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Who will win the ozone game? On building and sustaining cooperation in the Montreal protocoll on substances that deplete the ozone layer

Kiel Working Papers, No. 579

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Suggested citation: Heister, Johannes (1993) : Who will win the ozone game? On building and sustaining cooperation in the Montreal protocoll on substances that deplete the ozone layer, Kiel Working Papers, No. 579, http://hdl.handle.net/10419/46850

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Who Will Win the Ozone Game ?

On Building and Sustaining Cooperation in the Montreal Protocol on Substances that Deplete the Ozone Layer

by Johannes Heister

June 1993

Institut für Weltwirtschaft an der Universität Kiel
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ISSN 0342 - 0787

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On Building and Sustaining Cooperation in the Montreal Protocol on Substances that Deplete the Ozone Layer

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Abstract: This paper presents an analysis of the Montreal Protocol on Substances that Deplete the Ozone Layer. It advances the view that the Developing World did not exploit its relatively strong bargaining position in negotiations over sidepayments and that the concessional ten-year grace period for less developed countries is a cause of instability of the agreement. The paper derives conditions under which sidepayments and sanctions can produce stable cooperation. It applies basic non-cooperative game theory and the subgame perfect Nash equilibrium as solution concept and compares the non-cooperative outcome with the Nash bargaining solution of a hypothetical cooperative game.

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1. Introduction

The history of Chlorofluorocarbons (CFCs) is a remarkable story. It tells about successful research, high-rising industrial production of CFCs for numerous purposes and the emergence of a pressing global environmental problem — the destruction of the earth's ozone layer — which can only be solved by international cooperation. Table 1 lists the most important stages.

Table 1 — CFC history

1930	Thomas Midgley Jr. discovers the CFCs (Shea 1988:18).
1974	World-wide production of CFC-11 and -12 reaches 800,000 tonnes annually.[1]
1974	Molina and Rowland present the theory that CFCs destroy the stratospheric ozone layer.
1978	CFCs in aerosols (spray cans) are banned in the USA.[2]
1985, spring	The ozone hole over Antarctica is discovered (Farman et al. 1985).
1985, March	The "Vienna Convention for the Protection of the Ozone Layer" is adopted. The Parties to the Convention accept the general obligation to protect the ozone layer. The convention provides for joint research and mutual information.
1987, September	The "Montreal Protocol on Substances that Deplete the Ozone Layer" is adopted. The Protocol imposes a time table for the phase-down of consumption of CFCs (50% by the year 2000) and a freeze of halons.
1990, June	The Parties to the Montreal Protocol meet in London. The Protocol is adjusted and amended. Provisions for a complete phase-out of CFCs (by the year 2000), halons and some other ozone depleting substances are introduced.
1992, November	The Parties to the Montreal Protocol meet in Copenhagen. They decide to phase out the production of CFCs by the end of 1995 (as had already earlier been announced by the USA and the EC) and to stop halons by the end of 1993.[3] The Parties also adopt new or stricter phase-down provisions for other compounds. In reaction to the Copenhagen decision, the EC brings its own CFC-phase-out deadline forward to the end of 1994.[4]

The main virtue of the CFCs is their chemical stability. They are not toxic, since they do not react with other chemicals, and they are not inflammable. Moreover, they are cheap to produce. CFCs are ideal as a coolant in refrigeration (Freon), as a foam blowing agent (Styrofoam), as aerosol propellants in spray cans and as a solvent in the electronic

1 Production data for the countries reporting to the Chemical Manufacturers Association. EPA (1987), here adopted from Morrisette (1989:795).

2 On the long discussion about possible damage to the ozone layer in the USA see Morrisette (1989).

3 "Bush verfügt Produktionsverbot für FCKW bis 1995", Frankfurter Allgemeine Zeitung, 13 February 1992. M. Simons, "Ozone Peril is Shocking Europeans into Action", International Harald Tribune, 4 March 1992. "Schon ab 1996 Verzicht auf schädliche FCKW", Nachrichten für Außenhandel, Eschborn, 2 December 1992.

4 "Umweltminister beschließen schärfere Abgaswerte ...", Handelsblatt, 17 December 1992.

industry and in dry-cleaning. Halons, a similar chemical, are mainly used in fire fighting.[5]

In 1986, world consumption of CFCs and halons was 1,140,000 tonnes with a total ozone depletion potential of 1,232,000 tonnes.[6] Production shares were for North America 29%, West Europe 37%, East Europe 12%, Asia, Pacific and Latin America 22%. In 1984/85, per capita consumption of CFC-11/12 was around 0.85 kg in the USA and in the EC; in China it was 0,02 kg. The data show a weak relationship between CFC consumption and GNP of roughly 60 tonnes per billion dollars of GNP. (All data UNEP 1989 ch. 2, and OTA 1989)

Life on earth is protected against dangerous solar radiation by a layer of relatively ozone rich air in the stratosphere (12-25 km above ground level). The ozone layer hinders the passage of ultraviolet radiation to the earth's surface. Particularly the powerful short-wave UV-B radiation is destructive to biological systems. UV-B radiation causes or promotes skin cancer, cataracts, allergic reactions, immune insufficiency and other diseases. It reduces the growth of plants and has adverse effects on crop yields and possibly on entire (aquatic) food-chain systems. It even damages some materials (plastic products) and increases smog (UNEP 1989 ch. 5).

Ozone, the three-atom form of oxygen (O_3), is built up by a chemical reaction triggered by sunlight above the tropics, from where global air circulation transports some of it to the poles (Shea 1988:7). The delicate ozone equilibrium in the stratosphere is tipped off by the release of anthropogenic trace gases, particularly CFCs and halons. The characteristic ozone destroying element is chlorine in CFCs and bromine in halones. During their long life-time, which for some compounds lasts up to 100 years, CFCs and halons emitted into the troposphere migrate slowly to the stratosphere. There, the compounds are broken up by powerful solar radiation and release their chlorine or bromine parts. Each chlorine or bromine atom then catalyses the destruction of a myriad of ozone molecules. This chain reaction depletes the ozone layer, which then lets dangerous UV-B radiation penetrate to the earth's surface.[7,8]

2. Impact of ozone depletion across world regions

Although every part of the world is affected by ozone depletion, there appear to be some systematic regional differences concerning the impact level and its (political) perception and valuation. The latitudinal distribution of ozone depletion is not even.

5 Besides CFCs and halons, which were first controlled by the MP, there are some other ozone depleting substances. Some of them were added to the list of controlled substances by the London and Copenhagen Amendments to the MP. In most parts of the paper, CFC stands for all ozone depleting substances.

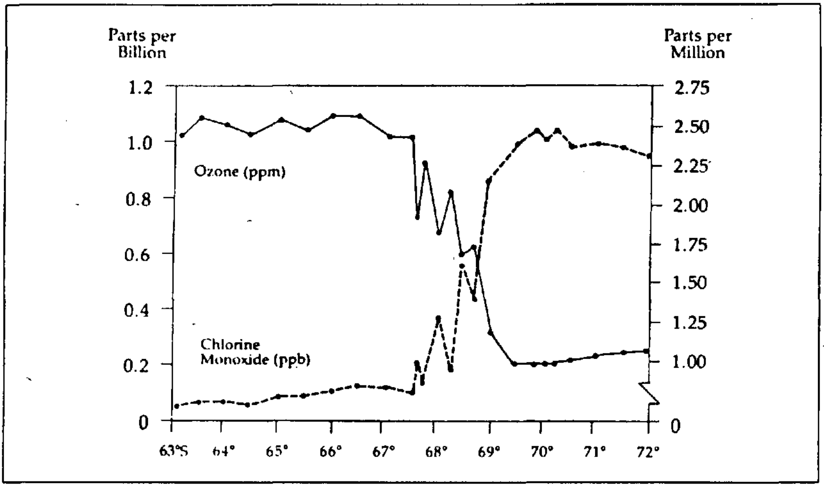
6 CFC-11 and CFC-12 have an ozone depletion potential of 1.

7 The exact chemical process is much more complicated. For details refer to UBA (1989).

8 Apart from depleting the ozone layer, CFCs and related compounds are very effective greenhouse gases, which significantly contribute to global warming.

Less depletion occurs around the equator. Depletion levels are considerably higher towards the poles with a particularly heavy loss of stratospheric ozone after the extremely cold antarctic winter (ozone hole). Figure 1 illustrates this pattern for the southern hemisphere.

Figure 1 — Atmospheric concentration of chlorine monoxide and ozone by latitude, southern hemisphere, 1987



Source: Shea (1988:10).

The ozone hole over Antarctica has already started to widen over the southernmost part of South America, New Zealand and southern Australia. In some regions in Australia and New Zealand the current level of UV-B radiation and the "burn time" is regularly broadcasted to warn people to protect themselves when outdoors.[9] Inhabitants of Chile's far south are reported to suffer from eye irritations, allergies and severe skin burns; farmers and fishermen report that sheep, wild rabbits and salmon are going blind.[10]

A similar ozone hole has not yet opened up over the North Pole. However, depressed ozone levels and a serious increase in chlorine concentration has been detected in the northern hemisphere, too. In the winter of 1992, scientists voiced warnings that the exceptionally high level of chlorine in the stratosphere of the northern latitudes could, under unfavourable weather conditions, develop an ozone hole by spring. In spring

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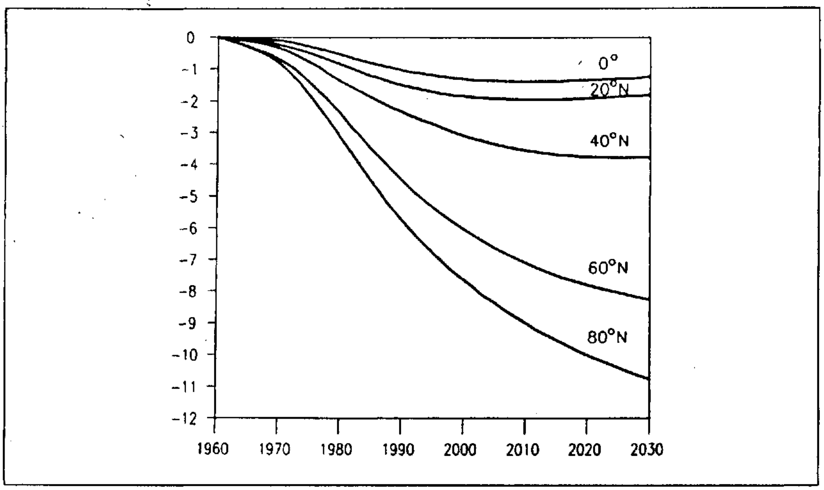
9 "Ripa mahnt Vorreiterrolle der Gemeinschaft an", Handelsblatt, 5 March 1992. "Tödliche Sonnenflecken: Die Angst vor dem Ozonloch über der südlichen Erdhälfte hat den Lebensstil der Neuseeländer nachhaltig verändert", Süddeutsche Zeitung, 19 March 1993.

10 L. Crawford, "Russian scientists to assist Chile in study of ozone layer depletion", The Financial Times, Frankfurt and London, 18 February 1992.

1993, ozone concentration over Europe was down by more than 20 per cent.[11] Figure 2 shows a remarkable (estimated) decline in total ozone concentration for different northern latitudes between 1960 and 2030. Ozone erosion near the equator has not yet been detected. Obviously, the countries of the northern and southern high latitudes face higher ozone depletion rates and are therefore probably more severely affected than countries located more closely to the equator.[12]

Figure 2 — Loss of total ozone for different northern latitudes between 1960 and 2030 (spring, in per cent of total ozone concentration)



Source: UBA (1989:23).

The impact of UV-B radiation shows a similar latitudinal bias. The biosphere in equatorial regions is adapted to the naturally higher solar radiation levels in these regions. Therefore, higher UV-B levels may be less damaging to the vegetation in equatorial regions and the impact on crop yields may be less severe. Similarly, dark-skinned people are generally less susceptible to UV-caused skin cancer than light-skinned people. Therefore, without adaptive measures being taken, fewer lives may be lost due to ozone depletion among the dark skinned population in countries closer to the equator than in higher regions (UNEP 1989:37).

The valuation of UV-B-caused damage is likely to differ between regions and countries of different level of economic development and different political systems (UNEP

11 J. Wille, "Das Ozonloch ist - noch - nicht über uns", Frankfurter Rundschau, 8 February 1992. B. James, "Ozone Hole Widens, Populated Regions Face Radiation Risk", International Herald Tribune, 5 February 1992. "Wir haben noch kein Ozonloch, aber genug Grund zur Sorge", Frankfurter Rundschau, 23 March 1993.

12 However, ozone depletion is set off to some extent by the screening effect of air pollution in industrial countries.

1989:37f). The political valuation of diseases and lost lives is probably lower in less developed countries (LDCs) than in developed countries (DCs). The social discount rate in LDCs tends to be higher due to a relatively higher weight of today's needs. Global causes for local environmental disasters are probably out of the perception of the majority of people in LDCs. Moreover, the political system in many LDCs offers not much opportunity for democratic participation and public pressure. Therefore, a less pronounced reflection of peoples' needs and preferences in the political valuation and decision making process in LDCs as compared to DCs is likely. The danger of ozone depletion may thus be undervalued by LDCs.

The above observations indicate that there probably is an important difference in the perceived costs of ozone depletion in LDCs as compared to DCs. This difference exists, because the distribution of damages is biased against DCs, which are generally located closer to the poles than the great majority of LDCs, and because richer countries have a higher valuation of such damages. This view is supported by the observation that rich northern and southernmost countries, particularly Canada, Norway, Finland, Australia and New Zealand, have fought vigorously for a strong ozone treaty (Benedick 1991:7).[13]

3. The Montreal Protocol

In the Vienna Convention for the Protection of the Ozone Layer (March 1985), which is in force since August 1988, a great number of nations agreed on the principle objective to "protect human health and the environment against adverse effects resulting from modifications of the ozone layer".[14] In particular, Parties agreed to co-operate as is relevant for reaching the purpose of the Convention. Cooperation covers research, the formulation and implementation of measures, particularly the development of a protocol to the Convention, and exchange of information and the development and transfer of technologies and knowledge.

Based on the Vienna Convention and after growing scientific evidence that a serious threat to the ozone layer and the earth exists, the Montreal Protocol (MP) was adopted in September 1987 and came into force in January 1989. Already in June 1990, the Member Parties met in London and agreed on adjustments and amendments to the MP. Existing controls were tightened and more ozone depleting substances were included.[15]

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13 The noted imbalance may be set off to some extent by the global warming effect of most ozone depleting substances, since global warming may affect LDCs more severely than most DCs. However, recent research indicates that ozone depletion may reduce warming. Since the regional costs of global warming are still very obscure this paper ignores them.

14 The Vienna Convention and the Montreal Protocol with its amendments and adjustments are reprinted in Rummel-Bulska and Osafo (1991).

15 The story of negotiating the MP is told in a remarkable way by US diplomat Richard Benedick (1991).

Apart from the principle obligations to reduce CFCs and related substances, the MP shows two important features. First, it contains a great number of concessions for LDCs including a grace period and financial transfers. Second, it provides for trade restrictions against non-members. Both features are designed to induce newly industrialized countries and LDCs to accept the MP, and to defend it against free-riding. Of some importance for strengthening and adjusting the MP is the regular revision process concerning controlled substances. Here, decisions by a two-third majority vote are possible. Weakly developed are monitoring procedures. Monitoring relies entirely on national control and self-reporting.[16] Non-compliance procedures were introduced at the Copenhagen meeting in November 1992. They mainly consist of procedural rules. But non-compliance reports shall be made available to any person upon request. And, apart from rendering appropriate assistance, Parties may decide upon and call for steps to bring about full compliance.

For the purpose of this paper, it is of particular interest to note how the MP treats LDCs that operate under its Article 5.[17] As was pointed out above, it is likely that LDCs are less affected by ozone depletion and hence may be less interested in an agreement on CFC control than DCs. LDCs may therefore behave opportunistically, and in order to win their permanent cooperation, DCs must advance the MP and entice LDCs to participate. This is possible, in principle, by calling for sanctions against non-Parties and non-compliant Parties and by sidepayments and other concessions (carrot and stick approach, Somerset 1989).

3.1 Trade restrictions

Trade restrictions in the MP ban imports of CFCs and other controlled substances from non-Parties (beginning January 1990) and exports to non-Parties (beginning January 1993). They also comprise im- and export restrictions for products that contain or are produced with controlled substances and include technologies, products, equipment etc. for producing controlled substances.

Newly industrialized export-oriented countries and LDCs that are unable to produce CFCs themselves would be hit particularly hard by the MP's trade restrictions. The Republic of Korea is an example for acceding to the Vienna Convention and the MP only in reaction to the threat of trade restrictions.[18] A similar example is Taiwan, which

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16 For difficulties with reporting and monitoring see Benedick (1991:179f).

17 Article-5-countries are developing countries (UN definition) with a calculated consumption of controlled substances of less than 0.3 kilograms per capita. Only very few newly industrialized or oil exporting countries do not fall under Article 5. For the sake of brevity, Article-5-countries are collectively referred to as LDCs in this paper.

18 "Korea schließt sich Ozonschutz an", Nachrichten für Außenhandel, Eschborn, 6 March 1992.

is reported to suffer an estimated loss in exports of between 100 and 200 New Taiwan $ (ca. 6.5 - 13 million DM) if the trade restrictions of the MP came into effect.[19]
The MP does not explicitly extend those trade restrictions to Parties found in non-compliance. However, the Copenhagen meeting of the Parties has produced an indicative list of possible measures against countries found in non-compliance. These measures include the suspension of specific rights and privileges under the MP, which permits to use the trade restrictions of the MP against a defector.[20]

3.2 Concessions concerning LDCs

The following special concessions that favour LDCs have been introduced into the MP.

- **Grace period:** LDCs that consume less than 0.3 kg of CFCs and halons (Annex-A-substances) per capita enjoy a grace period of 10 years. They may delay reductions until the year 2000, and thereafter obligations are based on the 1995-97 average consumption level or 0.3 kg per capita if lower.[21]
  The figure of 0.3 kg may seem small compared with a per capita consumption of 0.85 kg in the USA (1984/85). It is, however, very large when measured against the current consumption level in many LDCs (e.g., China: 0.02 kg) and when considering the large population figures of these countries. Even within the bounds of the MP, LDCs have theoretically the potential to offset the reduction efforts of all DCs. The MP implicitly induces LDCs to step up their production in order to reach the highest possible base year level and to built up a stock of CFCs for recycling after controls have become obligatory.[22]
- **Technology transfer:** Parties will take every practical step to "ensure that the best available, environmentally safe substitutes and related technologies are expeditiously transferred" to LDCs "under fair and most favourable conditions" (London revision). DCs did not accept an outright obligation to transfer technologies for reasons of intellectual property rights policy.
- **Multilateral Fund:** Parties establish a financial mechanism, including a Multilateral Fund, for the implementation of the MP in LDCs.[23] The Fund is financed by contributions from DCs and managed by the Parties jointly.[24] The financial mechanism

19 "Ozonloch schafft auch in Taiwan Bewegung", Nachrichten für Außenhandel, Eschborn, 3 March 1992. Taiwan has not signed the MP for diplomatic reasons, but (like other countries too) Taiwan is treated like a Party as long as it fulfils the MP's obligations.

20 On the possible application of trade restrictions against non-Parties to Parties found in non-compliance see also Sorensen (1988).

21 For Annex-B-substances (London amendment) the level is 0.2 kg per capita.

22 Recycling is not covered by the MP. It does not add to production neither to consumption figures and is in fact encouraged.

23 An Interim Multilateral Fund was established as part of the London Revisions (London Revisions of the MP, Annex IV, Appendix IV, cf. Benedick 1991:259f). The Fund was re-affirmed and permanently established as the Multilateral Fund by the Copenhagen meeting.

24 Some 50 per cent of the Fund's revenues is covered by contributions from only three countries: Germany (10,66%), Japan (14,87%) and the USA (25%), see: Forth Meeting of the Parties to the MP,

shall meet all agreed incremental costs in LDCs.[25] For the first three years, the Fund was set to US $160 million plus 80 million if more countries (notably India and China) joined.[26]

- **Non-compliance**: LDCs may notify the secretariat that, having taken all practical steps themselves, assistance remains inadequate to fulfil the control obligations. The Parties then consider the case and decide on appropriate remedial actions. Until a decision, no non-compliance procedure shall be invoked on the notifying Party.
- **Revision**: No later than 1995, the situation of LDCs, including the effective implementation of financial and technological assistance, shall be reviewed by the Parties and any necessary adjustments concerning the time schedule of control measures applicable to LDCs shall be adopted.

3.3 Compliance in the long-run

The MP has achieved nearly world-wide cooperation and has successfully imposed strict environmental obligations in a prisoners-dilemma-like situation characterized by free-riding incentives and important differences in the Parties' national interests. One may therefore wonder how it was possible to induce so many countries (including China and India) to sign the MP.
The prospects for sidepayments and the promise of DCs to pay the incremental costs of LDCs may have played a role. Incremental cost funding leaves LDCs at least not worse off than without the MP. But LDCs have a relatively strong bargaining position. Since ozone depletion is felt more in industrial countries, LDCs could have demanded higher sidepayments. But DCs were able to restrict payments to incremental costs. Hence, it seems that LDCs were unable to exploit their bargaining power. The threat of trade restrictions may have helped to limit payments to LDCs. Another explanation may be found in the concessions, especially the ten-year grace period, which render the implementation of the MP in LDCs more flexible.

The particular design of the MP gives rise to questioning its long-run stability. It is not clear whether all Parties will adhere to the MP or whether a breach is likely to occur in the future. Permanent compliance with the MP by an opportunistic country can only be expected if, for each and all future periods, the discounted gains from compliance exceed those from breaching the MP. Compliance by LDCs is likely as long as the grace period is in effect (until the year 2000), since for that period control obligations are weak and do not seriously conflict with growth expectations in LDCs. In this period

Draft Decisions, Annex XIV, Nov.92, UNEP/OzL.Pro.4/L.1/Rev.2. The Fund operates as part of the Global Environmental Facilities (GEF) at the World Bank, but under a separate status.

25 Incremental costs are those costs of a project that exceed the costs that a country would bear in its one interest.

26 India, for instance, has claimed substantial compensation when joining. See, "Wider die Öko-Kolonialisten: Wie man in Indien über den Erd-Gipfel denkt", Frankfurter Rundschau, 13 February 1992.

incremental costs will be relatively low such that large transfers by DCs to LDCs are not required.

This, however, may be different after the year 2000 when DCs will irreversibly have stopped their CFC consumption and phasing-out in LDCs, who may have stepped up CFC production by that time, is to begin. Reciprocity in CFC reductions, which is already weak due to the smaller ozone depletion and radiation effect in most LDCs, can no longer be employed to strengthen compliance. Moreover, rising incremental costs may be difficult to cover by the Multilateral Fund and disputes between Parties over funding may arise.[27] In this situation, LDCs may have an incentive to disregard the MP. They may simply fail to fulfil their reduction obligations, tacitly or openly. Moreover, it is conceivable that, with a worsening of the ozone and radiation situation in DCs, LDCs discover their bargaining power and, in return for compliance, demand transfer payments from DCs substantially higher than incremental costs.[28]

It therefore seems that the concessions to LDCs have burdened the MP with a serious time inconsistency. Moreover, the gains from saving the ozone layer seem to be unevenly distributed between DCs and LDCs, which may be unsustainable in the long-run. These observations cast some doubt on the eventual stability and effectiveness of the MP. Whether trade sanctions will be used in cases of non-compliance and whether this would be sufficient to guarantee long-run compliance, particularly by countries with a large internal market, remains an open question.[29]

The remainder of this paper is a stylized analysis of the MP. The analysis treats non-Parties and non-compliant Parties alike. It assumes that the ozone game is played by two homogeneous groups of countries, namely DCs who advance the MP and opportunistic LDCs. The following Sections investigate some features of the MP in a formal framework. Section 4 analyses the MP as a one-shot game with two players. It shows that the threat of sanctions is unsuitable for achieving agreement and compliance. The Section compares the outcome of the non-cooperative ozone game with the solution of a hypothetical cooperative Nash bargaining game of identical structure. Section 5 extends the analysis to a game with many LDC-players which face a coalition of DCs individually. This Section studies the willingness of LDCs to accede to and comply with the MP in a multi-player setting when non-Parties and defecting Parties face the threat of trade sanctions. Section 6 models the MP as a two-period ozone game with two players. It derives strict conditionality between transfer payments and irreversible CFC reductions as an important condition for the stability of the MP. Section 7 concludes the paper by discussing whether the MP can be expected to be stable in the long-run.

27 Already during the Copenhagen meeting, LDCs criticized DCs for hesitating to make agreed upon funds available to the Multilateral Fund (UNEP/OzL.Pro4/L.2, 24 Nov. 92). See also "Sehr hohe Beitragsrückstände: Sieben EG-Staaten schulden Ozonschicht-Fond Geld", Nachrichten für Außenhandel, Eschborn, 16 December 1992.

28 In this context, it is interesting to note that the Multilateral Fund was only established at the London Meeting of the Parties upon pressure from LDCs who were already members of the MP. See Markandya (1991:7).

29 On the question of compliance see also Enders and Porges (1992).

4. The two-players one-shot ozone game

We assume that binding commitments are not possible in the ozone game described in Sections 4.1, 5 and 6. Hence, we apply non-cooperative game theory and the subgame perfect Nash equilibrium as the relevant solution concept. The leading question in these Sections is under which conditions cooperation will emerge and will be stable. If the stabilization of cooperation proofs feasible, it seems possible that the non-cooperative ozone game mutates into a cooperative game, in which the relevant issue is how to divide the gains from cooperation between the partners. This question will briefly be dealt with in Sections 4.2 by applying the cooperative Nash bargaining concept.

The following model is simplistic. It assumes that the direct gains form CFC reductions (U) can only be realized in full cooperation between DCs (player A) and LDCs (player B). The notion behind this assumption is that, in the long-run, the ozone layer will definitely be destroyed by either group's emissions, since either group is individually capable of pushing the accumulated quantity of ozone depleting substances in the atmosphere beyond the relevant threshold. Moreover, the model assumes that all direct gains from cooperation accrue only to DCs ($U=U_A$), which reflects the smaller damage in LDCs and allows us to isolate the effect of sidepayments and sanctions and study it more conveniently. The model is completed by the costs of reducing CFCs for both players (C_A, C_B), by sidepayments T to LDCs, and by A's costs of imposing sanctions (S_A) and their impact on B (S_B).

4.1 Conditions of cooperation

The above described scenario is captured by the game Ozone I. The payoff matrix in Table 2 shows the gains from stopping CFC emissions and the relevant costs for both players and for each strategy combination.

Table 2 — Ozone I: Payoff matrix, base case

		Strategies Player **B** phase-out	emit
Strategies Player **A**	phase-out	(U_A-C_A ; -C_B)	(-C_A ; 0)
	emit	(0 ; -C_B)	(0 ; 0)

The payoffs in Ozone I are calibrated against the status-quo situation (no MP) in which each player maximizes his/her own utility function without respect to the other player's utility. Hence, phase-out costs C_A and C_B are incremental costs in the language of the MP. In the non-cooperative outcome (emit; emit) both players have utility zero. If both players A and B choose phase-out, they have to face costs C_A or C_B respectively, and player A gains utility U_A ($U_A > C_A$) whereas B gains nothing but is left with her costs C_B.[30] Hence, cooperation is not a feasible solution. To continue emissions is always the dominant strategy for B, even if A could commit himself to play phase-out. Since the strategy combination (phase-out; emit) would leave A with a real loss, A plays emit as well. The outcome of Ozone I is the non-cooperative (emit; emit).

The cooperative solution can only be reached if player A is able and willing to alter the payoff matrix. He can do this by raising the costs of continued emissions for B through imposing sanctions with impact S_B on B and costs S_A for himself, and/or by making side-payments T to B to give B a positive payoff from cooperation. The adjusted payoff matrix (Ozone II) is given in Table 3.

Table 3 — Ozone II: Payoff matrix with sidepayments and sanctions

		Strategies Player **B**: phase-out	Strategies Player **B**: emit
Strategies Player **A**	phase-out	$(U_A - C_A - T\ ;\ T - C_B)$	$(-C_A - S_A\ ;\ -S_B)$
	emit	$(0\ ;\ -C_B)$	$(0\ ;\ 0)$

Ozone II assumes that sanctions will only be imposed if A phases out and B emits and that transfers are only paid if both players phase out. Depending on the severity of sanctions and/or on the amount of transfers, Ozone II may have a cooperative outcome. On first sight, this is the case if the following conditions hold:[31]

A: $$U_A - C_A - T \geq 0 \quad (1)$$

B: $$T - C_B \geq -S_B \quad (2)$$

Inequality (2) is the participation condition for B, who will only cooperate if the impact of sanctions S_B is not more costly than her costs of phasing out minus received transfers. Since sanctions will only be imposed by A if A plays phase-out, B's decision is subject to A's rationality constraint (1), namely that A's total gains are not negative.

If A could commit himself to impose sanctions on B despite his potential loss, Ozone II would have two Nash equilibria: (phase-out; phase-out) and (emit; emit). But being sovereign, A cannot credibly commit himself to punish B, because executing sanctions would hurt A more than simply playing emit as well. The threat of sanctions is therefore not credible. Since both players know that sanctions are an ineffective threat, the non-cooperative outcome (emit; emit) remains the only Nash equilibrium. A different outcome is only possible if (2) is replaced by (3).

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30 To assume a cooperative utility gain U_B for B, too, would not alter the results qualitatively as long as $U_B < C_B$.

31 We assume that players behave sympathetically, i.e. if a player is indifferent between two alternatives, he chooses the cooperative alternative.

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B: $T-C_B \geq 0$ or $T \geq C_B$ (3)

In this case in which A pays at least B's costs, B's payoff from cooperation is non-negative and the cooperative Nash equilibrium is at least as good for both players as the non-cooperative one. Hence, A can safely play phase-out, since (3) ensures that B will play phase-out, too. Condition (3) reflects the fact that in Ozone II sanctions are not credible and thus have no effect.[32] Therefore, to achieve cooperation, A must adopt a transfer scheme that satisfies (3) and (1). Hence, only for those transfers for which $U_A-C_A \geq T \geq C_B$ holds the cooperative Nash equilibrium results.

We summarize the result of this Section as follows: In a one-shot ozone game with two sovereign players, sanctions are not credible and ineffective. The transfers necessary to lure a coalition of opportunistic countries into cooperation are independent of announcing sanctions to be imposed in case of non-cooperation. Transfers must in any case be selected in such a way that both players gain a non-negative payoff from cooperation.

4.2 The cooperative Nash bargaining solution

The above result describes the lower bound for transfers that guarantee a cooperative solution. This lower bound is, however, not necessarily the outcome of a bargaining game between A and B over the amount of transfers that are acceptable for both players in a situation of cooperation. If cooperation can be made certain by paying transfers, cooperative bargaining theory may become the relevant solution concept for predicting the distribution of the total gains from cooperation.

Strategic bargaining between A and B over sharing net gains can be modelled by Rubinstein's (1982) strategic bargaining approach of alternating offers over infinite time, in which players' shares depend on the difference in their time preferences (or other bargaining costs). If players' time preferences are equal, Rubinstein's model yields a symmetric equal split outcome (safe of a small first mover advantage). An equal split outcome can also be reproduced by the axiomatic Nash bargaining solution, which we will employ here as a benchmark solution. The simple Nash bargaining solution distributes the gains from cooperation minus the conflict payoffs to both players in equal shares.[33] Formally, the Nash bargaining solution is a joint maximization problem of the form $(u_1^*-c_1)(u_2^*-c_2) = \max (u_1-c_1)(u_2-c_2)$, in which u_i is the utility of

32 Sanctions may, however, have an effect in a repeated game with alternating moves. See Eaton and Engers (1992).

33 The Nash bargaining solution applied here assumes that the bargaining power of both players is equal. Asymmetries in preferences, disagreement points, the bargaining procedure and in players' beliefs about their environment can be captured in the construction of the relevant threat points. Asymmetries in players time preferences must be treated by using the asymmetric generalized Nash solution of the form $(u_1-c_1)^{\varepsilon}(u_2-c_2)^{1-\varepsilon}$, $0 \leq \varepsilon \leq 1$. See Binmore et al. (1986:186).

cooperation and c_i the utility of non-cooperation (conflict payoff) for both players i=1,2 and Σu_i is constant.

In our case, $c_i=0$ for A and B, since sanctions are not a credible threat against B and therefore the non-cooperative strategy combination (emit; emit) yields 0 for both players. Maximizing (4) with respect to T produces the Nash-transfers T^* in (5).

$$\max_{T}: \quad (U_A - C_A - T)(T - C_B) \tag{4}$$

$$T^* = 1/2(U_A - C_A + C_B) = C_B + 1/2[U_A - (C_A + C_B)] \tag{5}$$

The result (5) shows that A pays B's costs of phasing out CFCs and transfers half of his total net gains from saving the ozone layer to B, thus sharing the net gains from cooperation equally between both players.

4.3 Plausibility of the Nash bargaining result

The above Nash bargaining result seems to contradict the limitation of transfers in the MP to incremental costs (C_B), which, in our model world of Ozone II, gives LDCs no profit from cooperation. Nevertheless, many LDCs have signed the MP and have agreed to its adjustments and amendments. If the assumption that LDCs have considerable bargaining power in the ozone game is correct, there must be other reasons for this outcome. These reasons may include: (a) The direct gains from cooperation in DCs (U_A) may be very small. (b) There may be large gains from reducing CFCs cooperatively in LDCs as well ($U_B>0$). (c) There may be tacit sidepayments. (d) The result that sanctions are irrelevant may not apply. (e) The approach of a one-shot game with two players may be too coarse to describe the problem adequately. The following paragraphs examine those reasons.

It seems that prospective gains from cooperation can become very large. Several countries have conducted extensive studies on the costs and benefits of phasing out CFCs. Such studies are subject to great ecological and economic uncertainties. In particular, the valuation of health effects and the applied social discount rate heavily affect the results (UNEP 1989 ch. 5.4). Nevertheless, they are intuitive with respect to the magnitude of net benefits. A US EPA (1988) study suggests that, under a wide range of alternative assumptions, the benefits of phasing out CFCs world-wide outweigh the possible costs by far. A typical example is given in Table 4. A similar result is presented by Smith and Vodden (1989), who assess the costs and benefits of the MP for Canada (Table 5). The reported total gains are impressive. However, the data do not permit to derive the value of cooperation between DCs and LDCs, which is the incremental benefit of adding LDCs to the ozone coalition.

Table 4 — Costs and benefits of CFC reductions through 2075 by scenario, United States only, in billions of 1985 dollars (a)

Scenario	Health and Environmental Benefits	Costs	Net Benefits (minus costs)	Net Incremental Benefits (minus costs)(b)
CFC Freeze	3314	7	3307	3307
CFC 20% Cut	3396	12	3384	77
CFC 50% Cut	3488	13	3475	91
CFC 80% Cut	3553	22	3531	56

(a) See Regulatory Impact Analysis (US EPA 1988) for assumptions and definitions of scenarios. Estimates assume a 2 percent discount rate and $3 million per unit mortality risk reduction. All dollar values in the Table reflect the difference between the No Controls scenario and the specified alternative scenario. Valuation of health and environmental benefits applies only to people born before 2075; costs are estimated through 2075. (b) Changes in net incremental benefits represent movement to the indicated scenario from the scenario listed above it.

Source: US EPA (1988) Segment of Exhibits 10-9. Here reproduced from UNEP (1989:41).

Table 5 — Net present value of implementing the Montreal Protocol under various assumptions, Canada only, in million dollars

	Benefits	Costs	Net present value
Base case (a)	3237	194	3043
High social discount rate (b)	995	196	799
Low value of life (c)	939	194	745
Low social discount, low value of life (d)	28766	1415	27361
Low value of life, slow industry response (e)	939	292	647

(a) Assumes 7.5% social discount rate, 8.0% private discount rate, and value of life of $10 million. (b) Assumes 10% social discount rate, 10% private discount rate, and value of life of $10 million. (c) Assumes 7.5% social discount rate, 8.0% private discount rate, and value of life of $2.8 million. (d) Assumes 2.0% social discount rate, 6.0% private discount rate, and value of life of $2.8 million. (e) Assumes 7.5% social discount rate, 8.0% private discount rate, and value of life of $2.8 million and slow response by all industries other than the aerosol industry.

Source: Smith and Vodden (1989:420).

Barrett (1989, 1991) suggests that the benefits of cooperation between all countries are relatively small. He argues that the signatories have not obliged themselves to much more reduction than is in their individual interest, i.e. U_A is small. Hence, according to Barrett, the MP was easy to sign. This assessment appears to hold even more in the case of cooperation between the coalitions of DCs and LDCs, since LDCs presently have a small share of world-wide production capacity for and consumption of ozone depleting substances. However, what is relevant for our analysis is the potential future production capacity of LDCs under conditions of economic development unimpeded by any ozone treaty. Lack of technology is no hurdle. CFCs are relatively easy to produce (Benedick, 1991:4). The U.S. Office of Technology Assessment (1989:295) estimates that the consumption of CFC-11 and -12 in LDCs could, by 2009, reach the 1986 level of 660 metric tonnes in DCs.[34] Mintzer (1989:20) estimates that, if only China, India, Indonesia, and Brazil increased their domestic consumption of CFCs to the level of 0.3 kilograms per capita by 1995, which would be covered by the MP, global production and use of controlled substances would approximately double from the 1986 level. Hence, the impression that cooperation with LDCs is needed, since the gains from cooperation (U_A) can become large in the future relative to a situation without any ozone treaty seems justified.

Another question is whether there will be gains from cooperation other than sidepayments in LDCs as well, i.e. $U_B>0$. We have argued above that the damage in LDCs caused by ozone depletion is smaller than in DCs and that large benefits for LDCs would not exist or would not be reflected in the political process. Gains from cooperation may nevertheless exist in LDCs. But for the magnitude of sidepayments, the difference between the perceived utilities U_A and U_B counts. If this difference is large, high Nash-transfers are a necessary result of the cooperative Nash bargaining game. Unfortunately, we have no data to prove that the difference is large. The ecological uncertainty of ozone depletion is substantial, which may in fact have led many LDCs to cooperate without demanding more than coverage of incremental costs.

The Parties may also have linked the ozone treaty to other issues of international relations. This raises the complexity of the game and allows for sidepayments that can pass undiscovered by the public. Such out-of-treaty sidepayments are often non-monetary, which is an important advantage in diplomatic negotiations and international relations. They may even come as tacit agreements on completely different issues.[35] However, the larger the number of participants in a multilateral treaty is the less likely are out-of-treaty sidepayments between the parties. A reason for this is that an equal and clearly observable treatment of all parties to a treaty is an important prerequisite for broad agreement. In the ozone case, LDCs may hope for more development aid or may believe that the technology transfers agreed in the MP will break the way to additional export earnings and beneficial cooperation in other fields. However, these motivations must remain largely speculative. It seems that the available information on benefits and tacit sidepayments does not provide a clue for a different result.

According to Section 4.1, transfer payments are independent of the threat of sanctions. However, intuition and evidence do not support this result.[36] Hence, we may wonder whether the Ozone II game is correctly specified. Ozone II is a one-shot game with two

34 OTA's estimates seem particularly plausible with a view to the huge need for refrigeration in most of these countries. According to press reports, new CFC production facilities are presently under construction in China and India. See "Ozonkiller FCKW noch bis Ende 1994", Süddeutsche Zeitung, 15/16 February 1992. Compare also "Wider die Öko-Kolonialisten: Wie man in Indien über den Erd-Gipfel denkt", Frankfurter Rundschau, 13 February 1992, and Simonis and von Weizsäcker (1990:4,6).

35 Examples are the International Columbia River Treaty between Canada and the U.S. (Krutilla, 1966) and the Colorado River Treaty between Mexico and the U.S.

36 Compare the behaviour of some NICs (Korea, Taiwan) reported above (Section 3.1).

players. It reflects a bilateral monopoly with DCs who demand ozone protection on the one side and LDCs who supply this service against payment on the other side. A bilateral monopoly model is, however, unlikely to reflect the reality of the ozone world correctly. It is perhaps justified to treat DCs as a cartel for issues that affect them jointly vis à vis LDCs. But it is probably misleading to assume that LDCs act as a cartel, too. Instead, it is more plausible that they face the block of DCs one by one. Hence, the situation could rather be characterized as a monopsony. In a monopsony situation, the bargaining power of LDCs is much reduced. They may be more susceptible to pressure and to the threat of sanctions, because isolation, i.e. non-existence of a LDC-coalition, enhances the impact of sanctions on the isolated country and reduces the cost of imposing sanctions. Section 5 will investigate this approach in more detail.

Another complication lies in the fact that the ozone game is not a one-shot game as we have assumed above. As a one-shot game, Ozone II describes a long-run result and not a development. Contrary to the ineffectiveness of sanctions noted above, the trade restrictions in the MP may have a short-run effect. DCs are probably not capable of building up their own CFC production rapidly. Therefore, CFC trade restrictions may, at least temporarily, reduce LDCs' consumption of CFCs. Since reduced CFC consumption in LDCs benefits the ozone layer and thereby DCs, trade restrictions may not necessarily imply net costs for DCs. Hence, the trade restrictions in the MP may be a credible threat initially. In the long-run, however, their stabilizing effect may wear out with the installation of CFC production capacities in LDCs to supply the domestic market. But these capacities can also be used strategically as pressure instrument in future negotiations over the MP and DCs' sidepayments.[37] Already the ozone game as we observe it in the Vienna Convention and the MP is a repeated game with quite a number of provisions for renegotiations. But the strategy set of players is even larger. It comprises numerous out-of-treaty options in the course of time from hidden violations to an open breach of the ozone treaty. We deal with these strategic options in Section 6.

5. The multi-players one-shot ozone game

In this Section, we model an ozone game in which a cartel of DCs (player A) faces each LDC (player b) individually. Player A is determined to ensure full cooperation at minimum costs. A's strategic parameters are transfers T and sanctions S(Γ), with Γ denoting the intensity of sanctions.

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37 Compare, e.g., "Die Ozon-Locher kommen bald aus Indien", Frankfurter Rundschau, 23 February 1993.

5.1 The model

Player A must be prepared to deal with a group of non-cooperative players, B^-, and a group of cooperative players, B^+, which together form the group B. The absolute size of each group A, B, B^-, B^+ is measured in terms of each group's GDP, i.e. Y_A, Y_B, Y_B^-, Y_B^+.[38] k denotes the degree of cooperation: $k = Y_B^+/Y_B$ ($0 \le k \le 1$) measures the relative size of B^+, $(1-k) = Y_B^-/Y_B$ measures the relative size of B^-.[39] B consists of arbitrarily many identical members b_i of size Y_{bi} ($\Sigma Y_{bi}=Y_B$). Player b of size Y_b is one representative, arbitrarily small member of B. b plays the game against A and decides whether to cooperate or not.[40] Table 6 shows the payoffs in the game Ozone III.

Table 6 — Ozone III: Payoff matrix in the multi-players game

		Strategies Player b: phase-out	Strategies Player b: emit
Strategies Player A	phase-out	$(kU_A-C_A-kT-S_A^+\ ;\ (t_b-c_b)Y_b-s_b^+)$	$(kU_A-C_A-kT-S_A^+\ ;\ -s_b^-)$
	emit	$(0\ ;\ -c_bY_b)$	$(0\ ;\ 0)$

A's phase-out payoff function is $kU_A-C_A-kT-S_A^+$ no matter whether b plays cooperatively or not. It reflects A's costs of possible sanctions (S_A^+) against the non-cooperative players in B^-. Moreover, the existence of B^--players leads to a decline in A's utility from cooperation, hence kU_A, but it also reduces A's transfer bill, hence kT instead of T under full cooperation (k=1). A's strategy and payoff function is independent of the particular strategy of any particular b_i, but it depends on the number of cooperative versus non-cooperative members in B, i.e. on k.

Player b's cooperative payoff is $(t_b-c_b)Y_b-s_b^+$, her non-cooperative payoff is $-s_b^-$.[41] If b plays cooperatively, she faces costs c_b ($=C_B/Y_B$) and receives transfers t_b ($=T/Y_B$) both weighted with b's size Y_b. But in addition, b must take into account that she has to share the costs of sanctions against (possible) B^--members (s_b^+) if she signs the phase-out treaty. If b does not sign, she must face the impact of sanctions imposed on herself (s_b^-).

Hence, there are two conditions for a stable cooperative solution. A's payoff must be positive (6) and b's payoff from cooperation must be larger or equal to his payoff from non-cooperation (7). If only one of both conditions is not met, cooperation is impossible.

38 We use GDP as a proxy for a country's reliance on CFCs. Compare Section 1.

39 For a different approach that involves fixing a minimum participation level k in order to build large cooperating coalitions and counter free riding see Black, Levi and de Meza (1990).

40 The assumption that all players in B are identical entails that b's participation decision coincides with the participation decision of all other players in B. The assumption is relaxed later.

41 Player b's payoff may be supplemented by a utility gain if A plus a number of b-players phase out. But this would hardly affect our results, since most of the effect cancels out in (7) and is zero for a marginal b-player.

A: $$kU_A\text{-}C_A\text{-}kT\text{-}S_A^+ \geq 0 \tag{6}$$

b: $$(t_b\text{-}c_b)Y_b\text{-}s_b^+ \geq \text{-}s_b^- \tag{7}$$

We complete the model by specifying the costs and the impact of sanction for each type of player. The specification is simplified, but it captures the basic notion we pursue in this paper.

A: $$S_A^+ = \Gamma\gamma(1\text{-}k)Y_A \tag{8}$$

b^+: $$\begin{aligned} s_b^+ &= \Gamma\alpha(1\text{-}k)Y_b && \text{for } k>0 \\ &= 0 && \text{for } k=0 \end{aligned} \tag{9}$$

b^-: $$\begin{aligned} s_b^- &= \Gamma[\delta+\beta(k\text{-}Y_b/Y_B)]Y_b && \text{for } k>0 \\ &= \Gamma\delta Y_b && \text{for } k=0 \end{aligned} \tag{10}$$

(8) - (10) reflect that the cost and impact of sanctions for all types of players depend on the intensity of sanctions Γ, on the share of cooperative versus non-cooperative b-players k, on the players' size Y_A and Y_b and on the cost or impact parameters characteristic for each type of player. γ and α measure the basic costs for A and for the cooperative b^+-player of imposing sanctions, and δ and β measure the basic impact of A's and b^+'s sanctions on the non-cooperative b^--player. ($0 \leq \Gamma, \gamma, \alpha, \delta+\beta \leq 1$)
The costs of sanctions S_A^+ and s_b^+ are zero in the case of full cooperation (k=1). They increase with falling cooperation ($k \rightarrow 0$) up to a maximum that depends on Γ and on γ or α respectively. s_b^+ jumps to zero again in the case of zero cooperation (k=0), since in this case B^+ is an empty set. The impact of sanctions s_b^- is $\Gamma\delta Y_b$ in the case of zero cooperation (k=0), since this share of the burden can be inflicted on b^- by A alone. In the case of partial cooperation (k>0), b^- suffers an additional impact that the cooperative b^+-players inflict on her. But k decreases when b defects. Therefore, in comparing cooperation to defection in (7), the relevant degree of cooperation for specifying s_b^- in (10) is $k'=(Y_B^+\text{-}Y_b)/Y_B=k\text{-}Y_b/Y_B$. When full cooperation is reached (k=1), sanctions imposed on a defecting marginal b-player ($Y_b \rightarrow 0$) have maximum impact. (See Figure 3 for s_b^+ and s_b^-.)

5.2 Minimum participation

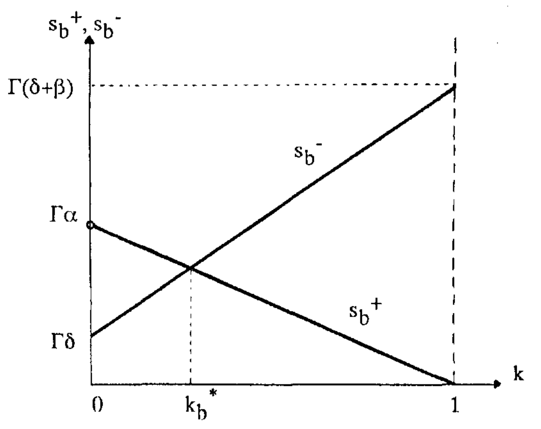
For both players A and b, the value of k is critical in choosing a strategy: Cooperation must be large enough to render the proposed scheme profitable for A and to induce b to participate in it. We deal with b's participation constraint first. Inserting (9) and (10) into (7) yields (11) which we solve for k to derive the critical value k_b^* (12).

b: $$(t_b\text{-}c_b)Y_b\text{-}\Gamma\alpha(1\text{-}k)Y_b+\Gamma[\delta+\beta(k\text{-}Y_b/Y_B)]\,Y_b \geq 0 \tag{11}$$

$$k_b^* = \frac{c_b - t_b + (\alpha-\delta)\Gamma + \beta\Gamma Y_b/Y_B}{(\alpha+\beta)\Gamma} = \frac{c_b - t_b}{(\alpha+\beta)\Gamma} + \frac{\alpha-\delta}{\alpha+\beta} + \frac{\beta}{\alpha+\beta}\frac{Y_b}{Y_B} \quad | \Gamma \neq 0 \quad (12)$$

k_b^* is the minimum level of participation for any player b. Effective participation at or beyond k_b^* guarantees that b cooperates. The last term of (12) reflects the fact that defection reduces cooperation and thus the impact of sanctions on the defector. k_b^* increases in player's size, but the term's influence is normally very small and disappears for marginal b-players ($Y_b \rightarrow 0$). If we assume that A has fixed his transfers to incremental costs ($t_b = c_b$), then (12) simplifies further to $k_b^* = (\alpha-\delta)/(\alpha+\beta)$ and the minimum participation level depends solely on b's cost and impact parameters, since the intensity of sanctions Γ cancels out. Hence, in this case, the intensity of sanctions does not influence b's decision. If A is able to threaten b with credible sanctions such that $\delta \geq \alpha$, then k_b^* is set to zero and b always cooperates. But if $\delta < \alpha$, it is only rational for b to cooperate if a sufficiently large number of b-players does likewise so that at least k_b^* is reached (Figure 3). If incremental costs are not covered by A, it is obvious from (12) that reducing transfers below incremental costs increases the minimum participation level and vice versa. Moreover, in this case, the intensity of sanctions comes into play in that the less severe sanctions are (Γ small) the more k_b^* increases (for $t_b < c_b$) or decreases (for $t_b > c_b$).

Figure 3 — Minimum participation level for b ($t_b = c_b$, $Y_b \rightarrow 0$)



Successful cooperation between A and b requires that A's rationality condition (6) holds, too, because otherwise A's threat of sanctions against outsiders is not credible. Inserting (8) into (6) and solving for k yields A's minimum participation level k_A^*.

A: $$k_A^* = \frac{C_A+\Gamma\gamma Y_A}{U_A-T+\Gamma\gamma Y_A} \tag{13}$$

$\Gamma\gamma Y_A$ reflects the influence of the costs of sanctions on k_A^*. If sanctions are not used (Γ=0) or are costless for A (γ=0), then k_A^* depends solely on U_A and on the associated costs C_A and T. k_A^* is necessarily larger than zero, even without costs of sanctions, since only a minimum level of cooperation gives A sufficient utility (kU_A) to cover his costs C_A and the associated transfers kT. With increasing costs of sanctions, k_A^* increases quickly, surpasses k_b^*, and becomes the overall binding participation constraint.

To convince b that A will stick to his sanction scheme when minimum cooperation at k_b^* is realized requires $k_A^* \leq k_b^*$. Hence, (14) must hold. (To keep things simple we assume incremental cost transfers, $c_b=t_b$ or C_B=T, and a marginal b-player, $Y_b \rightarrow 0$.) Solving (14) for Γ yields the maximum intensity of sanctions (Γ^*) that A can impose without overriding b's minimum participation level k_b^*.

$$k_A^* = \frac{C_A+\Gamma\gamma Y_A}{U_A-C_B+\Gamma\gamma Y_A} \leq \frac{\alpha-\delta}{\alpha+\beta} = k_b^* \qquad | c_b=t_b, Y_b \rightarrow 0 \tag{14}$$

$$\Gamma^* \leq \frac{\alpha(U_A-C_A-C_B)-\beta C_A-\delta(U_A-C_B)}{\gamma(\delta+\beta)Y_A} \tag{15}$$

A numerical example illustrates that Γ must indeed be small to satisfy (14): α=0.05, β=0.1, γ=0.05, δ=0.02, U_A=100, C_A=10, C_B=10, Y_A=100000 produces $k_A^*=k_b^*$=0.2 and $\Gamma^* \leq 0.002$.

Above we have established minimum conditions for cooperation which, if satisfied, guarantee that cooperation between A and b-players is stable. Furthermore, assuming that all players in B are identical, partial cooperation at or beyond the minimum participation level k_b^* ($\geq k_A^*$) immediately leads to full cooperation (k=1). In the event of full cooperation, sanctions are not executed, but they remain a credible and effective threat against isolated players who consider reneging. Cooperation, once achieved and then supported by sanctions, is self-enforcing if coalition-forming by players who are inclined to renege is unlikely or can be prevented, since for an isolated marginal b-player it is better to participate in punishing a defector instead of suffering sanctions herself. Additionally, the threat of sanctions against non-cooperative or reneging players can be reinforced by raising the intensity of sanctions *after* cooperation has emerged and by creating suitable institutions.[42]

42 For instance, sidepayments can be paid into a fund that is shared out to the intended recipients in the following period. If a party violates the treaty, it forfeits its share, which can then be used to compensate complying parties for their cost of imposing sanctions on the violator.

5.3 Cooperation and transfers

We have not yet addressed the question why cooperation should emerge at all and how A can promote its start. An isolated player b_i has no reason to believe a priori that cooperation will emerge and reach a level at or beyond the critical values k_b^* and k_A^*.[43] Hence, the threat of sanctions by other b-players and by A may not be credible. This impasse is not easy to break, particularly in the framework of a one-shot game and under the assumption that all b-players are identical. Promoting cooperation and reducing transfers are competing aims. More interesting in terms of A's strategy and perhaps more realistic is the case of a dynamic game with non-identical players in B with which A negotiates individually and in sequence. In this case, underpaying incremental costs and inducing cooperation is theoretically feasible. In the following paragraphs, we discuss some conceivable strategies under both assumptions.

First, there may be certain a priory beliefs about other players intentions. Some player b_j may have a distinct expectation k_{bj}^e concerning the emerging level of cooperation.[44] In a world of uncertainty and imperfect information, A may be able to promote such expectations to start cooperation and b_j may have to rely on them for choosing her strategy.[45] If b_j's expectations for cooperation exceed k_b^* ($k_{bj}^e \geq k_b^*$), she will cooperate — and so will every other identical player b_i so that the level of cooperation will immediately jump to full cooperation (k=1). In this case, expectations are a self-fulfilling prophecy. Obviously, A can exploit possible high expectations for cooperation. If k_b^e is much larger than k_b^*, A can reduce his transfers somewhat below incremental costs in a trade-off for a higher k_b^*.

Sequential negotiations with non-identical players in B allow A to exploit possible differences in expectations ($k_{bi}^e \neq k_{bj}^e$) or minimum participation levels ($k_{bi}^* \neq k_{bj}^*$) for reducing the transfer bill and/or promoting cooperation.[46] If players in B are different, A can select his negotiation partners strategically. He can first deal with those players b_j who have a high willingness to sign an agreement, because their expectation for cooperation k_{bj}^e is higher and/or their minimum participation level k_{bj}^* is lower than those of b_i, since, for instance, b_j may be more susceptible to sanctions. If the number

43 In international legal practice, the risk for each Party that signs an agreement as to whether a minimum participation level will be reached is contained by making the agreement's coming into force conditional on a certain minimum number of ratifications. Contractual obligations to sanction non-Parties is additional justification for this practice. The MP requires the deposition of at least 11 instruments of ratification, acceptance, approval or accession representing at least two-thirds of 1986 estimated global consumption of the controlled substances.

44 Distinct expectations are possible, if b_i does not know that all b-players are identical as we assume here.

45 A different approach would be to specify b_i's willingness to cooperate as a random variable that would be updated upon observing k_b^* and the behaviour of all other members in B. A low k_b^* would raise the level of cooperation and the probability of full cooperation, but full cooperation need not emerge instantaneously. On the contrary, if cooperation remains below k_b^* in a first round, the individual willingness to cooperate may collapse, which makes it much more difficult to reach an agreement in a second round.

46 Differences in minimum participation levels are possible if players in B differ with respect to the relevant parameters (c_b, α, β, δ) or in size (Y_b). Compare (12) above.

of b_j-players is large enough so that their signing the agreement lifts cooperation above the minimum participation level k_{bi}^* of the yet abstaining players b_i, the latter will follow suit. If b_j's cooperation lowers the participation expectation of the abstaining b_i-players, it will be easier and less costly for A to induce the latter to sign the agreement in a second or third round of negotiations.

Second, with identical players, A can try to reduce k_b^* (and k_A^*) as much as possible (to zero or below k_b^e) to induce the start of cooperation. As can be seen from (12), A can reduce k_b^* by selecting a sanction scheme with large parameters δ and β. If $\delta \geq \alpha$, k_b^* is set to zero (under incremental cost transfers). Alternatively, A may reduce k_b^* by overpaying incremental costs, possibly coupled with a weak intensity of sanctions (Γ small). But increasing transfers raises k_A^*, which, as can be seen from (13), cannot be reduced below a minimum level larger zero by weakening the intensity of sanctions ($\Gamma \to 0$) or by introducing an appropriate institutional commitment to pay transfers and/or impose sanctions. Hence, A's strategy to drive down k_b^* may not be credible in the eyes of a b-player, whose participation expectation is too low. Even sanctions that benefit A and which can reduce k_A^* to zero may not allow to reduce transfers, since reducing transfers always increases k_b^*.

In the case of sequential negotiations with non-identical players, A may use his transfer payments strategically to reduce the minimum participation requirement k_{bj}^* of those players b_j who move first. By promising early movers payments above incremental costs ($t_{bj} > c_{bj}$), A can induce them to cooperate. This either raises participation immediately above the minimum participation level or it reduces the participation expectation of yet abstaining players or both. In both cases, abstaining players become increasingly willing to cooperate. A can than gradually lower his transfer offer to latecomers — even below their incremental costs. Thus, the strategy of sequential negotiations can lead to competition between players in B for being served first.[47]

A third option for promoting cooperation is available to A if A happens to earn a benefit from imposing sanctions on b-players ($\gamma < 0$, in contrast to our previous assumption). In this case, A can reduce k_b^* as described above *and* relax his own participation constraint k_A^* simultaneously, so that his strategy including the sanction scheme becomes a credible threat for b-players, for whom cooperation is then imperative. Under such particular conditions, sanctions can be an instrument to start cooperation and sustain it after the agreement has come into force.

It seems that this third option was used by DCs for designing the MP and promoting cooperation. First, at least initially, the impact of DCs' CFC-trade restrictions on CFC importing LDCs (δ) is probably severe whereas the costs of participating in such trade

47 Whether A can use this strategy to reduce his total transfer payments T below overall incremental costs C_B must be left open to question. It also needs to be investigated how the strategy of sequential negotiations is affected by A's rationality constraint.

restrictions against outsiders (α) is probably very small for most LDCs. Hence, α-δ is presumably smaller than zero and, under incremental cost transfers, we can set k_b^* to zero. Second, sanctions in the form of trade restrictions on CFCs are likely to reduce world wide CFC consumption and emissions at least temporarily, which benefits the ozone layer and thereby DCs. Additionally, selling substitutes to LDCs may be more profitable than selling ordinary CFCs.[48] Hence, with beneficial trade restrictions, k_A^* may well be zero, which renders A's threat of trade restrictions credible. Therefore, signing the MP may have been the dominant strategy for most LDCs whereas complying with its terms later on may be a different matter.

We summarize above result as follows. The role of sanctions in international environmental agreements is ambiguous. A sanction scheme is a powerful tool for stabilizing existing international cooperation if parties do not collude in breaching the agreement. But proposing a sanction scheme against outsiders and defectors before cooperation has started can make the initiation of cooperation much more difficult. Special cases that facilitate the start of cooperation are: high a priori expectations for the emergence of cooperation, positive returns from sanctions and the dynamics of sequential negotiations with non-identical players. In these cases, which may have played a role in designing the MP, sanctions can be compatible with initiating cooperation. But in any case, chances to reduce transfer payments below incremental costs seem to be very limited.

6. The Montreal Protocol as a game in two periods

Repeated games are different as compared to one-shot games in that the time dimension opens the possibility to retaliate for a non-cooperative move. Above, we have analysed a situation in which the state of the world was fixed after the signing of the treaty. Renegotiations were excluded and the treaty had to be kept no matter what. However, in analysing the role of sanctions, we have already pointed to their contract stabilizing effect. In this Section we introduce a distinct time structure and investigate the strategies that players then have. We use the bilateral situation of player A against player B as in Section 4 and make the same assumptions concerning payoffs and costs. But we assume a time path as in Figure 4 and model the game as a two-period game, period 1 ($_1t$) from year 1-10 and period 2 ($_2t$) starting with year 11. In period $_1t$ the agreement is signed, A phases out CFCs and makes transfers to B. In period $_2t$ B phases out or breaches the agreement. This pattern is motivated by the MP; it reflects the grace period for LDCs.

48 However, this effect is probably only temporary, since suppliers in LDCs may take over. But the transitional period may have been enough to induce LDCs to at least sign the MP.

Figure 4 — Time path in the two-period ozone game

	Year		
Period $_1t$	1	-	Start of the game. A and B sign the agreement.
		-	A starts with phasing-out at costs C_A.
		-	A transfers T (=C_B) to B.
	10	-	A has completed his phase-out operation.
Period $_2t$	11	-	B must start with phasing-out at costs C_B.
		-	B decides to honour or breach the agreement.
		-	Game ends.

The payoffs for A and B in each single period are given in Table 7. If A and B sign the agreement in period $_1t$, player A invests in CFC substitutes and in transfers to B. If B does not sign the agreement in $_1t$, A can invest in substitutes and impose sanctions on B or he can continue emissions. In period $_2t$, A harvests the gains from phasing out CFCs if B complies, or he continues sanctions against B.[49]

Table 7 — Ozone IV: Payoffs in period 1 and 2

		B phase-out	B emit
Period $_1t$	phase-out	$(-_1C_A-_1T \; ; \; _1T)$	$(-_1C_A-_1S_A \; ; \; -_1S_B)$
A	emit	$(_10 \; ; \; _10)$	$(_10 \; ; \; _10)$
Period $_2t$	phase-out	$(_2U_A \; ; \; -_2C_B)$	$(-_2S_A \; ; \; -_2S_B)$
A	emit	$(_20 \; ; \; -_2C_B)$	$(_20 \; ; \; _20)$

In both periods, considered separately, cooperation is impossible. This is obvious in $_1t$; in $_2t$ the threat of sanctions is not credible, since A cannot commit himself to sanctions that would make him worse off than continuing emissions. However, in non-cooperative repeated games, players are confronted in each period with a payoff matrix that reflects not only their current but also their expected future payoffs. But they do not take past payoffs into account, which are sunk costs or bygone profits. Since the players' strategies in $_2t$ are anticipated by both players when entering the game in $_1t$, their strategy set is larger in the two-period game. It combines the possible actions for both players in both periods. This yields a new game that can be represented by a four-by-four matrix that shows the payoffs for each two-period strategy combination.

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49 Possible phasing-out costs for A in $_2t$ have been neglected here for simplicity.

Table 8 — Ozone V: Combined two-period payoff matrix (po=phase-out, e=emit)

A \ B	po/po	po/e	e/e
po/po	$({}_2U_A - {}_1C_A - {}_1T \; ; \; {}_1T - {}_2C_B)$	$(-{}_1C_A - {}_1T - {}_2S_A \; ; \; {}_1T - {}_2S_B)$	$(-{}_1C_A - {}_1S_A - {}_2S_A \; ; \; -{}_1S_B - {}_2S_B)$
po/e	$(-{}_1C_A - {}_1T \; ; \; {}_1T - {}_2C_B)$	$(-{}_1C_A - {}_1T \; ; \; {}_1T)$	$(-{}_1C_A - {}_1S_A \; ; \; -{}_1S_B)$
e/e	$(0 \; ; \; -{}_2C_B)$	$(0 \; ; \; 0)$	$(0 \; ; \; 0)$

In Table 8, we have omitted the strategy combinations (e/po; •/•) and (•/•; e/po), since we are mainly interested in those combinations in which both players agree to cooperate in ${}_1t$ and choose their actions freely in ${}_2t$.[50] However, we have added the combination (e/e; e/e) as the ultimate conflict situation.

The question is, whether the fully cooperative strategy combination (po/po; po/po) can be reached. Ozone V has the two trivial Nash equilibria (e/e; po/e) and (e/e; e/e). Additionally, the cooperative outcome (po/po; po/po) is a Nash equilibrium if the strategy po/po yields a bigger pay-off for each player than each player's second best alternative. Hence, for cooperation to emerge (16) and (17) are necessary conditions.

A: $${}_2U_A - {}_1C_A - {}_1T \geq 0 \tag{16}$$

B: $${}_1T - {}_2C_B \geq {}_1T - {}_2S_B. \tag{17}$$

But the cooperative outcome may not be subgame perfect yet. Although (16) may hold, (17) is not a sufficient condition for cooperation, since sanctions ${}_2S_B$ are not credible: If B signs in ${}_1t$ and breaches the agreement in ${}_2t$, i.e. B plays po/e, A is caught in a very bad situation, since then he has not only borne his costs of total phase-out but has also paid transfers to B in ${}_1t$ without getting any return from doing so in ${}_2t$. Hence, B can be sure that A will play po/e to minimize his loss by avoiding the cost ${}_2S_A$ of sanctioning B. However, since A will anticipate B's defection, he will select e/e right in the beginning, which means that the treaty will never be signed. Hence, full cooperation is not a subgame perfect equilibrium and the combinations (e/e; po/e) and (e/e; e/e) are the only feasible outcomes of Ozone V.

Taking the non-credibility of sanctions in ${}_2t$ into account, cooperation in Ozone V is only sustainable if holding on to the agreement in ${}_2t$ is more profitable for B than to renege. This means that A must pay transfers in ${}_2t$ that satisfy (18).

B: $${}_1T - {}_2C_B + {}_2T \geq {}_1T \quad \text{or} \quad {}_2T \geq {}_2C_B \tag{18}$$

50 The first omitted combination would amount to starting the same game in period ${}_2t$, since B will not respond with phase-out if A does not play phase-out in ${}_1t$. The second omitted combination is similar to the one-shot game except for sanctions being imposed on B in ${}_1t$ for not signing.

(18) supersedes (17). Hence, transfers must match B's incremental costs in each period and there is no room to prepay B for investments to be undertaken later. Furthermore, transfers in $_1t$ are redundant as an instrument to sustain cooperation. But if they are paid to get cooperation started, overall transfers will exceed incremental costs.

Hence, stability of the MP requires that the Monetary Fund pays LDCs' incremental costs and that it does so on the grounds of strict conditionality.[51] Moreover, if the costs of using ozone friendly substances remain permanently higher than the corresponding costs of using CFCs, then paying transfers to opportunistic countries becomes a permanent engagement.

7. Who will win the ozone game?

The grace period for LDCs is a critical feature of the MP. On the one hand and for the reasons listed below, the grace period has helped DCs to keep down their transfer payments to LDCs and to render the trade restrictions against outsiders more credible, which helps to stabilize the MP.

1. The compliance costs of LDCs after the year 2000 will be lower than those in DCs a decade earlier, since by that time substitutes will have become available at decreasing costs. This reduces the need for transfers.

2. The grace period has reduced the present value of LDCs' compliance costs, since LDCs tend to have a relatively high rate of time preference. Therefore, the introduction of the grace period has probably curtailed LDCs' bargaining power, which has probably helped to keep down the transfers to LDCs.

3. The grace period permitted to conclude an early treaty at a time when LDCs had not yet developed their production capacities for CFCs and other ozone depleters. Hence, the threat value of future CFC-emissions by LDCs was lower at the time of negotiations compared to a possible later situation with substantial CFC production capacities and related sunk costs in LDCs.

4. Supplying LDCs with CFCs or cheap (subsidized) substitutes during the grace period and possibly thereafter reduces the risk that LDCs build up an irreversible domestic CFC production, which would render trade restrictions ineffective and which would have to be bought out by higher transfers.

5. The early phase-out in DCs renders the envisioned sanctions more credible, since the costs of a ban on trade in CFCs fall for DCs with the development and immediate introduction of substitutes and the replacement of the related production equipment in DCs.

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51 At present, the Fund pays for country studies and for reduction projects undertaken by LDCs voluntarily.

6. Moreover, selling substitutes is probably more profitable than selling CFCs, which are easier to imitate by LDCs. A conversion and phase-down programme for CFCs in LDC that is supported by a successful world-wide ban on CFC exports that de facto excludes competition from LDCs secures a big export market for DCs' chemical companies. Thus, trade restrictions against outsiders may prove to be even profitable instead of costly for DCs.[52]

On the other hand, the grace period for LDCs has created a problem of time inconsistency. In combination with DCs' transfer payments and trade restrictions against outsiders it has enticed LDCs to accede to the MP. But as sovereign states, LDCs have not been able to commit themselves credibly to their phase-out obligations after the grace period. Whether incremental cost transfers and the MP's trade restrictions will be sufficient to keep LDCs from eventually reneging remains an open question. Hence, DCs have accepted a certain risk, which must be countered in the course of implementing the MP.

The regular meeting of the Parties to the MP and the concurrent public pressure, which can be supported by the publication of the official reports, is likely to make the attempt of serious non-compliance an unpleasant adventure for any government. Reputation plays an important role in international relations. Since the ozone game is embedded in a much broader supergame between sovereign states, reneging on the MP can have negative side effects in other areas of (potential) cooperation. Moreover, elaborated non-compliance procedures including the imposition of trade restrictions are now available to rectify individual cases. If LDCs do not collude in breaking the MP and if the Parties to the MP can deal with non-compliant LDCs separately, which is likely given the provisions for assistance and the new non-compliance procedures, then sanctions can be credible. In addition, a widening of the game by resorting to general principles and enforcement mechanisms of international treaty law remains always possible.

The stability of the MP can further be enhanced by applying the Monetary Fund strategically. First, the Fund should be administered on the basis of strict conditionality. It should pay for real reduction investments, if possible ex post. Second, the Fund should invest extensively in CFC reductions in LDCs as early as possible already during the grace period in order to forestall the installation of new CFC production capacities in LDCs. Third, the Fund should give priority to irreversible investments that build up a

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52 The development and expected availability of substitutes was a major reason for the breakthrough in international negotiations over CFCs. Furthermore, some leading chemical companies, particularly DuPont in the USA, had eventually realized that a profitable market for CFC substitutes lies ahead. Hence, the true reason for trade restrictions may well be commercial rather than environmental — and enforcing the MP may be but a welcome side effect. See Markandya (1991), who emphasizes the benefits from technology of CFC substitution, and Oberthür (1992), who gives an account of the role of industry in deciding to abandon CFCs.

stock of ozone-friendly capital in LDCs that would become obsolete if a country decided to renege. For instance, investment in new refrigeration equipment that cannot be run with CFCs are sunk costs that reduce the incentive to breach the MP.[53] Fourth, the Fund should be available to pay compensation to loyal Parties for costs that these incur if sanctions against a non-compliant Party become inevitable. This renders sanctions more credible.

The MP can be handled very flexibly. The regular revision process allows for an early adaptation of the MP's provisions to new developments and to looming violations of treaty obligations. Flexibility has the advantage that unavoidable violations can be accommodated, which gives the impression that the MP is very stable. But flexibility is an ambiguous stabilization instrument. It also invites opportunistic parties to force renegotiations by threatening not to comply. Thus, the eventual outcome need not necessarily coincide with the provisions of the treaty that was originally agreed upon and signed. In particular, it is possible that much higher transfers will become necessary to avoid violations. In the end, it will be difficult to tell whether simply a country's incapacity to comply or an attempt to exploit its (possibly growing) bargaining power as a sovereign state was at the origin of an (imminent) violation and thus may have become the reason for a relaxation and adaptation of the MP's obligations and provision. When compared with non-sovereign contractual relations, the latter behaviour would, of course, have to be rated as a clear breach of the original treaty, although it is not observable as such.

To conclude, the ozone game is characterized by an unevenly distributed bargaining power to the advantage of LDCs. If LDCs built up their production capacity and consumption of CFCs and other ozone depleting substances only moderately, they could easily offset all reduction efforts by DCs. Moreover, LDCs could perhaps do this at relatively small environmental costs to themselves but with inflicting potentially large damage on DCs. The ozone layer problem can thus be used for global blackmail.
It seems that LDCs have so far abstained form using this power. If they had formed a cartel in negotiations, they might have been able to exploit their favourable position in order to obtain higher sidepayments, perhaps in the form of development aid. In the long-run, the cooperative Nash bargaining outcome may reflect the distribution of the bargaining power more correctly and may thus be closer to a sustainable distribution of the gains from protecting the ozone layer than the financial provisions in the MP. Hence, it seems that DCs have outfoxed the Developing World over the ozone issue. Particularly two of the celebrated new elements in the MP can be held responsible for this success: the provision for sanctions against non-Parties in combination with the

53 Compare Stähler (1992).

grace period for LDCs. The monopsonist cartel of DCs vis à vis the many LDCs may have done the rest.[54]

We must leave the question open whether the MP can eventually be called a success story. We will have to wait and see which position LDCs will take at the turn of the century. There are many loopholes and weak provisions in the MP. It remains to be seen in how far LDCs will want and are able to use these opportunities for creeping out of their phase-out obligations and how high incremental costs and monetary and non-monetary transfers will finally be. Nevertheless, it seems that the MP stands a good chance of being honoured eventually — and at a very moderate price for the industrial half of the world.

Acknowledgements

This paper originated from a project about the stability of international environmental agreements. I gratefully acknowledge financial support by the Volkswagen Foundation. I am indebted to Gernot Klepper, Andreas Kopp, Peter Michaelis, Ernst Mohr and Frank Stähler for valuable comments on an earlier draft of this paper. All deficiencies and errors are, of course, in my sole responsibility.

54 It is unlikely that a similar strategy will be successful in future negotiations over global environmental issues, e.g., climate change, the rain forests, biodiversity. In preparing for the UNCED in Rio in June 1992, LDCs have tried to join forces and face pressure from DCs jointly. See: "Keine Entwicklung ohne Ausbeutung natürlicher Reichtümer", Frankfurter Allgemeine Zeitung, 28 April 1992; "Rio ist ein Schimpfwort — Malaysia: Der Süden steht geschlossen gegen den Norden", Frankfurter Rundschau, 13 February 1992; "Wider die Öko-Kolonialisten: Wie man in Indien über den Erd-Gipfel denkt", Frankfurter Rundschau, 13 February 1992. Compare also Heister, Klepper, Stähler (1992).

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