protagonist can choose to try to dominate the other party in a purely 22/ See Gladwin and Walter, especially Chapters 2 and 3.

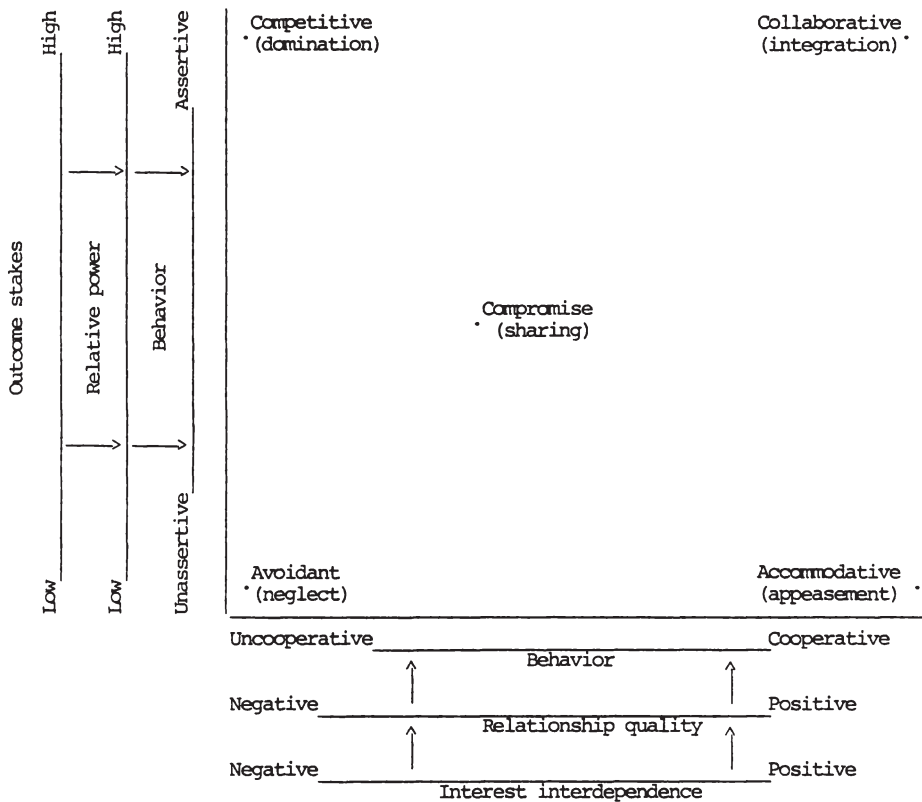


Exhibit 5

Source: Thomas N. Gladwin and Ingo Walter, Multinationals Under Fire: Lessons in the Management of Conflict (New York: John Wiley, 1980).

competitive effort (assertive/uncooperative). It can leave the field and avoid the conflict entirely (unassertive/uncooperative). Alternatively, it can accommodate or appease the other side (unassertive/cooperative). Or it can choose to work fully with the opposition in a collaborative effort to achieve a solution (assertive/cooperative). Compromise, involving moderately assertive and/or cooperative behavior, may also be appropriate under certain circumstances. Of course, opponents in any given conflict may be fractionated, with different behavior applied to each, or treated in different ways at different ways at different points in time via sequential applications of conflict management strategies.

What determines how assertive or cooperative conflict management strategy ought to be? Assertiveness is determined by the protagonist's stakes in the outcome of the conflict, modified by its power to influence outcome of the conflict relative to the power position of the other side. High stakes and power tend to produce assertive behavior, for example, while low stakes and/or low power tend to suggest avoidance. Cooperativeness is determined by the degree of interest interdependence (zero-sumness) inherent in a conflict and the relationship quality that exists between the protagonists. A zero-sum game with poor relationship quality, for example, would tend to bias conflict behavior toward non-cooperation, while a positive-sum game in which both sides can gain, coupled to a favorable relationship

quality, would tend to produce cooperative behavior. In the former case the outcome is likely to be competitive or avoidance-oriented behavior, while in the latter case appeasement or collaboration are much more likely to result.

How can this general non-market conflict management model be applied to the case of CFCs? What does the model suggest, in the light of the empirical and conceptual discussion we have presented in this paper, about an optimal strategy for the United States?

Outcome stakes. For the United States, the outcome stakes in the ozone depletion issue would appear to be relatively high. The prospective damage assessments are perhaps more serious in the U.S. than elsewhere, the theory of ozone depletion is perhaps more widely accepted even in the absence of hard evidence, and the general aversion to risk seems considerably higher in the U.S. than in much of the rest of the world. The stakes are raised further by the enormous costs of moving beyond non-essential aerosols into cutbacks of other CFC uses as refrigerants and foam blowing agents. This would suggest a relative assertive international stance on the CFC issue.

Relative power. The relative power of the United States with respect to CFCs themselves has been eroded, as we have repeatedly pointed out, by the unilateral action to ban non-essential uses of CFCs in aerosols in 1979. Nonetheless, a partially compensatory gain may have achieved

by virtue of the "demonstration effect" of U.S. leadership on a highly controversial issue. Moreover, the U.S. remains the single largest national market in the world, access to which makes a great deal of difference elsewhere. Whereas the U.S. no longer calls the shots in world trade, which bounds the pressure tactics it can successfully apply, it remains sufficiently powerful economically to exert considerable influence particularly in areas where stakes are not viewed as highly abroad.

Interest interdependence. The protection of the ozone shield is clearly a positive-sum game. To the extent that there is in fact a problem, it will benefit all of mankind, albeit not symmetrically. We have noted, however, that unilateral action by the United States has altered the nature of the problem to some extent from bi-directional to uni-directional transfrontier pollution, and this has eroded somewhat the degree of interest interdependence inherent in the nature of the conflict. This is reinforced by differences in technologies and possible costs of emissions abatement between the U.S. and other major CFC producers and users. Interest interdependence therefore remains positive, but less so than may formerly have been the case.

Relationship quality. As we have noted, the relationship quality between the U.S. and the other major CFC producers and users remains good. All are developed, market-economy countries at comparable stages of economic development, which

should aid consensus-building. Open channels of communications and organizations such as OECD should help to cement the quality of the relationship. However, to the extent that Communist countries and developing nations gain in importance as CFC emitters, the relationship quality can be expected to deteriorate. While some may place a premium on relationships with the U.S. on ecological matters, others may opt for a "free rider" position. Moreover, U.S. pressure tactics and incessant nagging on other risk-related ecological and safety issues may have further soured relationships and made other countries increasingly circumspect about following the American lead.

We conclude, therefore, that the CFC problem at present falls in the upper right quadrant of our conflict management matrix, presented in Exhibit 5. Before the unilateral U.S. actions on CFCs in non-essential aerosols, collaboration was probably the unambiguous objective of U.S. international policy--combining high stakes and power with good relationship quality and a positive-sum game. Since then, and with growing conflicts on a range of issues extending from nuclear power to automobile safety, the appropriate conflict management strategy has probably moved toward the southwest, toward compromise. This will be reinforced as developing and Communist countries gain relatively as CFC emitters. Nevertheless, international cooperation and collaboration in the global ozone management problem remains clearly the most promising overall strategy for the United States.

Implementing a Strategy

The kind of strategy that is suggested by the foregoing model ought to have a number of distinct but interrelated dimensions. Several of these stand out as being of paramount importance.

Scientific consensus. First and foremost, there is a need to develop a consensus on the scientific basis and validity of the ozone depletion theory. Present indications are that any observations of shifts in stratospheric ozone and their linkage to the presence of CFCs will be a long time in coming. Even the presence of CFCs in the stratosphere has been subject to a great deal of controversy. Any collaborative approach to the problem depends fundamentally on scientific consensus under such uncertain conditions. This consensus must extend to basic agreement on the risks involved. In order to avoid a deterioration in relationship quality, scientific consensus must be reached voluntarily with an absolute minimum of pressure. The publication of major studies in 1979 and 1980 in the U.S. may help in moving closer to a scientific consensus. Additional progress could be made through the International Council of Scientific Unions (ICSU) and its Scientific Committee on Problems of the Environment (SCOPE), which links the national academies of science of various nations. This could be accomplished by means of an initiative through the International Environmental Policy Committee (IEPC) of the National Academy of Sciences.

Risk reduction techniques. Agreement on the underlying scientific relationships should develop a consensus on the basic sources of risk and on the magnitude of these risks. These should be pushed further at an international level, perhaps through a study conducted by a recognized institution such as the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria, on risk reduction and modification. This should also include work on different national perceptions of risk and possible differences in response-patterns. Rather than engaging in cost-benefits analyses, such studies should be limited to a cooperative, international investigation of the risks involved, their consequences, and ways of modifying them

Technical substitution aspects. Costs of substitutes for CFCs have been investigated in great detail in the United States, but again it is our impression that no effort has been made to reach an international consensus. This should be high on the list of international collaborative activities. Work along such lines should be commissioned by an international organization such as UNEP or OECD and carried out by responsible research organizations such as Battelle, Mathematica or their counterparts abroad.

Cost-benefit analyses. A recent report to EPA prepared by the National Research Council contains elements of all of the above, plus a serious attempt at extended cost-benefit analysis. It will doubtless have an impact abroad, as well

as generating renewed controversy. Cost-benefit assessments of the CFC problem and its resolution should next be taken into the international arena to involve researchers from other countries and aid in the task of building a consensus. This should probably be done under the auspices of the Environment and Industry Division of the OECD environment directorate, and be lagged somewhat behind the aforementioned efforts at reaching consensus on the scientific, risk, and technical dimensions of concern.

Formulation of prototype policies. Based on the kinds of international collaborative efforts just outlined, it should be possible to reach agreement on a set of "appropriate" policies for the use of CFCs, again under the auspices of OECD. This could take the form of a formal "code of conduct," which has been the result of international discussions of other difficult areas in the past--such as the operations of multinational companies. Or it could result in a set of general "principles" or "guidelines" that are not legally binding but might possess considerable intellectual force--such as the "polluter pays principle" negotiated in OECD several years ago.

Bilateral initiatives. While we are placing a great deal of emphasis on the value of international collaborative attempts to achieve consensus on ozone management policies, this should not preclude significant bilateral initiatives on the part of the United States. Examples include the

formation of coalitions between the U.S. and major foreign CFC producing and consuming countries in furtherance of least-cost, preemptive solutions; communications between the U.S. and foreign environmental groups; dissemination of information on the CFC problem through U.S. and foreign media; subsidized research and development as well as direct assistance, preferably channelled through international organizations, to the poorer among foreign country governments; and development and implementation of a workable global monitoring system. In all such activities, close links should be forged between the responsible U.S. agencies--particularly EPA and the Department of State--and overt pressure tactics should be avoided at all costs. However, consideration should be given to the possibility of delaying further unilateral U.S. actions until an international consensus has been reached.

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Reciprocal Transfrontier Pollution^{*}

by

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1. Introduction

Production and consumption activities generate waste products or residuals which cause pollution when they are discharged into the environment. In general, residuals stem from geographically identifiable sources of pollution. But the residual discharge is followed by ecological diffusion processes the extend of which depends on the residuals' characteristics as well as on the properties of the recipient environmental medium (air, water).

Political boundaries often separate connected ecological systems so that one country's residuals discharge may cause pollution in other countries. In this case we are confronted with transfron-

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tier pollution,¹⁾ which may be one-directional or multi-directional. The prototype of a one-directional transfrontier pollution problem is that of an upstream polluter and the downstream pollutee. But from a systematic point of view the general case of transfrontier pollution is of the multi-directional or reciprocal type and there are, in fact, many empirical examples of reciprocal transfrontier pollution (RTP) problems. These range from small-scale "regional" and medium-size "international" to truly "global" problems like ocean pollution or pollution of the stratosphere cause e.g. by supersonic aircraft, by chlorofluorocarbons releases or by carbon dioxide from the use of fossil energy resources.

In order to emphasize the empirical relevance of global RTP the nature and hazards of the chlorofluorocarbons (CFCs)-ozone problem serves as a good example:²⁾ The ozone layer in the stratosphere can be viewed as a global "common property" resource. Its beneficial services of shielding the earth from damaging ultraviolet radiation and maintaining the current surface temperature were taken as free goods until recently natural scientists discovered that worldwide releases of CFCs cause gradual depletion of the ozone layer. This in turn has two major negative feedbacks: First it increases health hazards, in particular the risk of skin cancer. Furthermore, it deteriorates production conditions mainly in the agricultural sector by changing the mean annual surface temperature.³⁾ These adverse effects are worldwide and, even more

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- 1) There are various earlier studies on transfrontier pollution. See, for example, OECD (1974a), I. Walter (1975), J.R. Markusen (1975), R. d'Arge (1976), H. Tulkens (1979).
 - 2) For the following see, in particular, M.J. Molina and F.S. Rowland (1974) Committee on Impacts of Stratospheric Change (1976), T.B. Stoel, R.I. Compton, and S.M. Gibbons (1977), I. Walter, T.N. Gladwin, and I.L. Ugelow (1978), Umweltbundesamt (1978).
 - 3) The available evidence on changes of surface temperature and its welfare cost appears to be controversial - even with respect to the "sign" of the effects. Probably any climate change induced by CFCs releases represents a negative production externality worldwide. See also R.C. d'Arge and V.K. Smith (1978).

important, they are almost independent of the emitting country.⁴⁾ Hence the discharge of CFCs by one country not only diminishes its own welfare but also the welfare of all other countries. The emitting country only bears part of the damage and creates negative externalities for all other countries. Thus for the set of countries that are the (major) CFCs-polluters the release of CFCs constitutes a RTP problem whereas the rest of the world suffers passively from transfrontier pollution of the upstream-downstream type.

From the basic idea of the polluters-pay -principle which appears to be widely accepted in the transfrontier pollution context,⁵⁾ it follows that the polluting countries should take action to stop or at least cut back their residuals emissions. But here we are at the heart of the problem. If one polluting country implements a unilateral national effluent regulation policy it bears the full costs (consisting of "regulation inputs" and losses from weakened international competitiveness) of its program. But at the same time it creates a twofold benefit for the other polluting countries: Their relative international competitiveness is strengthened and they take a free rider position with regard to the reduced environmental damage. Even if all polluting countries carry out some uncoordinated national policy to reduce their own residuals emission, the overall impact is likely to be insufficient unless substantial cooperation between the polluting countries is reached. A basic requirement for cooperation is to reach agreement on the overall effort necessary to reduce the transfrontier pollution. But it is even more important and difficult to agree on the relative cost shares. Hence an efficient and fair solution to RTP problems essentially presupposes international bargaining among the polluting countries.

It is the objective of this paper to clarify the analytical

4) "Whatever is released is, before long, mixed throughout the atmosphere", Committee on Impacts of Stratospheric Change (1976, p. 2).

5) At least this observation holds for the OECD-member countries. See OECD (1974).

structure of RTP problems and to investigate solution possibilities under various behavioural assumptions. In section 2 the model is exposed. For the issue under consideration it must be viewed as a "minimum model" omitting many complicating features of reality. This simple model is transformed in several steps until the game theoretic nature of the RTP problem becomes evident: We end up with a two person game in which each player's strategy space is the national residuals emission level and where his pay-off-function is some "derived" welfare function defined on the joint strategy set. Section 3 shows the allocative and welfare impact of non-cooperative behavior. The solution concept of an equilibrium point is applied. It clarifies the analogy of our problem to oligopoly theory where the entrepreneurs exhibit Cournot-type behavior. The result that noncooperative behavior leads to Pareto-inferior allocations implies that there are, in general, opportunities for mutually beneficial bargaining or negotiations. Of particular interest for the RTP problem is the issue of unilateral national emission regulation, that are implemented by one country prior to (or instead of) international negotiations. The model of this paper supports the view that "moderate" unilateral reductions of emissions are rational (welfare increasing) for the regulating country if this country believes that the other country will remain inactive. Furthermore, negotiations remain advantageous for both sides, in general, even after unilateral regulations have been implemented.

In section 4 various aspects of the RTP bargaining problem are addressed. First, the Nash solution concept for simple bargaining games is introduced. Such games are characterized by a predetermined conflict situation, that specifies the disagreement payoffs. But it appears reasonable to make the disagreement payoffs endogenous to the game, which leads to a so-called general bargaining game including the concept of mutually optimal threat strategies. This concept takes care of the two countries' bargaining power in a sophisticated way and therefore appears to be a satisfactory approach on the conceptual level. Then the issue of unilateral residuals emission regulation is reconsidered in the

context of the general bargaining game. We show that the unilateral reduction of emissions by one country does not influence the outcome of the bargaining process if the reduction is not "too strong". Otherwise, the country which has implemented unilateral regulation can avoid unfavourable bargaining results (due to this regulation) only if it threatens the other country convincingly to adopt less restrictive emission regulation in case of a conflict.

The final subsection is devoted to strategic manipulation. Although this issue arises in various social contexts it appears to be particularly significant in RTP bargaining situations: At the present state of scientific evidence diverging national damage assessments can be defended without being obviously incompatible with the available "knowledge". Hence each country has an incentive not to report its true assessment. Strategic manipulation of this type clearly affects the bargaining process and may lead to allocative inefficiency.

2. The Model

For simplicity we restrict the subsequent analysis to the case of two countries. We further exclude from our analysis foreign trade effects of residuals discharge regulations. There are, of course, substantial trade flows between many pairs of countries (and the rest of the world), so that our assumption to completely ignore international trade is a loss of realism. It appears acceptable as a first approach, however, if it can be assumed that regulation-induced changes of trade flows in RTP related products do not lead to major trade dislocations. ⁶⁾

The third simplifying basic assumption is that we neglect intertemporal aspects ⁷⁾ of the problem that may play an important rôle for various reasons. For example, accelerated residuals releases may adversely affect the natural recovery rate of the environment and lead-lag relationships in national effluent regulation may influence the countries' bargaining power and, hence, the bargaining solution itself. Various studies on RTP problems also stress the issue of irreversibilities that cannot be adequately handled in a static framework. Uncertainty and risk are further principle characteristics of RTP issues that are not appropriately considered in this paper, since we assume simple point estimates for costs and benefits that may, however, reflect diverging damage assessments between countries. In summary, even though we are aware of various simplifications of the subsequent analysis we feel that significant parts of the allocation problem remain to be clarified in the absence of the complications listed above. The limitations of the model must, however, be considered when its results are interpreted or used for policy recommendations.

6) This assumption appears to be safe in the CFCs-ozone problem where according to I. Walter et.al. (1978, p. 176) "...international economic dislocations to be experienced by the U.S. ... would be miniscule in comparison to the purely domestic economic dislocations", even though they depend considerably on the regulatory scenario chosen. Trade effects are explicitly analysed in the approach of J.R. Markusen (1975). With substantial analytical effort, international trade could be incorporated into the present model along the lines elaborated by H. Siebert, J. Eichberger, R. Gronych and R. Pethig (1980).

7) For interesting intertemporal studies of related problems see G.R. Munro (1978) and H. Tulkens (1979).

We now proceed to specify the model in detail. In the paper the superscript or subscript i indicates variables relating to country i ($i = 1, 2$). By e_i we denote the residuals emission of country i . The state of the environment in country i is described by a real valued indicator s_i . It is assumed that s_i is uniquely determined by the emissions e_1 and e_2 of both countries via the differentiable and convex environmental interaction function⁸⁾

$$(1) \quad s_i = S^i(e_1, e_2) \quad (i=1, 2)$$

satisfying⁹⁾ $S^i(0, 0) = 0$, $S^i_1, S^i_2 > 0$, and $S^i_{12} = S^i_{21} \geq 0$. The difference $S^i(e_1, e_2) - S^i(0, 0)$ will be interpreted as the deterioration of country i 's environment when the amounts e_1 and e_2 of residuals are released into the air. If the cross derivative of S^i is positive, the marginal damage of one country's emission is positively correlated to the other country's total emission. In this case there is no unambiguous way to assign the "proper" damage share to each polluter.

In the case of global RTP we observe rapid and perfect diffusion of residuals in the world's ecological system, e.g. the stratosphere, so that the effects of a given emission may be (almost) independent of the location of the polluting source. This hypothesis is captured in equation (1) by the special case that $S^1 = S^2 = S$ and that S satisfies $S_1 = S_2$ for every given (e_1, e_2) . Then the damage only depends on the aggregate (world-wide) emission $e_1 + e_2$. Another special case is obtained if $S^i_1 > 0$ but $S^j_1 = 0$ for $i, j = 1, 2$ ($i \neq j$). For $e_i > 0$ we have one-directional

8) For more details about this concept of an "environmental interaction function" or "pollution function" see R. Pethig (1979a, 1979b).

9) In this paper we apply the convention that for a function $F(x, y)$ the derivatives are denoted by $F_x := \partial F / \partial x$, $F_{xx} := \partial^2 F / \partial x^2$, $F_{xy} := \partial F / \partial x \partial y$ etc. As an additional simplification we write F_i instead of F_x if and only if $x = e_i$ ($i = 1, 2$). If no confusion is possible we also write, for example, F_q instead of F_x , if $x = q_i$ ($i = 1, 2$).

transfrontier pollution where country i is located upstream.¹⁰⁾

In the next step we introduce the negative feedbacks of pollution on the economies. First the state of the environment is assumed to affect the consumers' well-being. Each country's welfare is determined by a differentiable and strictly concave¹¹⁾ welfare function

$$(2) \quad w_i = \hat{W}^i(q_i, s_i) \quad (i=1,2)$$

such that $\hat{W}_q^i > 0$ and $\hat{W}_s^i < 0$. The negative partial derivative \hat{W}_s^i reflects the marginal welfare loss of adverse health impacts and other damage due to increased pollution, whereas \hat{W}_q^i indicates the welfare gain of a small increase in the quantity q_i of country i 's consumption good (= "national product"). Note also that the concept of concavity of a function presupposes that its domain is a convex set. Hence the domain $D(\hat{W}^i)$ of the welfare function \hat{W}^i and \hat{W}^+ , which is the "consumption sets" of country i in economic interpretation, is assumed to be convex. It is clearly plausible that this consumption set is bounded from above with respect to the state of the environment and does not include zero consumption of the consumption good. The introduction of these properties would create complications in the subsequent analysis of some "derived" consumption sets (which to some extent could be solved by tedious arguments).¹²⁾ For simplicity of exposition

10) These remarks on one-directional transfrontier pollution show that the analytical framework of this paper is also adequate to handle this type of pollution problem. The major difference to RTP and the only reason why we do not elaborate this special case ($S_j^j = 0$ for $j = 1$ or $j = 2$) is that allocative efficiency would require transfer payments.

11) This assumption is much more restrictive than the standard hypothesis of quasi-concavity, which would be sufficient for all results of the paper except for the proof that the welfare possibility set is convex. The welfare function can be viewed as a representation of social preference ordering. It is known that not every preference ordering which can be represented by a (continuous) quasi-concave function can also be represented by a concave function. For necessary and sufficient conditions see W. Fenchel (1956) and for approximation results see Y. Kannai (1974).

12) See, for example, the procedure in R. Pethig (1979a).

we avoid these difficulties in this paper by assuming that $D(\hat{w}^i) = \mathbb{R}_+^2$ for $i = 1, 2$.

The second negative externality of pollution consists of deteriorating production possibilities.¹³⁾ With fixed factor endowments (which are not made explicit here) the countries' production possibilities are specified by the differentiable transformation functions¹⁴⁾

$$(3) \quad q_i = \hat{T}^i(e_i, s_i) \quad (i=1,2)$$

satisfying $\hat{T}_i^i > 0$ and $\hat{T}_s^i < 0$. For given $s_i \geq 0$, the graph of $\hat{T}^i(e_i, s_i)$ is country i 's production possibility frontier between the consumption good (q_i) and residuals generation (e_i) that is assumed to be a (useless) by-product in the production of the consumption good.¹⁵⁾ $\hat{T}_i^i > 0$ establishes the by-product property of residuals and $\hat{T}_s^i < 0$ implies that ceteris paribus the production possibilities decrease with increasing pollution. Figure 1 illustrates the transformation function \hat{T}^i from eq. (3) for three different values of s_i . It is well-known that production externalities like the state of the environment in the present model generate conceptual analytical difficulties by making the production set non-convex¹⁶⁾ or the transformation function non-concave, respectively. Even if the transformation curve \hat{T}^i is strictly concave for given s_i - as depicted in figure 1, it is logically impossible that the complete function is concave (given the assumption $\hat{T}_s^i < 0$) on an unbounded domain. However, one can "guarantee" concavity of \hat{T}^i in the relevant part of its domain

13) The "costs" of decreasing temperature in the case of stratospheric pollution and their order of magnitude are studied by R. d'Arge (1976). J.R. Markusen (1975) does not include production externalities in his model.

14) For a more detailed discussion of these concepts see R. Pethig (1977) and R. Pethig (1979a).

15) It is also possible that residuals are not only released in the course of production but also in (or after) the process of consumption. Here we neglect these complicating aspects of the problem. See, for example, I. Walter et.al. (1978).

16) See D.A. Starrett (1972).

as follows.¹⁷⁾ Since factor endowments are fixed it is not possible to "produce" arbitrarily large amounts of residuals. Let e_i^0 be the maximum attainable residuals emission¹⁸⁾ and define $s_i^0 := S^i(e_1^0, e_2^0)$ and $D(\hat{T}^i) := \{ (e_i, s_i) \in \mathbb{R}_+^2 / e_i \leq e_i^0, s_i \leq s_i^0 \}$. We now assume that \hat{T}^i is a strictly concave function on $D(\hat{T}^i)$.

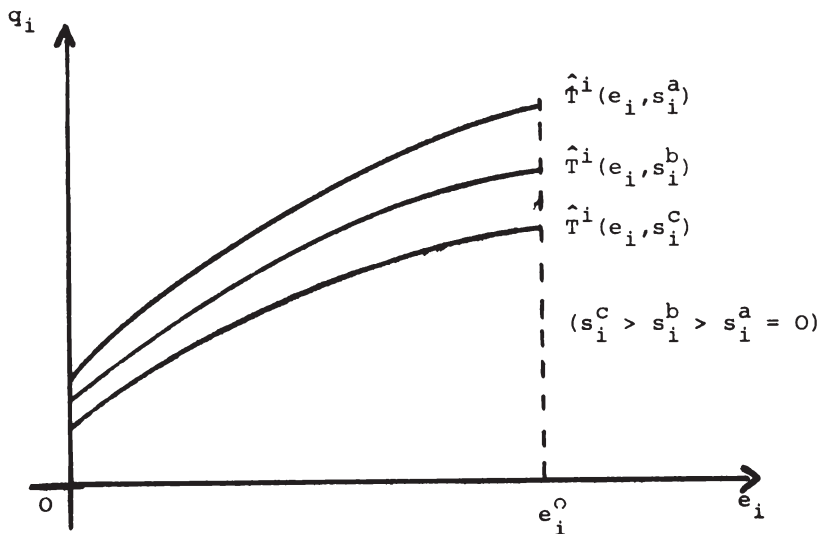


Figure 1

With equations (3) our model is completed. Its analytical structure may best be summarised by figure 2, where the two countries' interdependency via their emissions e_1 and e_2 is illustrated. It is, however, possible and also convenient for our further study to establish this interdependency in a more direct way. For this purpose we consider the eqs. (1) in eqs. (3) and define "derived" transformation functions by

$$(3') \quad q_i = T^i(e_i, e_j) := \hat{T}^i [e_i, S^i(e_i, e_j)] \quad (i, j = 1, 2; i \neq j)$$

17) The following procedure is discussed in a more general setting by R. Pethig (1979a, p. 154 n.).

18) This value e_i^0 is indicated in figure 1.

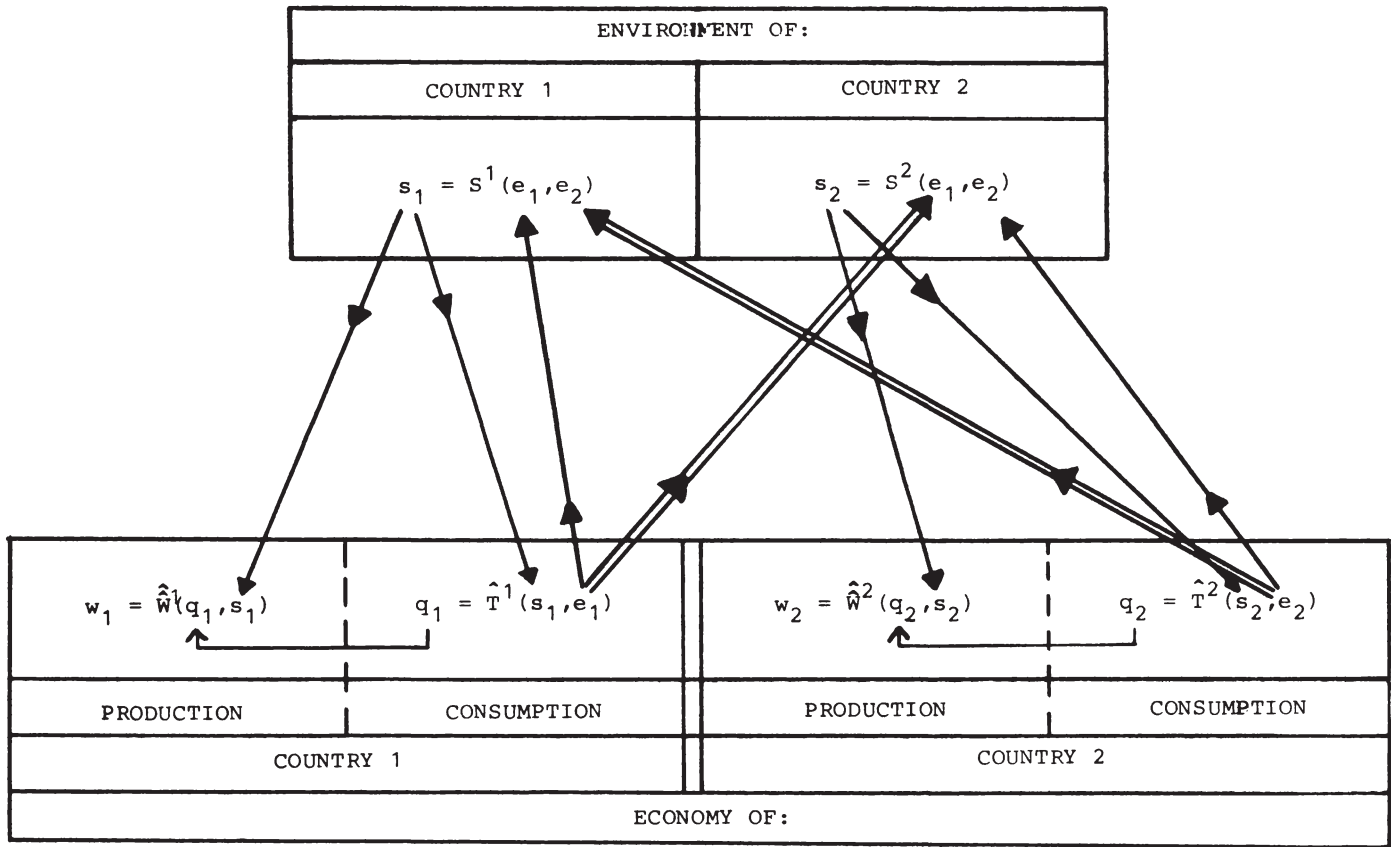


Figure 2

The next step is to establish that the function T^i is strictly concave on the set $D(T^i) := \{(e_1, e_2) \in \mathbb{R}_+^2 \mid \text{for } i=1,2 : (e_i, s_i) \in D(\hat{T}^i) \text{ and } s_i = S^i(e_1, e_2)\} = \{(e_1, e_2) \in \mathbb{R}_+^2 \mid \text{for } i=1,2 : e_i \leq e_i^0\}$ under the assumptions that have been made about the functions \hat{T}^i and S^i . Consider $(e_1, e_2), (\bar{e}_1, \bar{e}_2) \in D(\hat{T}^i), (e_1, e_2) \neq (\bar{e}_1, \bar{e}_2)$ and define $e_{i\lambda} := \lambda e_i + (1-\lambda)\bar{e}_i$ for $i=1,2$. We have to show that $T^i(e_{1\lambda}, e_{2\lambda}) > \lambda T^i(e_1, e_2) + (1-\lambda) T^i(\bar{e}_1, \bar{e}_2) =: q_{i\lambda}$ for every $\lambda \in (0,1)$. Strict concavity of \hat{T}^i yields $\hat{T}^i(e_{i\lambda}, s_{i\lambda}) > \lambda \hat{T}^i(e_i, s_i) + (1-\lambda) \hat{T}^i(\bar{e}_i, \bar{s}_i) =: \hat{q}_{i\lambda}$, where $s_i := S^i(e_1, e_2), \bar{s}_i := S^i(\bar{e}_1, \bar{e}_2)$ and $s_{i\lambda} := \lambda s_i + (1-\lambda)\bar{s}_i$. By definition of T^i in (3') we conclude $q_{i\lambda} = \hat{q}_{i\lambda}$. Hence the proof is completed if $T^i(e_{i\lambda}, e_{j\lambda}) = \hat{T}^i[e_{i\lambda}, S^i(e_{i\lambda}, e_{j\lambda})] \geq \hat{T}^i(e_{i\lambda}, s_{i\lambda})$ for $i \neq j$. This inequality holds since $\hat{T}_s^i < 0$ and since $S^i(e_{1\lambda}, e_{2\lambda}) < s_{i\lambda}$ by the strict convexity assumption on S^i .

Observe that $T_j^i = \hat{T}_s^i S_j^i < 0$ and $T_i^i = \hat{T}_i^i + \hat{T}_s^i S_i^i \geq 0$ depending on how strong the production externality ($\hat{T}_s^i < 0$) is. The (partial) graph of the derived transformation function T^i is shown in figure 3 for two alternatively given values of e_j ($i, j=1,2; i \neq j$). Thus it is made explicit how country j 's emission e_j affects adversely country i 's production possibilities.

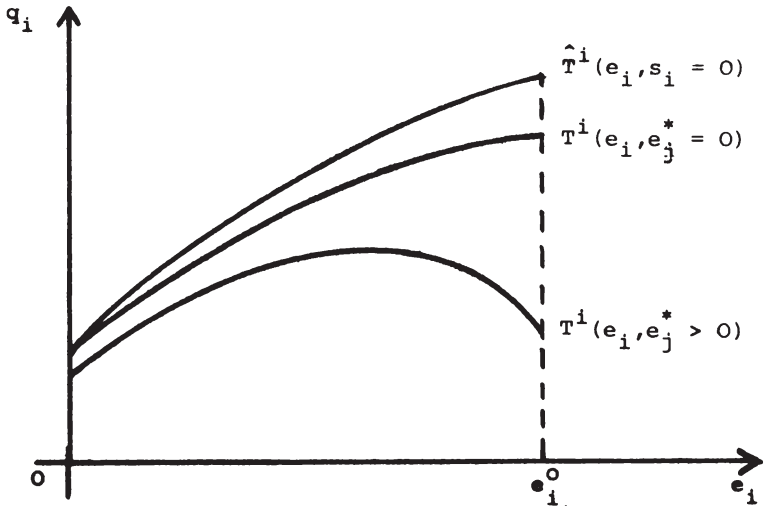


Figure 3

Similar to the generation of eqs. (3') from eqs. (1) and (3) we now take eqs. (1) in order to transform eqs. (2) into eqs. (2'):

$$(2') \quad w_i = \hat{W}^i(q_i, e_1, e_2) := \hat{W}^i [q_i, S^i(e_1, e_2)] \quad (i=1,2)$$

Since \mathbb{R}_+^2 is the domain of \hat{W}^i and of S^i it is obvious that the domain of \hat{W}^i is \mathbb{R}_+^3 . By the same arguments used for the proof of strict concavity of the function T^i one can show that the function \hat{W}^i is also strictly concave under the assumptions made on S^i and \hat{W}^i . In addition we obtain $\hat{W}_q^i > 0$ as well as $\hat{W}_1^i < 0$ and $\hat{W}_2^i < 0$. We now proceed to "compress" the model by combining the derived welfare function \hat{W}^i from (2') with the derived transformation function T^i from (3'). This yields

$$(4) \quad w_i = W^i(e_1, e_2) := \hat{W}^i [T^i(e_1, e_2), e_1, e_2] \quad (i=1,2)$$

The domain of the function W^i is $D(T^i)$, hence a convex set. We claim that W^i is a strictly concave function provided that the functions T^i and \hat{W}^i are strictly concave satisfying $\hat{W}_q^i > 0$. To show this consider $(e_1, e_2), (\bar{e}_1, \bar{e}_2) \in D(T^i), (e_1, e_2) \neq (\bar{e}_1, \bar{e}_2)$, and define $e_{i\lambda} := \lambda e_i + (1-\lambda) \bar{e}_i$ etc. as above. We have to establish that $W^i(e_{1\lambda}, e_{2\lambda}) > \lambda W^i(e_1, e_2) + (1-\lambda) W^i(\bar{e}_1, \bar{e}_2) =: w_{i\lambda}$. Setting $q_i := T^i(e_1, e_2), \bar{q}_i := T^i(\bar{e}_1, \bar{e}_2)$ and $q_{i\lambda} = \lambda q_i + (1-\lambda) \bar{q}_i$ yields $\hat{W}^i(q_{i\lambda}, e_{1\lambda}, e_{2\lambda}) > \lambda \hat{W}^i(q_i, e_1, e_2) + (1-\lambda) \hat{W}^i(\bar{q}_i, \bar{e}_1, \bar{e}_2)$ by the strict concavity of function \hat{W}^i . The right-hand side of this inequality is equal to $w_{i\lambda}$ by definition of the function W^i in (4). Hence the proof is completed if $W^i(e_{1\lambda}, e_{2\lambda}) \geq \hat{W}^i(q_{i\lambda}, e_{1\lambda}, e_{2\lambda})$. Note that $T^i(e_{1\lambda}, e_{2\lambda}) > q_{i\lambda}$, since T^i is strictly concave. When combined with the assumption $\hat{W}_q^i > 0$, the desired result is obtained. The definition of W^i in (4) shows that the world allocation problem is uniquely determined by selecting some attainable emission tuple $(e_1, e_2) \in E = D(T^1) = D(T^2)$. Such a tuple not only determines the "consumption allocation" via (3') (and implicit in (4)) but also some "welfare allocation" (w_1, w_2) . More generally, the eqs. (4) define a mapping W from the set of

attainable emission allocations, E , into the two-dimensional space of welfare allocations. This mapping generates a welfare possibility set, denoted by $W(E)$. Since E is compact and convex and W is a continuous vector function, the welfare possibility set $W(E)$ is also compact and convex.

So far, we have not used the methods and the language of game theory explicitly. It is clear, however, that the model can be described (and summarized) as a two-person non-zero sum game $G := \{2, E_1, E_2, W^1, W^2\}$, where $E_1 := [0, e_1^0]$, $E_2 := [0, e_2^0]$ are the players' strategy sets and where the welfare functions W^1 and W^2 are the players' payoff functions. In section 3 we analyse and evaluate the equilibrium point of this game presupposing non-cooperative behavior, and section 4 concentrates on cooperation and bargaining.

3. Non-cooperative Behavior

3.1 The Concept of Equilibrium Points

An equilibrium point¹⁹⁾ of the game $G = \{2, E_1, E_2, W^1, W^2\}$ is defined by a strategy tuple (\bar{e}_1, \bar{e}_2) satisfying

$$(5) \quad \begin{aligned} W^1(\bar{e}_1, \bar{e}_2) &\geq W^1(e_1, \bar{e}_2) && \text{for every } e_1 \in E_1, \text{ and} \\ W^2(\bar{e}_1, \bar{e}_2) &\geq W^2(\bar{e}_1, e_2) && \text{for every } e_2 \in E_2. \end{aligned}$$

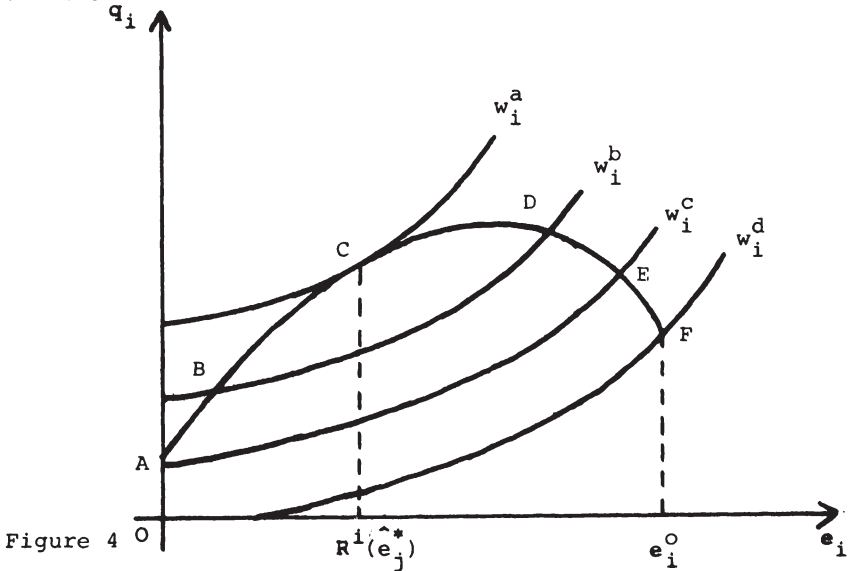
In order to show that under the assumptions made in section 2 there exists an equilibrium point for the game, we first consider

19) See, for example, J.C. Harsanyi (1977, p. 104). This concept is also used in oligopoly theory dating back to Cournot. See, for example, J.M. Henderson and R.E. Quandt (1971, chapter 6.3). The analogy of externality and public good issues to oligopoly theory and game theory was already stressed by O.A. Davis and A. Whinston (1962), G. Campa (1967) and H. Shibata (1971).

the "reaction function" for player i ($i, j=1, 2; i \neq j$):

$$(6) \quad e_i = R^i(e_j), \text{ where } R^i(e_j) \text{ is a solution to } \max_{e_i \in E_i} W^i(\tilde{e}_i, e_j).$$

$R^i(e_j)$ is country i 's best-reply strategy, if e_j is the (given) strategy of country j . In view of the definition of the function W^i , $R^i(e_j)$ is identical to the solution of maximising $\hat{W}^i(q_i, e_1, e_2)$ over e_i subject to the constraint $q_i \leq T^i(e_1, e_2)$. In figure 4 the line ABCDEF represents the graph of T^i (for given $e_j = \hat{e}_j$) and the four lines w_i^a to w_i^d ($w_i^d < w_i^c < w_i^b < w_i^a$) are indifference curves belonging to \hat{W}^i for given \hat{e}_j . The maximum is attained in the tangency point C. ²⁰⁾



The maximization procedure defined in (6) can also be directly illustrated with the help of the function W^i .

20) The marginal condition satisfied in this tangency point is $T^i_1 = -(\hat{W}^i_1 / \hat{W}^i_2)$. With this information, the national environmental protection agency can implement the emission standard $R(\hat{e}_2)$ (for given foreign emission \hat{e}_2), if it levies an emission tax T^i_1 measured in terms of the consumption good. For details see Pethig (1979a, 1979b).

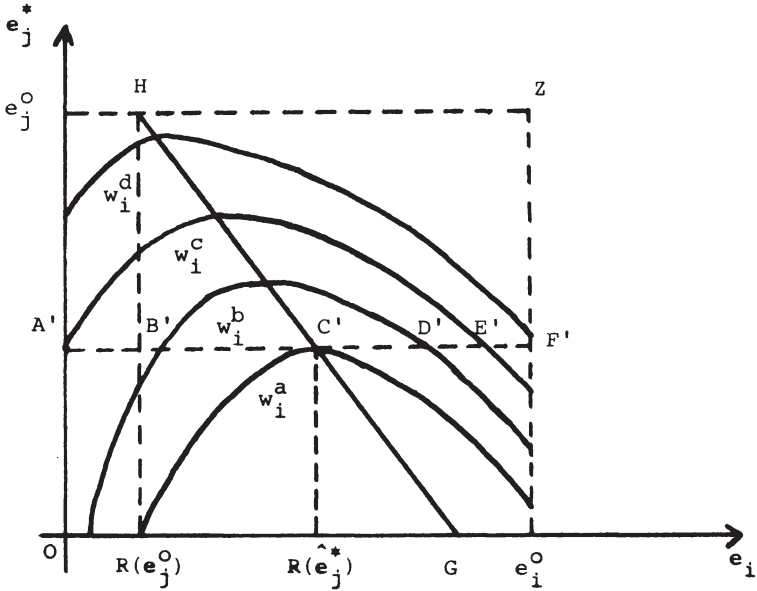


Figure 5

Since W^i is a strictly concave function its upper contour sets are strictly convex. In figure 5 four indifference curves w_i^a to w_i^d belonging to W^i (and not to \hat{W}^i like those in figure 4) are depicted, satisfying $w_i^d < w_i^c < w_i^b < w_i^a$. In order to see that the figures 4 and 5 are closely related, suppose that $OA' = \hat{e}_j$ in figure 5, where \hat{e}_j is the parametric value of e_j used in figure 4 in the transformation curve T^i and in the welfare function \hat{W}^i . Then the points A, B, C, D, E, and F completely correspond to the points A', B' etc. in figure 5. The welfare level rises from A(A') up to C(C') and then declines to F(F'). In fact, for given $e_j = \hat{e}_j$ the maximum domestic welfare is attained at the point C or C', respectively. Since in figure 5 the whole set \hat{E} is densely covered by indifference curves of the function W^i , we obtain some line GH as the locus of all maxima of indifference curves. This line GH is the graph of the domestic reaction function R^i as defined in (6).

We now want to show that the game G has an equilibrium point under the assumptions of section 2. By definition of R^i ($i=1,2$), the tuple (\bar{e}_1, \bar{e}_2) is an equilibrium point of G if and only if $\bar{e}_i = R^i(R^j(\bar{e}_i))$. This equivalence will be utilized to answer the existence question in the affirmative. First, we recall that the function W^i is strictly concave. Hence the functions $R^i : E_j \rightarrow E_i$ and $R^j : E_i \rightarrow E_j$ are well-defined and continuous on their respective domains. Consider now the function $\varphi : E \rightarrow E$, defined by $\varphi(e_1, e_2) := [R^1(e_2), R^2(e_1)]$. Since R^1 and R^2 are continuous²¹⁾, the function φ is also continuous on E . Furthermore, $E \subset \mathbb{R}^2$ is non-empty, compact and convex. Hence there exists (\bar{e}_1, \bar{e}_2) such that $(\bar{e}_1, \bar{e}_2) = \varphi(\bar{e}_1, \bar{e}_2)$ by Brouwer's fixed point theorem.²²⁾

This existence result does not presuppose that the reaction functions are monotone or negatively sloped. The slope of R^i is obtained when we set the derivative $W_i^i = \hat{W}_{q^i}^i T_i^i + \hat{W}_i^i$ equal to zero and then differentiate it totally. After some rearrangements we have

$$(7) \quad \frac{de_i}{de_j} = R_j^i = - \frac{\hat{W}_{q^i}^i T_i^i T_j^i + \hat{W}_{q^i}^i T_i^i + \hat{W}_{iq^j}^i T_j^i + \hat{W}_{qj^i}^i T_i^i + \hat{W}_{ij}^i}{\hat{W}_{q^i}^i (T_i^i)^2 + 2\hat{W}_{iq^i}^i T_i^i + \hat{W}_{q^i}^i T_{ii}^i + \hat{W}_{ii}^i}$$

Obviously, one needs additional assumptions on various derivatives in order to guarantee that the right-hand side of eq.(7) has negative sign. It should also be clear that, in general, multiple equilibrium points will exist. Monotonicity of the reaction functions is not sufficient to guarantee uniqueness.

In figure 6 the lines HG and LK are the graphs of the functions R^1 and R^2 , respectively. Hence their point of intersection, S , represents an equilibrium point. Figure 6 shows, furthermore, that

21) Clearly, R^1 and R^2 are not only continuous on E_1 and E_2 , respectively, but also on E .

22) See, for example, G. Debreu (1959, p. 17).

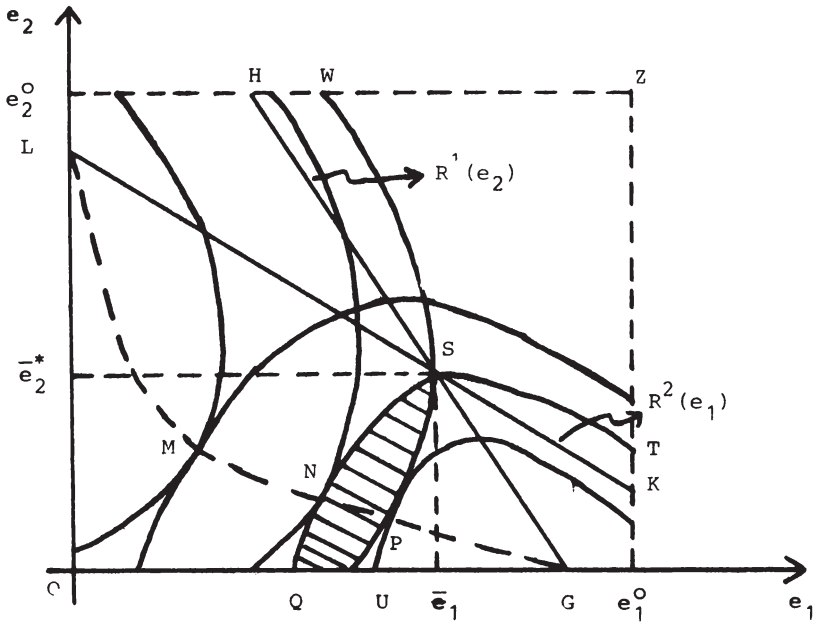


Figure 6

S is also the point of intersection between the indifference curve QNST belonging to the domestic country and the indifference curve UPSW belonging to the foreign country. Such an intersection of indifference curves in an equilibrium point is not "accidental", since by definition of R^1 and R^2 the (unique) indifference curve of country 1 that passes through the point S in figure 6 must have zero slope with respect to the e_1 -axis, whereas the indifference curve of country 2 that passes through S must have zero slope with respect to the e_2 -axis in point S. This in turn implies that the welfare allocation associated to an equilibrium point is dominated, i.e. there exist strategies $(e_1, e_2) \in \hat{E}$ such that $w^1(e_1, e_2) \geq w^1(\bar{e}_1, \bar{e}_2)$ and $w^2(e_1, e_2) \geq w^2(\bar{e}_1, \bar{e}_2)$ with at least one inequality holding strictly. To prove this we consider the problem of maximizing $w_i = w^i(e_1, e_2)$ on \hat{E} subject to the constraint $\bar{w}_j \geq w^j(e_1, e_2)$ (with \bar{w}_j constant). Its solution yields as a necessary condition for an undominated welfare allocation

(and for interior points of \hat{E}) the equation

$$(8) \quad \frac{W_i^i}{W_j^i} = \frac{W_i^j}{W_j^j}$$

This tangency condition of indifference curves is satisfied in figure 6 along the dotted line LMNPG. It is helpful to give an alternative illustration of these results using the set of attainable welfare allocations which has been derived at the end of section 2.

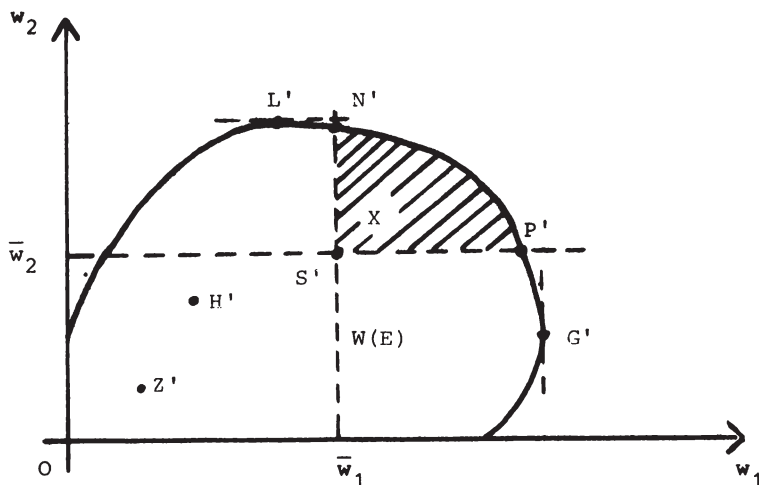


Figure 7

In figure 7 the points L', N', P', G' and S' correspond to the points L, N, P, G and S of figure 5. All points in the shaded area $S'N'P'$ (except the point S' itself) represent welfare allocations which dominate the welfare allocation assigned to the point S' .²³⁾ Hence this region is the negotiation or bargaining area. Except degenerate cases this area is non-empty so that both countries can improve their welfare position by bargaining. Before we turn

23) Note that the shaded area $N'S'P'$ in figure 7 corresponds to the shaded area $QNSPU$ in figure 6.

our attention to the bargaining issue we wish to further investigate some questions related to non-cooperative behaviour, that became empirically relevant, for example, in the ozone case by the unilateral ("non-cooperative") decision of the U.S. to ban certain CFCs emissions.

3.2 An Evaluation of Unilateral Emission Regulations

Until now we (implicitly) assumed that both countries act on the basis of full and true information on the detrimental effects of pollution. The historical course of events was different, however, in the CFCs-ozone problem: Some years ago politicians and citizens were completely ignorant of these effects and they became convinced of the common environmental threat only gradually and - as it appears - not in every country to the same extent. In terms of our model the case of ignorance can be expressed as follows. The politicians in each country believe that the state of the stratosphere does not generate negative externalities for producers and consumers, i.e. the (point) expectation is, that $\hat{W}_S^i = \hat{T}_S^i = 0$ for every $s_1 > 0$ and for $i=1,2$. Under these hypotheses the two countries' welfare states are not expected to be mutually interdependent via their respective residuals emission. Hence in the countries' perception national welfare maximization implies the maximization of the national product. This requires, in turn, to raise emissions up to the maximum levels e_1^0 and e_2^0 .

Suppose now that natural sciences provide the true information about the detrimental effects of pollution and assume that country 1 relies upon this information while country 2 does not.²⁴⁾

24) Such a situation was given in the CFCs-ozone problem. According to I. Walter et.al. (1978, p. 38) "... it appears that both public and official opinion in Europe did not rate the (CFCs-ozone, R.P.) problem as highly as did Americans". In the meantime (March 26, 1980) the Council of the European Community determined (1) not to increase production of certain CFCs and (2) to reduce (but not to ban!) the use of CFCs in aerosol cans.

In this situation the emission level e_2^0 will be maintained by country 2, because it is still welfare-maximizing relative to this country's unchanged belief that residuals emission is not harmful. On the other hand, country 1 is now convinced that its welfare depends on e_1 and on e_2 as well, i.e., that the welfare function W^1 from eq. (4) applies with indifference curves as drawn in figure 5. As long as country 1 cannot convince the other country of the correct view of the pollution impacts there is no hope for cooperation.²⁵⁾ But it is evident from figure 5 that in this case country 1 can improve its welfare position by unilateral emission reduction. In other words, if country 1 believes that country 2 will stick to its emission level e_2^0 , its best strategy is to reduce its own emission from e_1^0 to $R^1(e_2^0)$. In figure 5 this action means a move from point Z to point H. It turns out that $R^1(e_2^0)$ is country 1's maximum strategy²⁶⁾ from the game theoretic point of view. The optimal unilateral reduction of emissions, $e_1^0 - R^1(e_2^0)$, is the greater the stronger the negative consumption and production externalities are and the smaller the costs of emission reduction are in terms of consumption good forgone, i.e. the smaller T_1^1 evaluated at $s_1 = 0$. Observe that $R^1(e_2^0) = 0$ is possible. In this case the unilateral complete ban on residuals emission is optimal. Given that country 1's view on damage from pollution is also correct for the other country then country 2 always costlessly benefits from the unilateral emission reduction $e_1^0 - R^1(e_2^0)$. This can be seen from figure 6 when moving from Z to H, and in figure 7, where Z' and H' are assumed to represent the welfare allocations assigned to (e_1^0, e_2^0) and $(R^1(e_2^0), e_2^0)$, respectively.

25) In this context, the Natural Resource Defense Council believes that "the formation of a consensus among scientists of different nations on the gravity of the ..(RTP, R.P.) problem is perhaps the most important prerequisite to effective regulation worldwide" (T.B. Stoel, Jr., R.I. Compton, and S.M. Gibbons (1977, p. 131); quoted from I. Walter, T.N. Gladwin and I.L. Ugelow (1978, p. 182)).

26) See J. Harsanyi (1977, p. 105).

The considerations above on the optimality of unilateral regulation crucially depend on the regulating country's belief that the other country will not join its own view of the detrimental impact of pollution. The relevant question is, however, what the regulating country can gain by convincing the other country of the validity of its own damage assessment. To see this we suppose now that country 2 does accept the scientific evidence of damage from pollution after country 1 reduced its emission from e_1^0 to $R^1(e_2^0)$. The consequences of this new situation are rather different depending on whether cooperation takes place or not. If for one reason or another the countries do not cooperate, it can be expected that possibly after some period of mutual emission adjustments an equilibrium point such as S in figure 6 is reached. Since the initial emission allocation was $(R^1(e_2^0), e_2^0)$, the joint emission (\bar{e}_1, \bar{e}_2) prevailing in the equilibrium point may be such (as in the case of figure 6) that $\bar{e}_1 > R^1(e_2^0)$. In this case it would be optimal for country 1 to increase (!) its emission. Even more important is, however, that the transition from point H to point S in figure 6 implies a substantial welfare increase for country 1 whereas the welfare change for the other country is ambiguous.

Even though the lack of cooperation may not be unrealistic due to institutional or political barriers, it remains true for all scenarios of non-cooperative behavior that, in general, there is a non-empty negotiation set irrespective of the non-cooperative "history", i.e., independent of whether the initial welfare allocation is characterized by Z', H' or S' in figure 7. We therefore turn our attention to the bargaining issue now.

4. International Bargaining

It is intuitively clear that the solution to the bargaining problem is not, in general, independent of the conflict situation which is, by definition, the welfare allocation emerging in the

absence of any agreement. We argued in section 3.2 that one can conceive of different conflict situations, e.g. the points Z', H' oder S' in figure 7 depending on the "history of the conflict". For the time being we suppose that the conflict situation is unambiguously determined by some (unique) equilibrium point of the game, say, by the point S' in figure 7. In order to elaborate the basic structure of the bargaining problem under this assumption we briefly review the classical approach. It is characterized by the following two rationality requirements:²⁷⁾

1. Individual rationality: The agreement must represent, for both countries, a situation at least as favourable as the conflict situation. Let \bar{w}_1 and \bar{w}_2 be the coordinates of the conflict situation (point S' in figure 7). Then the negotiation or bargaining set (of attainable welfare allocations) is $X := \{ (w_1, w_2) \in W(E) \mid w_i \geq \bar{w}_i \text{ for } i=1,2 \}$. Individual rationality requires that the countries only agree on joint strategies (e_1, e_2) , such that $[W^1(e_1, e_2), W^2(e_1, e_2)] \in X$. Geometrically, X is the set of all points in the shaded area of figure 7.

2. Joint efficiency: The agreement will represent a situation that could not be improved upon any further to both countries' advantage because rational players would not accept a given agreement if some alternative arrangement could make both of them better off. When combined with the postulate of individual rationality this postulate reduces the welfare allocations that are candidates for agreement in international bargaining to the set $\bar{X} := \{ (w_1, w_2) \in X \mid \text{there is no } (\tilde{w}_1, \tilde{w}_2) \in X \text{ satisfying } w_i < \tilde{w}_i \text{ for } i=1,2 \}$. In figure 7 this set \bar{X} is represented by the upper right boundary of the negotiation area, i.e., the line between N' and P'.

In the present model the agreement set is typically non-empty and has more than one element. Hence the two rationality postulates

27) See J. Harsanyi (1977, p. 141 n.).

stated above are insufficient to yield a unique bargaining solution. In fact, the bargaining problem in a narrower sense only arises whenever \bar{X} contains more than one element.²⁸⁾

4.1. The Nash Solution

Since Nash's approach²⁹⁾ to this bargaining problem in the narrower sense is by now standard, we need not elaborate it in detail. Instead, we briefly review its presuppositions and show its immediate application to the RTP issue. Each country chooses a welfare demand \tilde{w}_1 and \tilde{w}_2 , simultaneously and independently of each other. If $(\tilde{w}_1, \tilde{w}_2) \in W(E)$ then each country receives the welfare that it has been asking for. Since $(\tilde{w}_1, \tilde{w}_2)$ is an attainable welfare allocation, there is, by definition of $W(E)$, at least one emission allocation $(\tilde{e}_1, \tilde{e}_2) \in E$ such that $\tilde{w}_i = W^i(\tilde{e}_1, \tilde{e}_2)$ for $i=1,2$. Hence the agreement on some $(\tilde{w}_1, \tilde{w}_2) \in W(E)$ implies an agreement on bilateral emission regulation.³⁰⁾ On the other hand, if $(\tilde{w}_1, \tilde{w}_2) \notin W(E)$, then each country will receive its conflict welfare level \bar{w}_1 and \bar{w}_2 . Again, the conflict situation (\bar{w}_1, \bar{w}_2) is assumed to be predetermined in this section.

The Nash solution to this bargaining game is derived from the following four postulates.³¹⁾

1. Joint efficiency

This postulate has already been introduced and interpreted above.

2. Symmetry

The solution $(\tilde{w}_1, \tilde{w}_2)$ of a symmetric game satisfies $\tilde{w}_1 = \tilde{w}_2$. A

28) J. Harsanyi (1977, p. 128 n.).

29) J.F. Nash (1950).

30) If $(\tilde{w}_1, \tilde{w}_2)$ is the image of W^1 and W^2 for more than one strategy tuple $(e_1, e_2) \in E$, then a strategy coordination problem arises, which does not appear to be serious when the number of players is small. See also J. Harsanyi (1977, p.133n.).

31) J.F. Nash (1950). Interpretation and evaluations (and more formal statements) can be found in various textbooks on game theory. See, for example, J. Harsanyi (1977, p. 144 n.).

bargaining game is said to be symmetric if its conflict point (\bar{w}_1, \bar{w}_2) satisfies $\bar{w}_1 = \bar{w}_2$ and if the set $W(E)$ is symmetric with respect to the $w_1 = w_2$ line.

3. Linear invariance

The emission allocation (e_1, e_2) that is associated to a solution of the bargaining game is independent of the unit of measurement and of the zero point that we choose for each country's welfare function.

4. Independence of irrelevant alternatives

Let (\bar{w}_1, \bar{w}_2) be the conflict situation and let $(\tilde{w}_1, \tilde{w}_2)$ be the solution to the bargaining game which has the payoff space $W(E)$. If $W(E)$ is substituted by $\tilde{W}(E) \subset W(E)$ such that (\bar{w}_1, \bar{w}_2) and $(\tilde{w}_1, \tilde{w}_2)$ are still elements of $\tilde{W}(E)$ then $(\tilde{w}_1, \tilde{w}_2)$ remains the solution to this new game.

Nash has shown that under these four postulates a unique solution to the bargaining game exists, if the payoff space is compact and convex.³²⁾ The payoff space of our present model is $W(E)$ and this set is proved to be compact and convex in section 3. Furthermore, Nash gave an interesting characterization of the solution:³³⁾ The solution $(\tilde{w}_1, \tilde{w}_2)$ to the bargaining game maximizes the function $v = V(w_1, w_2; \bar{w}_1, \bar{w}_2) := (w_1 - \bar{w}_1)(w_2 - \bar{w}_2)$ on X .

With the help of this property the Nash solution can be represented in figure 8 by the point P which is the (unique) point of tangency between the boundary of $W(E)$ and a rectangular hyperbola AB asymptotic to the lines S'C and S'D which in turn are parallels to the axes. It is obvious from figure 8 that the Nash solution is individually rational for both countries.

32) J.F. Nash (1950, p. 159).

33) See also J.F. Nash (1953) and J. Harsanyi (1977, p. 167 n.).

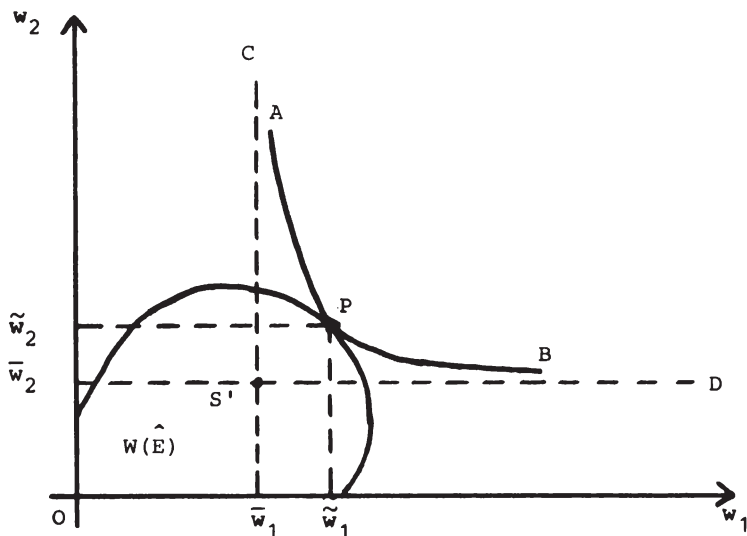


Figure 8

4.2 Mutually Optimal Threat Strategies

So far we considered the RTP problem as a so-called two-person simple bargaining game characterized by some predetermined conflict situation or disagreement payoffs (\bar{w}_1, \bar{w}_2) . Since the Nash solution is unique, the conflict payoffs (\bar{w}_1, \bar{w}_2) completely determine the agreement payoffs $(\tilde{w}_1, \tilde{w}_2)$ for given W^1 , W^2 and $W(E)$. It is also easy to see that the agreement welfare allocation $(\tilde{w}_1, \tilde{w}_2)$ in general varies when the conflict payoffs (\bar{w}_1, \bar{w}_2) change. More formally, the Nash solution can be viewed as a mapping from the set feasible conflict situations, $W(E)$, into the set of attainable welfare allocations that is also equal to $W(E)$. For our purposes it is convenient to express this mapping by two functions \hat{N}^1 and \hat{N}^2 from \mathbb{R}_+^2 to \mathbb{R}_+ such that $[\hat{N}^1(\bar{w}_1, \bar{w}_2), \hat{N}^2(\bar{w}_1, \bar{w}_2)]$ is the Nash solution to the bargaining game, if (\bar{w}_1, \bar{w}_2) is its predetermined conflict situation. This formulation suggests that the

selection of disagreement payoffs is an important part of the bargaining problem. Therefore the conflict situation should be "endogeneous" to the model, thus leading to a so-called general (as opposed to simple) two-person bargaining game.

Of course, it is not possible for any country to determine its own or the other country's disagreement payoff since e_1 and e_2 are arguments in both welfare functions. But each country can announce a national emission level to be implemented in case that no agreement would be reached. Let θ_i denote the conflict emission levels that have been chosen by country i . Then, by definition,

$$(9) \quad \bar{w}_i = W^i(\theta_1, \theta_2) \quad (i=1,2)$$

Each tuple (θ_1, θ_2) determines a conflict situation. Therefore θ_1 and θ_2 are also called threat strategies. It will be assumed that these threats are binding in the sense that the countries are bound to implement them if they later fail to reach agreement.³⁴⁾ This assumption appears to be plausible in the case of international negotiations where the fear of losing face or international reliability is a strong enforcement mechanism. In summary, the general bargaining game with binding threats operates as follows: The countries choose their threat strategies θ_1 and θ_2 at the beginning of the game thus defining the conflict situations via eq. (9). The disagreement payoffs (\bar{w}_1, \bar{w}_2) in turn determine the agreement payoffs $(\tilde{w}_1, \tilde{w}_2)$ by the simple bargaining game as described in the previous section.

Now the interesting and important question arises which threat strategy should be chosen by each country. Is there an optimal threat strategy for each country and, furthermore, are there mutually compatible optimal strategies for both countries? Since both countries' welfare is interdependent, each country can

34) For games without binding threats see J. Harsanyi (1977).

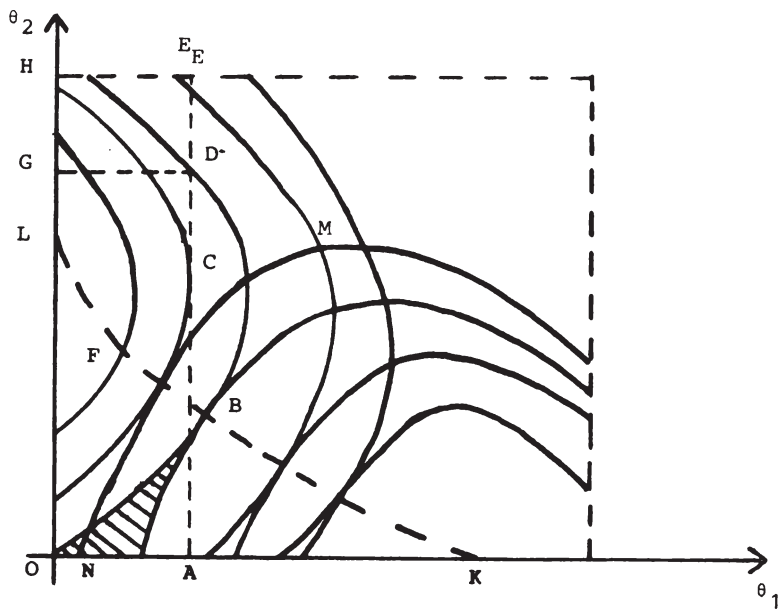


Figure 9

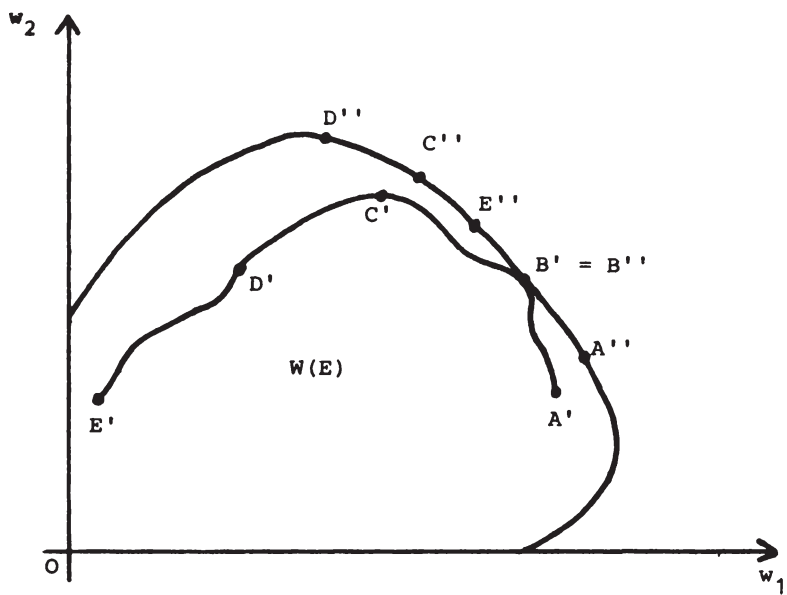


Figure 10

only choose a threat strategy which is optimal in the sense of welfare maximizing relative to some given threat strategy of the other country. "Intuitively an optimal threat strategy in Nash's sense is the threat strategy maximizing the relative strength of one's bargaining position against the opponent. It represents the best possible compromise between trying to maximize the costs of a conflict to the opponent and trying to minimize the costs of a conflict to oneself."³⁵⁾ In figures 9 and 10 a geometric interpretation is given. Suppose that the predetermined strategy θ_1 of country 1 is equal to OA in figure 9. Then, choosing a threat strategy $\theta_2 \in E_2$ is for country 2 equivalent to selecting a point on the dotted line ABCDE. Each point on this locus uniquely defines a welfare tuple since a welfare indifference curve of both countries passes through each point. Therefore the line AE can be mapped into the welfare space of figure 10, yielding some line A' B' C' D' E'. Observe that in C (and C') country 2's welfare is maximal and that in one and only one point such as B (B') the welfare possibility frontier is hit. Figure 10 suggests to interpret country 2's maximizing procedure as the problem to choose the best possible conflict point from the line A' B' C' D' E', where the best one means the point which yields the highest welfare for country 2 in the associated Nash solution (of the simple bargaining game). In figure 10 the points A", B" etc. are supposed to be the Nash solutions of alternative simple bargaining games with conflict situations A', B' etc., respectively. Let D" be the Nash solution with the greatest w_2 -coordinate and suppose that D' is the conflict situation corresponding to D". Associated to the point D' in figure 10 there is the point D in figure 9. Hence $\theta_2 = OG$ (in figure 9) is the optimal strategy for country 2 when the other country's threat strategy is given by $\theta_1 = OA$. It is clear that the situation described in figures 9 and 10 can only serve as an example. But one can easily see from figure 10 that the optimal conflict point from country 2's point of view must lie somewhere on the non-decreasing line segment E' C'.

35) J. Harsanyi (1977, p. 170n.).

In order to establish the existence of mutually optimal threat strategies we look at the two stage bargaining problem described above as a two-person game with strategy spaces E_1 and E_2 and with payoff functions

$$(10) \quad w_i = N^i(\theta_1, \theta_2) := \hat{N}^i [W^1(\theta_1, \theta_2), W^2(\theta_1, \theta_2)] \quad (i=1,2),$$

where the functions \hat{N}^1 and \hat{N}^2 are those that were introduced on p. . This reformulation clearly shows that we generated a game that is formally analogous to that of sections 2 und 3.1. Mutually optimal threat strategies are thus equivalent to an equilibrium point for the game $G_N := \{2, N^1, N^2, E^1, E^2\}$. Nash has shown³⁶⁾ that under the assumptions used in this paper a pair of mutually optimal strategies always exists and that in the case of multiple solutions all pairs of mutually optimal strategies are interchangeable. This implies that the welfare allocation being a solution to the general bargaining game is unique.

Harsanyi gives two interesting characterizations of mutually optimal threat strategies which will not be considered here in analytical detail.³⁷⁾ Basically his results are that a country achieves a higher final welfare level:

1. The greater its own willingness, and the lesser the other country's willingness, to risk a conflict in order to obtain better terms.
2. The greater its welfare gain associated with a small welfare loss of the other country on the upper right boundary of the set of attainable welfare allocations.
3. The greater damage that it could cause to the other country at a given cost to itself and the lesser damage that the other country could cause to its opponent at given cost to itself.

36) See J.F. Nash, (1953).

37) J. Harsanyi (1977, p. 169 n., in particular p. 179).

Even though the concept of mutually optimal threat strategies appears to be satisfactory on a conceptual level its immediate application to empirical issues of RTP will be extremely difficult because of the tremendous informational requirements. In particular, one would like to use this solution concept in order to evaluate actually implemented strategies for international negotiations but this would also require full computation of the "optimum". In spite of these limitations some interesting conclusions with respect to unilateral emission reductions can be drawn from the theoretical model.

4.3 Unilateral Pre-bargaining Regulation

With respect to the issue of international negotiations in RTP problems it is important to observe that the initial emission allocation did not play any rôle in the theory of mutually optimal threat strategies of section 4.2. In fact, as long as the countries convincingly announce that their strategy sets are E_1 and E_2 , respectively, for the bargaining game to be played, then the actual emissions are irrelevant for their relative bargaining power and hence for the solution of the game. On the other hand, suppose that before bargaining country 1 implements a unilateral reduction of emission from e_1^0 to $e_1' < e_1^0$ and determines not to increase its emission in the future. This procedure means in terms of our model that the country 1's strategy set E_1 is reduced to $E_1' := [0, e_1']$ which is a proper subset of E_1 . Consequently the game to be played is different from that one whose strategy sets are E_1 and E_2 . Denote by G the general bargaining game described in section 4.2 in which the strategy sets are E_1 and E_2 and let G' be the game which differs from G only in that E_1' is substituted for E_1 . Since $E_1' \subset E_1$ and $E_1' \neq E_1$, we have also $W(E) \supset W(E')$ and $W(E) \neq W(E')$, where $E' := E_1' \times E_2$ and where $W(E')$ is the payoff set of the game G' . Suppose further that $(\tilde{w}_1, \tilde{w}_2) \in W(E)$ is the unique solution to the game G and that $H(\tilde{w}_1, \tilde{w}_2) := \{(\theta_1, \theta_2) \in E \mid N^i(\theta_1, \theta_2) = \tilde{w}_i \text{ for } i=1,2\}$ is the set of joint threat strategies leading to this solution. Similarly let $(\hat{w}_1, \hat{w}_2) \in W(E')$ be the solution to the game G' and let $H(\hat{w}_1, \hat{w}_2) := \{(\theta_1, \theta_2) \in E' \mid N^i(\theta_1, \theta_2) = \hat{w}_i \text{ for } i=1,2\}$ be the corresponding set of joint threat strategies.

It is now interesting to inquire into the conditions for $(\hat{w}_1, \hat{w}_2) \neq (\tilde{w}_1, \tilde{w}_2)$. Note first that if the inequality holds then the change in payoffs is to the advantage of country 2. More precisely, then $\hat{w}_1 < \tilde{w}_1$ and $\hat{w}_2 > \tilde{w}_2$. This is so because by its decision to substitute E'_1 for E_1 country 1 cuts off favourable welfare options for itself but only unfavourable ones for the other country. For an illustration of this effect suppose that the maximum emission e'_1 of country 1 is equal to OA in figure 9. Then the joint strategy set E' of the game G' is represented by the area OAEH in figure 9. This area contains all high level indifference curves for country 2 whereas country 1 loses favourable welfare options.

The answer to the question under which conditions $\hat{w}_1 < \tilde{w}_1$ and $\hat{w}_2 > \tilde{w}_2$ follows immediately from the postulate of "independence of irrelevant alternatives": $(\hat{w}_1, \hat{w}_2) \neq (\tilde{w}_1, \tilde{w}_2)$ if and only if $(\tilde{w}_1, \tilde{w}_2) \notin W(E')$ or $(\theta_1, \theta_2) \notin E'$ for some $(\theta_1, \theta_2) \in H(\hat{w}_1, \hat{w}_2)$. It should be emphasized that $(\tilde{w}_1, \tilde{w}_2) \in W(E')$ is not sufficient for $(\hat{w}_1, \hat{w}_2) = (\tilde{w}_1, \tilde{w}_2)$. This result may appear to be counter-intuitive, but it can easily be shown with the help of the figures 9 and 10. Suppose as in the last paragraph that in figure 9 the set E' of game G' is represented by the area OAEH. Further, let B'' in figure 10 be the solution of the unrestricted game G . Since B'' corresponds to the point B in figure 9 we clearly have $(\tilde{w}_1, \tilde{w}_2) \in W(E')$. We have to show that B'' in figure 10 or B in figure 9 cannot be the solution to the restricted game G' . Consider therefore the set $E_B := \{(\theta_1, \theta_2) \in E' \mid W^i(\theta_1, \theta_2) \leq \tilde{w}_i \text{ for } i=1,2\}$ which is the set of all points in the shaded area in figure 9. Clearly, we have $[N^1(\theta_1, \theta_2), N^2(\theta_1, \theta_2)] \neq (\tilde{w}_1, \tilde{w}_2)$, if $(\theta_1, \theta_2) \notin E_B$. Our claim is proved if it is true that for any given $\theta_1 \in E'_1$ there exists $\theta_2 \in E_2$ such that $(\theta_1, \theta_2) \notin E_B$ and $N^2(\theta_1, \theta_2) > \tilde{w}_2$. Let $\bar{\theta}_1 < e'_1$ and select $\bar{\theta}_2 \in E_2$ such that the condition (8) is satisfied for the pair $(e_1 = \bar{\theta}_1, e_2 = \bar{\theta}_2)$. In other words, in figure 9 $(\bar{\theta}_1, \bar{\theta}_2)$ is a point on the (dotted) "efficiency line" LK to the left of the point B, and $[W^1(\bar{\theta}_1, \bar{\theta}_2), W^2(\bar{\theta}_1, \bar{\theta}_2)]$ is a point on the welfare possibility frontier. For this reason, $[N^1(\bar{\theta}_1, \bar{\theta}_2), N^2(\bar{\theta}_1, \bar{\theta}_2)] =$

$[W^1(\bar{\theta}_1, \bar{\theta}_2), W^2(\bar{\theta}_1, \bar{\theta}_2)]$. But we clearly have $N^2(\bar{\theta}_1, \bar{\theta}_2) > \tilde{w}_2$ and $(\bar{\theta}_1, \bar{\theta}_2) \notin E_B$. Suppose now that $\tilde{\theta}_1 = e_1'$. Then the foreign country may choose $\tilde{\theta}_2 = OK$ (in figure 9), in which case $(\tilde{\theta}_1, \tilde{\theta}_2) \notin E_B$ and $W^2(\tilde{\theta}_1, \tilde{\theta}_2) > \tilde{w}_2$. From the postulate of individual rationality we know that $N^2(\tilde{\theta}_1, \tilde{\theta}_2) \geq W^2(\tilde{\theta}_1, \tilde{\theta}_2)$. Hence it is proved that the point B in figure 9 cannot be the solution to the restricted game G' with strategy space OAEH.

In summary, this section has shown that a unilateral reduction of emissions by one country may influence the outcome of the bargaining process in favour of the other country if the reduction is "strong" and if the regulating country does not or cannot convince the other country that it is determined to adopt less restrictive emission regulation in case of a conflict.

4.4. Strategic Manipulation

It is a characteristic feature of many RTP problems that the information on adverse pollution effects and their proper evaluation is highly uncertain. Further scientific research and evidence may not exclude the possibility that considerably diverging national damage assessments can be defended without being obviously incompatible with the available "knowledge". This is particularly true in global RTP situations that concern the stratosphere. For example, in the case of the CFCs-ozone problem in the United States the administration and several scientists emphasized that they expect significant damage from CFCs releases for their country. This position has been substantiated by the U.S. unilateral pre-bargaining CFCs regulation. On the other hand it appears that in Europe there was and still is less concern about the ozone issue.

Suppose now that in our two-country model country 2 is less concerned in the beginning but that it then reconsiders the problem carefully and reaches about the same conclusion on damage assessment as the other country. Then the important question is whether the revelation of true judgement is in country 2's self-interest.

Has it an incentive to behave strategically³⁸⁾ and pretend (despite better knowledge) that in its view the damage is minor than it really "knows" it is? The answer is in the affirmative if its welfare position in a bargaining solution with "cheating" is better than its welfare when "the game is played with open card".

In order to see that cheating may be advantageous we consider for simplicity the extreme case where country 2 pretends that pollution from residuals emission has no detrimental effects on its own economy. Suppose that figure 6 contains the true welfare indifference curves for both countries. However, the indifference lines that are reported by country 2 satisfy $\hat{W}_S^2 = \hat{T}_S^2 = 0$. They are straight lines parallel to the horizontal axis in figure 6, such that the welfare index increases with increasing distance from the horizontal axis. If the (simple or general) bargaining game is played with the true characteristics of the country 1 and with the misrepresented characteristics of country 2, the solution will always be the point H in figure 6 since the optimal threat strategy of country 2 is $\theta_2 = e_2^0$.

The possible advantage of misrepresentation can be seen by comparing it with the alternative option of true revelation. Therefore consider the case that country 2 reports the true preferences as drawn in figure 6 but chooses non-cooperative behaviour. Then the equilibrium point S in figure 6 will be selected as a solution. Country 2's (true) indifference curves in figure 6 are such that its welfare level in S is lower than that in point H. Hence figure 6 is an example for the case in which misrepresentation is superior to preference revelation combined with non-cooperative behaviour.³⁹⁾ The second alternative, that is, prefe-

38) The issue of strategic manipulation has become well-known in the context of the theory of voting and in the theory of public goods. The relevant literature and an analytical treatment of the problem is given in R. Pethig (1978).

39) Observe that the assumption of complete denial of damage is not essential for the argument. It would take, however, considerable analytical effort to show this result with "moderate" underrating of damages.

rence revelation on both sides and cooperation, cannot be computed so easily without additional quantitative specification of the welfare functions involved. The following qualitative statement clarifies, however, the essential point. If the solution of the (general) bargaining game corresponds to a point on the dotted line segment NG in figure 6, then misrepresentation of preferences is in country 2's self-interest.

There is no intrinsic reason why manipulative strategies as outlined above for the case of country 2 are asymmetric between countries. Even though one may interpret one country's unilateral pre-bargaining regulation as an implicit preference revelation, it is conceivable that this country also engages in strategic misrepresentation of its characteristics. The country may pretend to have revised its previous damage assessment downward in the hope of some extra welfare gains.

Finally, we wish to emphasize that it is not the purpose of this subsection to recommend strategic manipulation to any country as a device to solve RTP problems. In our view there is a serious environmental threat to many countries that should not be considered as an entertaining poker game. The theorist wishes to check, however, whether the solution concepts studied or proposed are individually incentive-compatible. Our analysis suggests that this is not the case.

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