Adverse Selection and Participation in International Environmental Agreements

Suzi Kerr

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1 INTRODUCTION

Since 1987 and the signing of the Montreal Protocol on Substances which Deplete the Ozone Layer the issue of how funds and technology can be transferred to the developing world to facilitate their involvement in international environmental agreements has become an increasingly pressing issue. The Multilateral Fund of the Montreal Protocol and the Global Environmental Facility in the World Bank provide funding to projects that address ozone depletion, global warming, and biodiversity loss among other global environmental problems. These institutions currently handle relatively small flows of resources yet the problems that they address could potentially require large flows of investment and technology that would go well beyond their current capacity.

This paper looks at the question of how transfers of resources should be structured to induce countries to efficiently produce global environmental protection even when they have private information about their costs and benefits. Addressing this question is immediately relevant to the problem of Global Climate Change where the meetings under the Framework Convention on Climate Change are largely preoccupied with issues of how resources can be transferred and how much should be transferred. The recent Berlin Conference was unable to move forward to increase targets for CO_2 control and even the targets previously agreed by a group of developed countries seem unlikely to be achieved. No country wishes to move forward with expensive controls without a credible commitment from other countries about their own future behavior.[1] These commitments are impossible to create without an efficient method of financial transfers when the largest growth in CO_2 emissions is likely to come from developing nations. Because CO_2 emissions are largely due to energy use, its control could potentially have severe effects on the development of economies. If global climate change proves to be a serious concern addressing it could require massive transfers of resources well beyond the capacity of current international aid institutions. The form of new institutions set up to deal with this could have large effects on the world economy.

The paper deals with a stylized environmental problem that deals with a global public good. The pollution is uniformly distributed so it does not matter who does the abatement.
We assume that it is non-accumulative so that we can consider the problem as a static problem. The public good could be thought of as a stable global climate, tropical forest cover or the ozone layer. It could also apply to more local problems such as acid rain, polluted transboundary watersheds, or nuclear safety. If we drop the assumption that it is non-accumulative this could also apply to biodiversity depletion and desertification. We illustrate the results with examples from the negotiations over the Montreal Protocol and the transfer structures set up under its auspices.

The model is considering negotiations at the point where there is a group of countries that have cooperated to produce some of the public good and are now considering how to encourage production by other countries that will not produce without rewards or threats. The paper assumes that the countries already in the coalition have sufficient incentives to comply and continue to participate as long as their level of utility within the contract is maintained. For example this could be the signatories to the Montreal Protocol in 1990 when they are designing the London Amendments to try to induce the developing countries to participate.

[1] Of course there is also extreme scientific uncertainty which makes the choice of appropriate targets and domestic politics of introducing controls difficult.

The paper considers an international environmental agreement as a contract between the developed "core" countries and the less developed "non-core" countries where a cooperative agreement to produce the public good requires transfers of resources. We consider in particular the problem of adverse selection and private information about costs of environmental protection (or analogously benefits from protection), and how this does and should influence the way that transfer payments are designed.

The paper starts with the baseline cases of no cooperation and full cooperation and then investigates how problems with information affect the type of contract and outcome of the contract. We simplify to one developing or non-core country and characterize the developed countries as acting as a unified group. This is clearly unrealistic but helps to bring out the underlying tensions between developed and developing country interests.

We show that it is more efficient to write contracts before private information is created. We show that commitment is critical. For developing countries in our model this depend on the ability to make up front payments to enter the contract and have access to the transfers. Our model does not deal with the commitment problems of developed countries. The form of the contract does not have implications for the distribution of surplus from the agreement ex ante. The issues of distribution can be separately negotiated and dealt with through direct transfers. After the information is revealed though, there will be some distributional implications. Countries with low costs of protection will receive a surplus to induce them to produce more while the highest cost countries will receive no additional payoff. Finally we show that if countries have private information on the level of risk they face in carrying out protection it is possible to write contracts that separate on this basis so that very high-risk countries can be excluded or simply to give other countries more information about the possible variance in the agreement.

1.2 Structure of the Paper

The paper begins with a brief introduction to the global environmental problem of ozone depletion, and the status of international negotiation and cooperation. Section 3 introduces the model we use in this paper and describes the actors involved and their incentives. Section 4 establishes baselines of no cooperation and full cooperation both to establish the game structure and provide benchmarks against which we can compare the level of efficiency achieved in the later models. Section 5 looks at a specific case of asymmetric information about the costs of environmental protection and considers the effects of contracting before the information is revealed to either party with contracting in a situation of asymmetric information. Section 6 considers an additional information problem, lack of information about the distribution of possible costs, and shows that it is possible to write separating or pooling contracts, which achieve a limited level of efficiency. Section 7 discusses some policy implications of these models and suggests some directions for future research.

2 A Brief Introduction to Ozone Depletion

2.1 Ozone Depletion

Ozone is a trace gas, which absorbs UV-B rays in the stratosphere and prevents them reaching the earth's surface. In excessive quantities UV-B rays can cause skin cancer and biological damage. Ozone also affects temperature and circulation patterns in the stratosphere, which have major implications for the climate around the world. In 1974 the first evidence was found that human activity could lead to large changes in the amount of ozone in the stratosphere. This discovery led to a process of international discussion and later negotiations, which culminated in the Montreal Protocol in 1987.

The "ozone depleting substances" (ODS) include CFCs, Halons, Methyl Chloroform, Carbon Tetrachloride and HCFCs. These chemicals are uniformly mixed. That is, it makes no difference for the ozone layer where the chemical is emitted. In fact the most serious damage so far has occurred over Antarctica, which is probably the point on the globe farthest from the major CFC producers. This makes the ozone layer a pure public good.

2.2 The Montreal Protocol and the London Amendments

The Protocol, and the Vienna Convention which preceded it, were originally negotiated among developed countries, which are the major producers of the ozone depleting substances (ODS). These countries are in areas that are likely to be more affected by ozone depletion, and have populations with fairer skins who are more susceptible to UV-B radiation. In addition they are richer and more concerned about environmental amenities.

As the science developed further and suggested that the problem was even more serious than originally thought the developed countries realized that their reductions in ODS use would count for nothing if the developing countries expanded their own currently small production as they grew. The developing countries strongly opposed being limited by a Protocol that they had not been involved with developing, and which addressed a problem for which they were not responsible. Many of the developing countries also felt they had more serious problems to worry about. In particular it was impossible to coerce large countries such as China and India to control their production simply through the use of trade sanctions and diplomatic pressure. Some transfer of resources including technology was necessary to encourage their participation.

Table 2.1 Rights and Responsibilities of Developed Countries under the London Amendments to the Montreal Protocol

Developed Country Obligations	**Year**	
CFCs 11,12,113,114,115	1990-93	Freeze at 1986 levels[2]
	July 1993 - 1995	20% reduction
	1995 - 2000	85% reduction
	2000	Phase out
Financial Responsibilities to Multilateral Fund		Payments on basis of UN Scale of Assessments. Total initial contribution between $180 and $240 m

The issues of participation of and assistance for the developing countries were addressed in the London Conference in 1990. There many developing countries agreed to controls with a ten-year grace period in exchange for funding to cover the "incremental costs" of implementing the controls. The controls and financial responsibilities of developed country signatories are given in Table 2.1. The controls and the provisions for "article 5" countries, which are

[2] Article 2A, London Amendments to the Montreal Protocol.

developing countries which currently use less than 0.3 kg ODS per capita, are given in Table 2.2. [3]

Table 2.2 Rights and Responsibilities of Developing Countries under the London Amendments to the Montreal Protocol

Control Responsibilities	**Year**	
CFCs	1990-1997	Increase in consumption of controlled substances allowed up to 0.3 kilogram per capita to meet "basic needs".
	1997 - 2003	Freeze at lower of average 1995-97 levels or 0.3 kgs per capita. [4]
	July 2003 - 2005	20% reduction
	2005 - 2010	85% reduction
	2010	Phase out
Developing Country Rights	1990 onward	Multilateral fund will finance incremental costs to enable compliance with controls.[5]

These obligations and rights are a contract between the developed and article 5 countries. Although the article 5 countries have agreed certain targets, and the ultimate target is phase out, these will not be achieved for ten years (and there is some uncertainty about the strength of their commitment). Thus the developed countries want to use the funds from the Multilateral Fund in the most efficient way to carry out the lowest cost abatement first. By the time the higher cost abatement must be done technology may have improved and in any case it will have been deferred for a few years. Ideally, the executive committee of the Multilateral Fund would have perfect information on the costs and benefits of each country. However, if it does not, the way in which the transfers are designed will affect whether the private information held by the individual country will be revealed.

3 WHO ARE THE AGENTS AND WHAT ARE THEIR INCENTIVES?

There are two conceptually different groups of countries in terms of behavior with respect to global environmental agreements. These groups are different in terms of their costs and benefits, the openness of their domestic economic and political processes, and their ability to make credible international commitments. We characterize these groups in a simplified way as the "core" and the "non-core".

3.1 THE CORE

By the core countries we mean countries that care a great deal about the environmental problem and take a leadership role in addressing the problem. They are frequently the developed

3There were also controls on Halons 1211, 1301, 2402, other halogenated CFCs, Carbon Tetrachloride, Methyl Chloroform and other Halons.

4 Article 5 para. 1 and Para. 3 (a) London Amendments to th e Montreal Protocol.

5 Feasibility studies and technical assistance will also be financed. Article 10, Annex IV Appendix IV London Amendments to the Montreal Protocol.

countries for which environment has become a domestic priority. In the case of ozone they were not only developed countries but also those in vulnerable areas (temperate latitudes) with vulnerable populations (light skinned). Due in part to stability they have low discount rates so their present value of future benefits is relatively high. In addition they are highly risk averse with respect to low probability catastrophic outcomes. This leads them to have a high level of benefits from protection of the public good. Their costs of protecting the ozone layer are convex. Each country has the following utility function.

$$\mathbf{V_i = a_i\, Q - b_i Q^2/2 - c_i\, q_i^2\, /2} \qquad \mathbf{(3.1)}$$

The core countries have relatively open domestic economic and political processes and good information collection. In addition they have a history of concern about this issue so that domestic actors have carried out research and collected information and this information has been revealed through domestic actions. For example, the United States banned aerosols in 1978 because of concern about the ozone layer. This both demonstrated the depth of United States concern and also provided some information on the costs of phasing out one use of CFCs. This means that a_i, b_i, and c_i are transparent. This makes it possible for them to write an efficient cooperative agreement that fairly shares the benefits of cooperation between them.

Perhaps more importantly, the core countries are closely linked to each other in terms of trade, investment, national security and culture and have a history of cooperation on other issues. Therefore it is possible for them to provide sufficient credible punishments to sustain total cooperation within the core. The core do not care about the utility of non-core countries. As a simplification I model the core countries as a unified group with one utility function and ignore problems of differences in objectives, and incentives to defect within the group. This is clearly an optimistic exaggeration in reality but it is a useful simplification and true relative to the non-core countries. The utility of the core is:

$$\mathbf{V = AQ - BQ^2/2 - C\, Q_c^{\,2}/2 \qquad = V(Q_c,\, q)} \qquad \mathbf{(3.2)}$$

where $Q_c = \Sigma_\iota\, q_\iota$; $Q = Q_c + q$; q is the production of the non-core.

3.2 THE NON-CORE

The countries that are reluctant to join an international environmental agreement are often developing countries for which long-term environmental threats are a low priority relative to the pressing needs of poverty, local pollution and political stability. Their marginal costs of control are often considerably lower than the costs in the Core countries. This is because they have frequently taken no unilateral action to protect the public good and because their production processes are often inefficient and their technology and capital stock are rapidly developing. Thus in terms of efficiency they would be valuable members of an agreement but they have little incentive to participate.

Non-core countries frequently have non-transparent economic systems both because there is often heavy government involvement and because information collection is poor within the country. Frequently they do not have open political systems. These factors make it difficult to accurately observe their costs and benefits of cooperation.

In addition, non-core countries can be characterized as having relatively unstable political systems where governments are unable to make credible commitments to cooperation. The may be linked with the Core countries in terms of aid, investment and security agreements but these links are often not as strong as the links among core countries.

The utility function of a non-core country is given in (3.3) where q is the protection of the public good by the non-core country.

$$\mathbf{U = a - bQ^2/2 - cq^2/2 - \mu q \qquad = U(Q_c, q, \mu)} \qquad \textbf{(3.3)}$$

4 WHAT ARE THE WORST AND BEST POSSIBLE OUTCOMES?

4.1 PRIVATE PROVISION

The worst outcome for public good provision is the non-cooperative or private provision solution. We assume there is only one non-core country. This gives most of the intuition and is later extended to multiple agents to show how it affects the problem. We also initially assume that costs and benefits are observable; another assumption that is later relaxed.

It is easiest to think of the core as a Stackelberg leader making its production decision, and then the non-core country making its decision based on this. The core recognizes that the non-core's decision is contingent on its own decision.

Figure 1 Time Structure of Private Provision Game

Core countries
choose abatement level — Abatement realized

t_0 ------------------------t_1 -------------------t_2 ------------------------t_3 ---->

μ observed — Non Core countries decide
how much to abate

The Core's maximization problem is:

Max $\mathbf{L = V(Q_c, q) + \lambda_1 [U_2 (Q_c, q, \mu)]}$ **(4.1)**

FOCs:

Q_c $\mathbf{V_1 (Q_c , q) - \lambda_1 (U_{21}(Q_c, q, \mu)) = 0}$ **(4.2)**

λ_1 $\mathbf{U_2 (Q_c, q, \mu) \geq 0}$ **(4.3)**

q $\mathbf{V_2 (Q_c, q) + \lambda_1 (U_{22} (Q_c, q, \mu)) = 0}$ **(4.4)**

The first order condition when choosing the production level for the core Q_c depends on the disincentive for the non-core to produce (λ_1 $(U_{21}(Q_c, q, \mu))$) but does not take their utility into account. The non-core chooses q to satisfy (4.3) exactly.

$$\mathbf{Q_c = \frac{A - B\,q}{B+C+ bC/c_s}} \qquad \textbf{(4.5)}$$

$$\mathbf{q = \frac{a - bQ_c - \mu}{b + c}} \qquad \textbf{(4.6)}$$

From here we will indicate the private provision solution by underlining the protection level ($\underline{Q}_c$, $\underline{q}$) or utility level $\underline{U}$. These levels and the utility they imply are important for determining the incentives to participate and comply with the conditions of any contract.

We assume that $\underline{Q}_c$ is large enough that the marginal cost of production for the core is greater than μ for every value of μ. Thus it is always efficient to have every non-core actor produce positive amounts of protection.

4.2 Full Cooperation

If all countries were able to fully cooperate they would solve problem 4.7. The first order conditions and those from the private provision solution provide benchmarks against which we can measure the efficiency of any contract the core is able to write.

$$\textbf{Max } V(Q_c, q) + U(Q_c, q, \mu) \tag{4.7}$$

FOCs:

$$Q_c \quad V_1(Q_c, q) + U_1(Q_c, q, \mu) = 0 \tag{4.8}$$

$$q \quad V_2(Q_c, q) + U_2(Q_c, q, \mu) = 0 \tag{4.9}$$

4.3 Performance Contingent Contract

The core countries can be thought of as the principal in a contracting problem. This is congruent with their leading role in organizing and guiding the process of negotiation of many international agreements. They take this role both because of greater concern and because they have the power and capacity to do so.

The contract the core is designing must specify the quantity of protection they will carry out, Q_c, the amount of protection they expect from the non-core country (as a function of their cost parameter), $q(\mu)$ and the structure of transfers between the core and non-core both before the contract is implemented, K, and contingent on implementation $t(q, \mu)$.

If the core can observe the costs and benefits of the non-core, is able to make payments contingent on the protection level of the non-core, and both the core and non-core have utility which is quasi linear in the amount of the transfer $t(q, \mu)$ then the core can write a contract which implements the fully cooperative solution. We assume that the core is not able to credibly commit to produce a certain level Q_c. Therefore the core produces before the non-core produces and is paid. The assumption that the core is able to commit to a particular transfer schedule is not so unrealistic if you consider the payments made by the non-core on signing the contract (K) going into an international fund that is used to make the transfers.

Figure 2 Time Structure of Contract

Core countries design contract		Q_c fixed		Abatement realized	
t_0---------t_1	------------t_2	----------------t_3	--------------t_4	----------------t_5	-----------t_6--->
μ observed	Non-core accept contract and pay K		Non-core chooses q		t(q) paid to non-core

The problem the core wants to solve is:

Max $\quad$ **V(Q$_c$, q) - t (q(μ)) + K** **(4.10)**

Q$_c$, q, t(q), K

s.t.

(i) $U(Q_c, q(\mu), \mu) + t(q(\mu)) - K > U(Q_c, q(\mu'), \mu) + t(q(\mu')) - K \ \forall \mu'$ ICC

(ii) $U(Q_c, q(\mu)) + t(q(\mu)) - K \geq U(\underline{Q}_c, \underline{q}(\mu))$ Ex-ante PC

$\underline{q}$ and $\underline{Q}$ are solutions to the private provision case. Because of the concavity of the non-core's utility function with respect to q(i) can be replaced by (i)' and (iii).[6]

(i)' $U_2(Q_c, q(\mu), \mu) + t'(q) \geq 0$ ICC

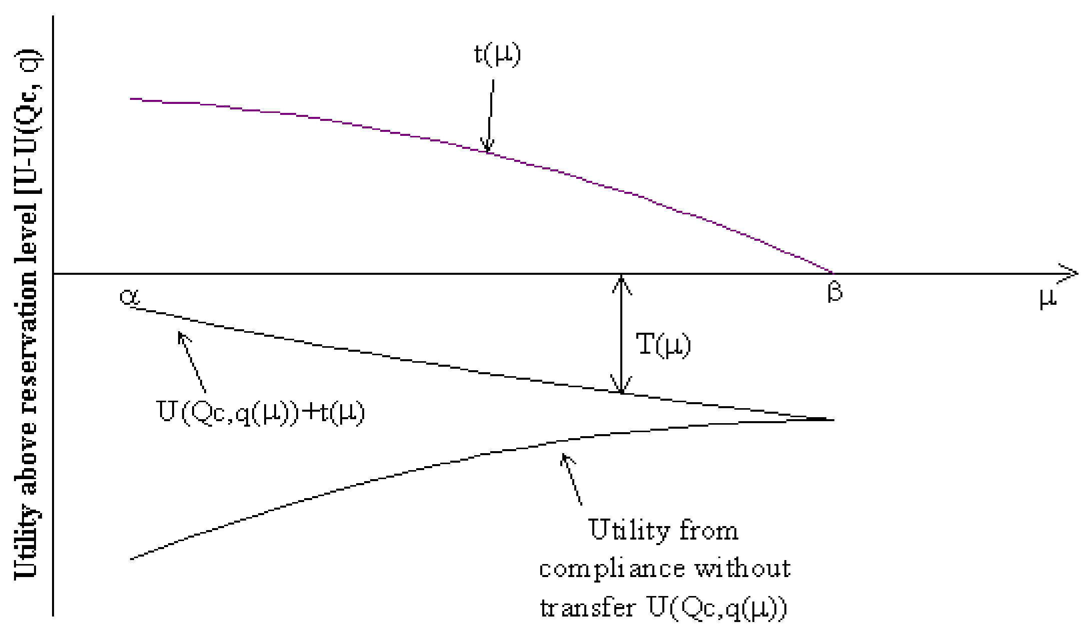
(iii) $U(Q_c, q(\mu), \mu) + t(q) \geq U(Q_c, \underline{q}(\mu))$ Ex-post PC

Condition (iii) is necessary to stop the non-core country from defecting from the agreement after the core has produced Q_c. We can integrate (i)' and set the constant of integration to satisfy the ex-post participation constraint (iii) to find t(q).

$$t(q(\mu)) = \int_0^{q(\mu)} -U_2(Q_c, s, \mu)\, ds \qquad (4.11)$$

$$T(\mu) = U(Q_c, \underline{q}, \mu) - U(Q_c, q(\mu), \mu) - t(\mu) \qquad (4.12)$$

Figure 3 Performance Related Transfer - T(μ) + t(μ)



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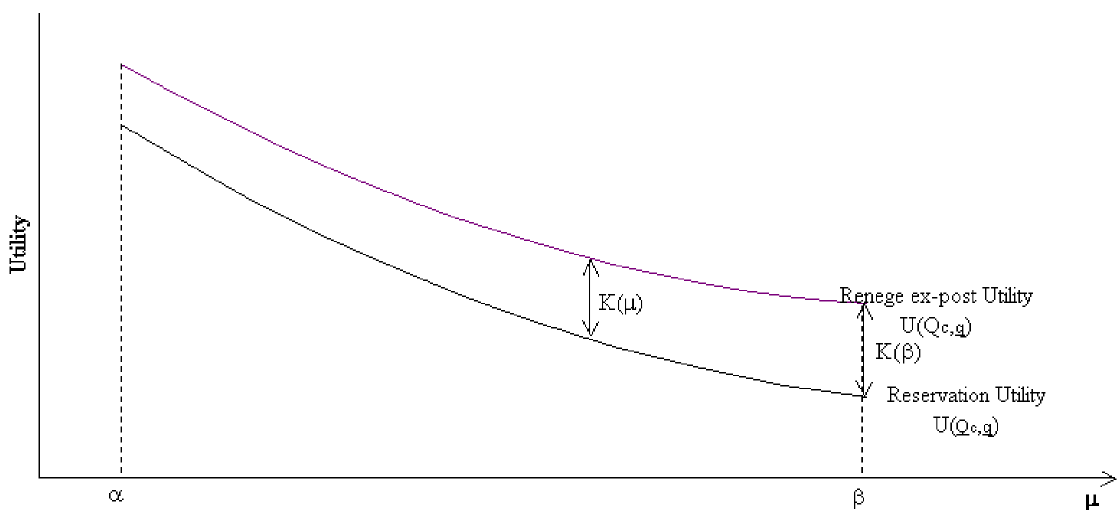
[6] The incentive compatibility constraint is in fact irrelevant given that the information is observable. We introduce it here only to establish the structure for later sections.

Thus the transfer t(μ) in the contract provides the correct marginal incentive while leaving the utility of the non-core country at their level of utility if they defect. The transfer t(μ) has a derivative equal to the net marginal cost (net of utility). T is chosen so that the non-core actor receives no surplus from the second half of the contract, after Q_c is produced, but still participates. Because there is no need for an incentive compatible contract T extracts all the surplus rather than being a constant.

The ex-ante payment K(μ) can be chosen to just satisfy the ex ante participation constraint. K is positive because by producing Q_c the non-core's utility is raised. The core extracts this surplus through K.

$$\mathbf{K(\mu) = [U(Q_c, \underline{q}, \mu) - \underline{U}(\underline{Q_c}, \underline{q}, \mu)]} \qquad \mathbf{(4.13)}$$

Figure 4 Payment by Core on Signing Contract - (K)



Substituting for t(q) T and K in (4.10) we get the following maximization problem for the core. This is identical to the problem in the full cooperative case and thus leads to an efficient outcome.

$$\max_{Q_c,\, q} \; \mathbf{V(Q_c, q) + U(Q_c, q(\mu), \mu)} \qquad \mathbf{(4.14)}$$

When the contract has been designed to be as efficient as possible so that the maximum possible surplus can be achieved, the participants can bargain over how to distribute this surplus. This can be regarded as a separate problem.

4.4 How could the Transfers in the London Agreements be Characterized?

The contract designed above can be thought of as an extremely stylized version of the Montreal Protocol process. The obligations imposed by the London Amendments as prerequisites for receiving funding from the Multilateral Fund could be construed as the payment K to enter the contract. The article 5 countries were required to provide monitoring information. They are subject to the global targets although with a grace period of 10 years. Although this is not an up-front payment in itself, publicly signing on to these obligations makes them vulnerable to international pressure later if they do not meet the targets because there is a strong expectation that countries will make a serious effort to comply with international agreements which they have agreed to. There are also immediate benefits to joining the Montreal Protocol. The most obvious of these is that non-signatories are subject to trade sanctions by signatories. The other benefits are the more amorphous benefits of being part of an international community.

As the article 5 countries agreed to sign the agreement the developed countries increased their own targets and hence production level in response. Before 1990 there was concern by developed countries that their own efforts would be wasted if the developing countries did not also control ODS emissions. When it began to seem that the treaty would be a global effort, the developed countries were able to increase their protection levels with less fear of ineffectiveness and free riding.

Bargaining between developed and developing nations in London was about the levels of targets for developed countries (which apply with a ten year lag), over the amount of money made available through the Multilateral Fund, and about who would be able to control the uses of those funds. The bargaining over relative obligations can be seen as bargaining over K although it also has efficiency implications in terms of optimal allocation of production. The bargaining over the structure of governance of the Multilateral Fund and the amount of its funding was an attempt by the potential article 5 countries to gain some control over the payments so that they can ensure a higher level of commitment by the developed countries. Problems with commitment by the developed countries are not included in our model.

The threat of the non-core countries was that they would not sign the agreement and therefore not control their use and production of ODS. In particular, India and China fought hard for favorable terms before agreeing to sign. By threatening to delay signing, the non-core countries could also threaten to find out more about their costs which would have reduced their risk but also made the core pay more to encourage the most valued countries (those with the lowest costs of protection) to enter. To a certain extent the countries that knew their potential value to the agreement were those that were able to bargain hardest.

The core countries could threaten not to provide funding but to continue to change the international technology standards so that gradually the non-core countries would be forced to convert without the benefit of funding. The surplus over which the core and non-core countries bargained is the sum of their net benefits from cooperation.

The payments for projects under the Multilateral Fund of the Montreal Protocol are designed to cover the "incremental costs" of conversion from ozone depleting substances. Incremental costs are defined on a project-by-project basis and are intended to cover the costs of activities that do not have commercial benefit for the country implementing the project. For example it covers the costs of patents, retraining, new equipment, and loss of productive capacity.[7] In order to be eligible for funding, an article 5 country must be a signatory of the London Amendments of the Montreal Protocol. The Multilateral Fund transfers could be considered as analogous to the transfer function t(q) + T which pays the net marginal costs of production while maintaining the utility of the article 5 country at its non-signatory level. These payments are not determined as a linear function of the amount of ODS capacity converted but take into account the specific costs of individual projects and pay just enough to make them worth doing on the margin.

Thus in many ways the structure of the London Amendments to the Montreal Protocol are very like the optimal structure of a contract with perfect information where there are problems with commitment. However there are also important differences.

Some article 5 countries have been forced to pay indirectly for the protection level by the developed countries because of the trade sanctions on non-parties to the Protocol and the reduced production of ozone depleting substances which made it harder and more expensive to import them for domestic use. Thus as Q_c rises the non-cooperative payoff may be reduced not increased. The countries that are vulnerable to these indirect effects, that is small open economies, have very little bargaining power and may get limited or negative surplus from the agreement.

In addition, the ex-post transfers under the Multilateral Fund are based on net short-run economic cost and thus ignore some of the ex-post costs and benefits to the article 5 country. Because the countries have agreed to delayed reduction targets, some of the benefits from doing a project under the Multilateral Fund are that they will find it easier to comply with these obligations. In addition when considering "incremental costs" the costs that do not count are those that lead to domestic economic benefit. This is generally not interpreted as including the environmental benefits from the protection. If these are significant, the article 5 countries are receiving some of the surplus from cooperation ex-post. The developed countries may be paying a higher cost than necessary on the margin, which may lead to under-protection.

The final important difference between the model and the actual London Amendments process is that this simple model assumes that all costs and benefits are common knowledge. This is not a realistic assumption. The next section looks at the effects of a specific relaxation of this assumption.

5 WHAT HAPPENS IF THE NON-CORE COUNTRIES DO NOT KNOW THEIR COSTS OF COMPLIANCE EX-ANTE?

One problem faced in the negotiation of the London Agreements was that the costs and benefits, of the non-core countries in particular, was not known. Not only did the core not know them but also the countries themselves did not know them. Thus they needed to write a contract that would be as efficient as possible when the article 5 countries learned the actual levels of cost.

The developed countries wanted the article 5 countries to find out their true costs and wanted to provide incentives for them to reveal this information so that abatement could be efficient as possible. This section deals with a stylized model of this problem where the

[7] See Annex XII Handbook for the Montreal Protocol on Substances that Deplete the Ozone Layer. (1993)

distribution of possible costs is known and the actual cost parameter is later revealed only to the non-core country.

The core utility function remains unchanged. We allow uncertainty in the linear portion of the non-core utility but assume the benefits and curvature of costs and benefits are known.

$$\mathbf{U = aQ - bQ^2/2 - cq^2/2 - \mu q} \tag{5.1}$$

where $\mu \sim U(\gamma, \sigma^2)$

$\sigma^2 = \dfrac{(\beta - \alpha)}{12}$

γ and σ (or α, β) are observed by all parties at t_0.

5.1 WHO DESIGNS THE CONTRACT AND DOES IT MATTER?

Because they do not have any private information about costs the core will design a screening contract to induce the non-core actors to reveal their costs truthfully.

However, if the roles were reversed and the non-core became the principal and designed the contract, the nature of the contract would largely be unchanged. The non-core will offer a signaling contract. The form of the contract offered by the non-core can reveal some of their private information. Therefore they design a contract which is identical regardless of their type and thus reveals no information but which provides incentives so that they can credibly commit to reveal their true type when the contract is accepted. These incentives lead to the same transfer function as that in the screening contract designed by the core. If the contract is written ex ante, the non-core does not know its own type and thus cannot reveal it through the contract design.

In the negotiation of the London Agreements it was not at all clear that the developed countries were the only ones with the ability to design the process. Some article 5 countries became very active in the design and thus should also be considered principals in the contract.

Distribution of Surplus

The difference between the signaling and screening contracts comes in the distribution of the surplus from the contract. Throughout the formal sections of this paper we assume that the core extracts all the surplus form the contract because it has the freedom to design the contract. If the non-core were the principal it would extract the entire surplus.

In reality the international agreements are designed by negotiation among nations and in particular between developed and developing nations and the shares of surplus each will be able to extract depend on their relative bargaining power. We can think of the efficient contracts defined in this paper as determining the "total pie" over which countries are bargaining. Once the form of the contract has been determined there will be bargaining that is only limited by the participation constraints of each type. The participation constraints are determined by their utility if the agreement is not signed.

5.2 CONTRACT WRITTEN EX-ANTE BY CORE; BEFORE INFORMATION IS REVEALED TO NON-CORE COUNTRIES

There are two points at which a contract could be designed. At t_1 neither the core nor the non-core know the costs the non-core will face. If a contact is written at this point it will involve a series of contracts for each possible level of μ realized among which the non-core can choose at t_4 when they have private information. The levels of Q_c and K are chosen to maximize expected utility and satisfy ex ante constraints. The alternative, discussed in section 5.2, is to design the contract at the point where μ is known by the non-core.

Figure 5 Time Structure of Contract

	Core countries design contract	Q_c fixed	Abatement realized
t_0-----------t_1------------t_2------------t_3-------------t_4----------------t_5-----------t_6 ----->			
γ,σ^2 observed by all.	Non-core accept contract and pay K	Non-core observe μ and choose q	t(μ) paid to non-core

5.2.1 CONTRACT DESIGN

Ex ante, information is symmetric so it is possible to achieve ex ante efficiency. Ex-post however, the non-core has private information so the contract has to provide them with incentives to reveal this information efficiently. The ex-ante maximization problem for the core is:

$$\max_{Q_c,\, q(\mu),\, t(\mu)} \int_\mu V(Q_c, q(\mu)) - t(\mu) - T + K \, dF(\mu) \qquad \textbf{(5.2)}$$

s.t.

(i) $U(Q_c, q(\mu), \mu) + t(\mu) + T > U(Q_c, q(\hat{u}), \mu) + t(\hat{u}) \quad \forall\, \mu, \hat{u}$ ICC

(ii) $\int_\mu U(Q_c, q(\mu)) + t(q(\mu)) + T \, dF(\mu) - K \geq \int_\mu U(\underline{Q_c}, \underline{q}(\mu)) dF(\mu)$ ex-ante PC

(iii) $U(Q_c, q(\mu), \mu) + t(q) + T \geq U(Q_c, \underline{q}(\mu)) \quad \forall\, \mu$ ex-post PC

<u>Claim 5.1</u>

(i) can be replaced by:

(i)' $U_3(Q_c, q(\mu), \mu) + t'(\mu) \geq 0$ ICC

(iv) $q'(\mu) \leq 0$

<u>Proof:</u> See Appendix 1

<u>Claim 5.2</u>

$$t(\mu) = \int_\mu^\beta -U_3(Q_c, q(\mu), \mu) \, ds \qquad \textbf{(5.3)}$$

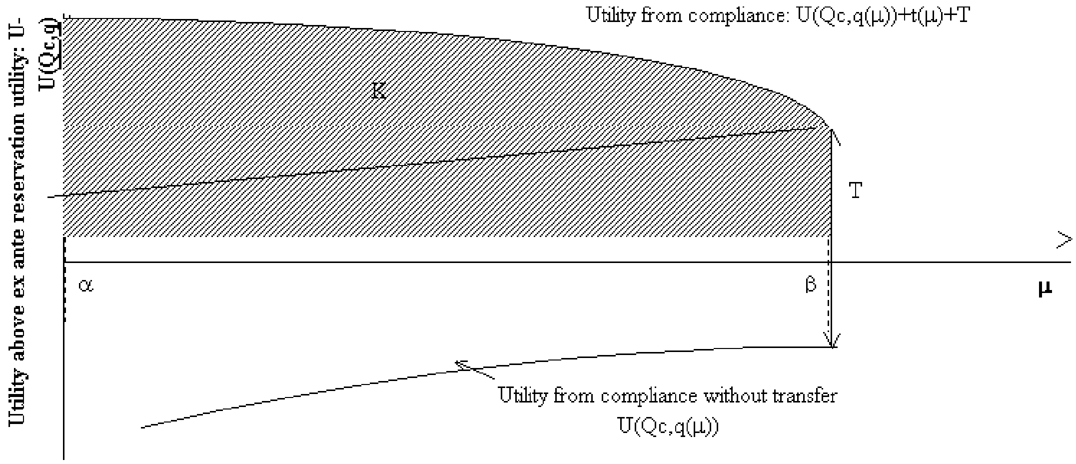
These payments are received if the non-core entrant chooses a protection level that is an element of the contract.

$$T = U(Q_c, \underline{q}(\beta)) - U(Q_c, q(\beta)) \tag{5.4}$$

$$K = \int_{\alpha}^{\beta} \Big[U(Q_c, q(\mu), \mu) + \int_{\mu}^{\beta} U_3(Q_c, q(s), s)ds + T - U(\underline{Q_c}, \underline{q}(\mu)) \Big] dF(\mu) \tag{5.5}$$

<u>Proof</u>: See Appendix 2

Figure 6 Ex ante and Ex post transfer with private information



$t'(\mu) > 0$. $t(\mu)$ which is the ex-post payment received by the entrant is always positive and makes their utility at least as great as their utility if they renege. $\underline{U} = U(Q_c, \underline{q}(\mu), \mu)$ which is the utility from reneging ex-post.

$$\partial [U + t(\mu) - \underline{U}] / \partial \mu = -q + \underline{q} < 0 \tag{5.6}$$

This means that for values of μ lower than β the non-core receive positive benefits from participating ex-post. This rise in utility as μ falls is concave because

$$\partial^2 [U + t(\mu) - \underline{U}] / \partial \mu^2 = 1/(B+b+c) - 1/(b+c) < 0 \tag{5.7}$$

If the core is able to extract the entire surplus the ex ante participation constraint is just satisfied. K is the maximum possible amount the core can extract from the non-core. If the non-core countries have some bargaining power they may get positive surplus from the contract by reducing K and the contract will still be efficient ex-ante.

Ex-post, the increase in utility from having participated in the contract is:

$$PU = [U - \underline{U}] + [U(\underline{Q_c}, \underline{q}(\mu), \mu) - K] \tag{5.8}$$

$E[PU] = 0$ ex ante. $[U - \underline{U}] \geq 0$ because this is the ex-post rationality constraint. Therefore the expected value of the second term must be negative. $\partial PU/\partial\mu < 0$. Therefore, those countries which have low costs, get net benefit from participating in the contract while those with high costs get enough benefit in the second stage of the contract to encourage them to comply but make a loss on the overall contract (depending on the actual ex ante payment).

Substituting the value of $t(\mu)$ and K (5.3 - 5.5) into (5.2) we get the following problem, which is equivalent to (5.2).

$$\max_{Q_c,\, q(\mu)} \int_\mu V(Q_c, q(\mu)) + U(Q_c, q(\mu), \mu) \; dF(\mu) \qquad (5.9)$$

s.t. (i) $q'(\mu) < 0$

FOCs:

Q_c: $\int_\mu V_1(Q_c, q(\mu)) + U_1(Q_c, q(\mu), \mu) \; dF(\mu) = 0$

$q(\mu)$: $V_2(Q_c, q(\mu)) + U_2(Q_c, q(\mu), \mu) = 0 \quad \forall \mu$

$$q(\mu) = \frac{A + a - (B+b)\, Q_c - \mu}{B + b + c} \qquad (5.10)$$

$$q'(\mu) = -1 / (B + b + c_s) < 0 \qquad (5.11)$$

$q'(\mu)$ is negative as required for the solution to satisfy the sufficiency conditions. Q_c is chosen to be ex-ante efficient. $q(\mu)$ is ex-post efficient conditional on Q_c. Although the choice of Q_c is inefficient ex post, if we think of this model as one with many non-core actors with levels of μ distributed $U(\gamma, \sigma^2)$ instead of one, the level of Q_c (which must be the same for all actors) will approximate efficiency ex post.

5.3 Delay Contract until information is revealed to non-core countries

An alternative strategy for the non-core countries would be to refuse to write a contract until they have the chance to determine their own costs of protection. They could do this because they do not want to (or are unable to) pay K to the core countries ex ante or because they do not want to take the risk that ex-post they will find that their costs are such that they have made a loss on the contract overall. Each of these problems could relate to domestic political concerns or a desire to maintain a particular balance between the rights and responsibilities of developed and developing countries. A contract where poor countries are required to make rich countries a large payment in return for uncertain future payments seems likely to be politically difficult. If K is limited, the core may prefer to contract ex post.

5.3.1 Designing the Contract

If a contract is written when there is asymmetric information, every non-core country must achieve an ex-post utility level higher than they would by not participating. However the asymmetry of information precludes an efficient solution and reduces the joint surplus of the core and non-core. If the non-core has the ability to negotiate over the ex-ante surplus it may be preferable to take the ex-ante contract and the up-front political cost and risk it involves. The expected return from the ex post contract sets a minimum level for the surplus the non-core must receive if they do sign an ex-ante contract.

We now assume that μ is private information for the non-core countries when the contract is written. When the contract is designed, Q_c is produced and K is paid. Then the non-core decide how much to produce and receive transfers based on the μ they declare and hence the $q(\mu)$ they produce.

Figure 7 Time Structure of Ex-Post Contract

```
      Core countries
      design contract        Qc fixed                    Abatement realized
t0----------t1------------------t2-------------t3----------------t4-------------t5 ----->
μ observed                  K paid        Non-core                t(q) paid
only by                                   chooses q               to non-core
non-core
```

The ex-post model is a standard adverse selection model where the core solves the following problem.

$$\max_{Q_c,\, q(\mu),\, t(\mu)} \int_{\mu} V(Q_c, q(\mu)) - t(\mu) - T + K \, dF(\mu) \tag{5.12}$$

(i) $U_2 (Q_c, q(\mu), \mu)\, q'(\mu) + t'(\mu) \geq 0 \quad \forall \mu$ ICC

(ii) $U(Q_c, q(\mu), \mu) + t(\mu) + T \geq U(Q_c, \underline{q}(\mu), \mu) \quad \forall \mu$ PC

(iii) $q'(\mu) \leq 0$ Monotonicity

$$t(\mu) = \int_{\mu}^{\beta} U_3(Q_c, q(s), s)\, ds \tag{5.13}$$

The constant T must be chosen to satisfy (ii). It is the same as in the ex ante contract.

K, the ex-ante payment by the non-core must be set so that the highest cost non-core member will be willing to join the contract. This actor gets no surplus from production so is only willing to pay the amount of utility they gain from an increase in Q_c.

$$K = U(Q_c, \underline{q}(\beta)) - U(\underline{Q_c}, \underline{q}(\beta)) \tag{5.14}$$

Therefore 5.12 is equivalent to:

$$\max_{Q_c,\, q(\mu),\, t(\mu)} \int_{\mu} V(Q_c, q) + U(Q_c, q, \mu) - \int_{\mu}^{\beta} -U_3 (Q_c, q(s), s) ds \;\; dF(\mu) \tag{5.15}$$

(i) $q'(\mu) \leq 0$ Monotonicity

Integrating by parts, and ignoring the monotonicity constraint, this is equivalent to:

$$\max_{Q_c,\, q(\mu)} \int_{\mu} V(Q_c, q) + U(Q_c, q) - \frac{F(\mu)}{f(\mu)} -U_3 (Q_c, q(s), s) \, dF(\mu) \tag{5.16}$$

FOCs:

$q(\mu)$: $V_2(Q_c, q)+U_2(Q_c, q) - F(\mu)/f(\mu)\ [-U_{23}(Q_c, q(\mu), \mu)] = 0$

Q_c : $\int_\mu V_1(Q_c, q)+U_1(Q_c, q) - F(\mu)/f(\mu)[-U_{13}(Q_c, q(\mu), \mu)]\ dF(\mu) = 0$

The last term in the first order condition for $q(\mu)$ is negative so there will be underproduction except at $\mu = \alpha$ where $F(\alpha) = 0$. This is equivalent to the standard result of "no distortion at the top" although in this case the most valuable and only efficient non-core actor has the lowest cost. The intuition for this result is that there is a tradeoff between achieving efficiency and minimizing the cost of separating by μ. Separation is achieved by providing a higher transfer to lower cost producers but also requiring a higher level of production. A low cost actor receives positive surplus from the high cost actor's contract because that contract pays enough to induce participation by the higher cost actor on the margin. The surplus from overstating costs by the low cost actor becomes greater the higher the production of the high cost actor and hence the transfer. The low cost actor must receive at least this surplus from its own contract. Thus the production level of the high cost actor is biased downward to make it cheaper to induce the low cost actor to choose its own contract and produce more. This distortion does not apply to the lowest cost actor because only upward constraints are binding and the lowest cost contract does not affect the contract of any other type. In the ex ante model there was no tradeoff because any surplus granted to lower cost actors to separate them could be extracted in expected value through K.

Q_c is chosen ex-ante. Even ex ante it could be inefficient if the choice of Q_c affects the amount of transfer the lower cost non-core country must be paid to separate them from the higher cost. However, U_{13} is zero so increasing Q_c has no effect on the cost of separation. Thus the core will choose Q_c to be efficient ex-ante.

5.3.2 Ex-ante and Ex-post contracting and the Montreal Protocol

Montreal as an Ex-Ante Contract

The negotiations in 1990 in London were creating an ex-ante contract to the extent that non-core countries still had very little knowledge about their current and potential uses of CFCs and other ozone depleting substances and even less about the true costs of phasing out their use.

After the London Amendments were concluded, many of the Multilateral Fund transfers in its first years were not for protection projects but rather to allow countries to assess their use of ODSs and to find potential projects for reducing ODS use. This would be valuable in an ex ante contract because once the contract is signed both the core and non-core have incentives to find the most efficient possible ways to control ODS. This activity made some cost information internationally observable but may also have created private information for the non-core countries and firms within the countries.

Although the Multilateral Fund is set up to cover incremental costs and thus provide no surplus to the country which carries out the project, to the extent that true costs are not observable it is likely that surplus is offered to countries in order to encourage them to offer larger more efficient projects and thereby reveal their low cost abatement opportunities. Small projects are unlikely to realize a surplus from the Fund due to the high costs of project design and approval. To the extent that these are fixed costs there are advantages to larger projects that may reward those with lower marginal costs because they are able to offer larger projects. There are also greater benefits to those who have concern about the environmental outcome. This is like having lower net costs. These countries are more willing to carry out projects and receive a higher surplus. Therefore the current system does provide some countries with net surplus above incremental cost and thus may encourage those who are able to achieve this surplus to take on more and larger projects. If these countries are those with lower net costs then this acts as a form of separation as required in the optimal contract.

Most of the projects implemented in the first three years of the Fund's operation involved either large countries or firms with some foreign ownership. It is not clear that these are the lowest cost projects although they probably have lower transaction costs. The direction of funding may partly be driven by the bargaining power of the relative countries as well as their capacity to make use of a fund such as this. This form of bias is not necessarily efficiency inducing.

Montreal as an Ex-Post Contracting Process

There are many reasons why the representation above is too simplistic. First, it is quite probable that there was a binding constraint on the commitment the developing countries were able to make at the beginning of the process. i.e. K is constrained. This implies that it is impossible to recoup all the costs of a separating contract and as in the ex post model, $q(\mu)$ will be biased downward. The major element of K as described above is their commitment to meet the targets after the 10-year grace period. It is still extremely uncertain the extent to which they will be forced to do this. If this was seen as a weak commitment it does not have a high value in terms of transferring surplus to the core.

Second, there was some private information even in 1990 so that the contract was not truly ex ante.

Third, even if the contract was a true ex ante contract some renegotiation was inevitable and in fact allowed for. This was partly because, for scientific and political reasons it is impossible to write a complete contract, and also because international agreements are by their nature not strictly binding particularly if a powerful country or group of countries wishes to change the contract.

The characterization of the core as able to make binding commitments is unrealistic. There have been some regrets and re-thinking of production targets within the developed countries. In the United States this has come in the form of a conservative backlash illustrated by Rush Limbaugh's argument that the ozone problem is a "conspiracy". In Europe there have been difficulties with compliance as the marginal costs rise and a black market has developed to avoid the controls. Although no government has yet backed down from their commitments, they have been unable to fully control their citizen's actions.

There have been problems with getting the developed countries to provide the agreed funding to the multilateral fund. Some countries have paid in the form of promissory notes and others have been very slow in making payments. If the developed countries anticipated this renegotiation by the developed countries they will have made less commitments to the process and this may mean that they will be less likely to meet their targets when their grace period expires.

6 WHAT IF THE NON-CORE COUNTRIES HAVE PRIVATE INFORMATION ABOUT THE DISTRIBUTION OF THEIR COSTS OF COMPLIANCE?

It is probably true that while countries do not know their true costs of abatement, they do have better information about these costs than a member of the core. In this section we analyze one specific type of information, information about the variance of their costs. Because the core's utility function is concave with respect to the production of the non-core, and variance in costs leads to variance in the level of production chosen and transfer received, the core prefers to contract with entrants with lower variance. Higher variance also implies that the contract needs to be defined for a larger range of possible costs, which makes the separating contract more expensive ex post. This becomes important if the possibility for payments by the non-core ex ante (K) is limited.

Another political reason for concern about variance in cost and hence compliance is that there may be uncertainty about the stability of the cooperative contract. If some players are observed frequently producing very low levels this may undermine confidence in and commitment to the overall equilibrium and lead to reduced cooperation or even collapse of the agreement.

In this section we show that it is possible to write a series of contracts that separate entrants according to their level of variance. We show that in this particular case the distribution of surplus and level of efficiency is the same in a pooled and separating contract and that efficiency is achieved ex ante for each level of variance.

6.1 SEPARATING CONTRACT

The time structure of our model with an unobserved distribution is given in Figure 8. The contracts are designed at a point where the non-core know their own distribution of costs but not the actual realization. The core designs a series of contracts for each level of variance where the number depends on how many entrants they want to include. We assume that Q_c is chosen before the specific contract is chosen and hence the actual levels of variance are revealed. There are two reasons for this assumption. First, if there are a large number of entrants with different levels of variance there can only be one level of Q_c for all entrants so it may as well be chosen based on expected levels of entry. Second, when non-core members make decisions about whether to accept a contract and which contract to accept they need to know the level of Q_c to make this decision.

We assume that the distribution of variances is known. $\sigma \sim U(\underline{\sigma}, \sigma')$ The variance of a uniform distribution implicitly defines the range. So for each σ_i there are corresponding α_i and β_i, where $\sigma_i = (\alpha_i - \beta_i)/12$. The mean of each distribution γ_i is assumed to be the same.

Figure 8 Time Structure for Unobserved Distribution

Core designs contracts
Q_c chosen (at t_1)

Q_c produced
μ_s realized (at t_3)

Abatement realized (at t_5)

0 ------------t_1 ---------t_2 -----------t_3---------------t_4 -------------t_5 ----------t_6 ------->

σ^2 observed only by S	S accepts and pays K	S decides whether to abate	transfer made

The overall problem faced by the Core when designing the set of contracts is given below.

$$\max_{Q_c,\ q(\mu,\sigma),\ t(\mu,\sigma)} \int_\sigma \int_\mu V(Q_c, q(\mu)) - t(q_s(\mu))\, dF(\mu|\sigma)\, dG(\sigma) \tag{6.1}$$

s.t.

(i) $U(Q_c, q(\mu,\sigma), \mu) + t(q(\mu,\sigma)) \geq U(Q_c, q(\hat{u},\sigma),\mu) + t(q(\hat{u}, \sigma))\ \forall \mu,\hat{u}, \sigma$ ex-post ICC

(ii) $U(Q_c, q(\mu,\sigma), \mu) + t(q(\mu,\sigma)) \geq U(Q_c, \underline{q}(\mu), \mu)$ ex-post PC

(iii) $\int_\mu [U(Q_c, q(\mu, \sigma), \mu)+t(q(\mu, \sigma))]dF(\mu|\sigma) \geq \int_\mu[U(\underline{Q}_c, \underline{q}(\mu)), \mu)]dF(\mu|\sigma)$ ex-ante PC

(iv) $\int_\mu U(Q_c,q(\mu,\sigma),t(\mu,\sigma))dF(\mu|\sigma) \geq \int_\mu U(Q_c,q(\mu,\sigma'),t(\mu,\sigma'))dF(\mu|\sigma)\ \forall \sigma,\sigma'$ ex-ante ICC

The problem of separating possible entrants by variance is intuitively very similar to discriminating among people with different levels of risk in an insurance contract. Thus separation is achieved by offering the low variance entrant a lower "premium" but also a contract that is more risky from the point of view of the high variance entrant. This is easily done because of the assumption of uniformity and therefore the difference in the support of the two distributions. A contract which is optimal for the low variance actor over its support but which forces the high variance to choose an element of this contract when its costs are outside this range creates lower payoffs for the high variance actor in the tails of the distribution relative to the optimal high variance contract. We prove this by showing that any two levels of variance can be separated and then showing that first order conditions for local separation are also sufficient conditions for global separation.

Suppose there are two possible levels of σ. Define (1) as the optimal contract for the lowest risk entrant if there was no need to separate, but with T raised so that the highest cost high variance actor will still comply with the contract at all levels of μ, and K adjusted so that $U_1(1)$ is equal to its payoff without the contract. (2) is the optimal contract for a higher risk entrant.

<u>Claim 6.1:</u> It is possible to write contracts that separate the non-core depending on their variance.

<u>Proof</u>

Contract 1: Low Variance Contract

$$t_1(\mu) = \int_\mu^{\beta_1} -U_3(Q_c, q(s), s)\, ds + T_1 - K_1 \tag{6.2}$$

These payments are received if the non-core entrant chooses a protection level that is an element of the contract.

$$T_1 = U(Q_c, \underline{q}(\beta_2), \beta_2) - U(Q_c, q(\beta_1), \beta_2) \tag{6.3}$$

This is an amount sufficient to induce the highest cost actor of the high variance type to comply ex-post with contract (1).

$$\mathbf{K_1 = \int_{\alpha_1}^{\beta_1} \Big[U(Q_c, q(\mu), \mu) + \int_{\mu}^{\beta_1} -U_3(Q_c, q(s), s)ds + T_1 - U(\underline{Q_c}, \underline{q}(\mu)) \Big] dF_1(\mu)} \qquad \textbf{(6.4)}$$

Contract 2: High Variance Contract

$$\mathbf{t_2(\mu) = \int_{\mu}^{\beta_2} -U_2(Q_c, q(\mu), \mu)\, q'(s)\, ds + T_2 - K_2} \qquad \textbf{(6.5)}$$

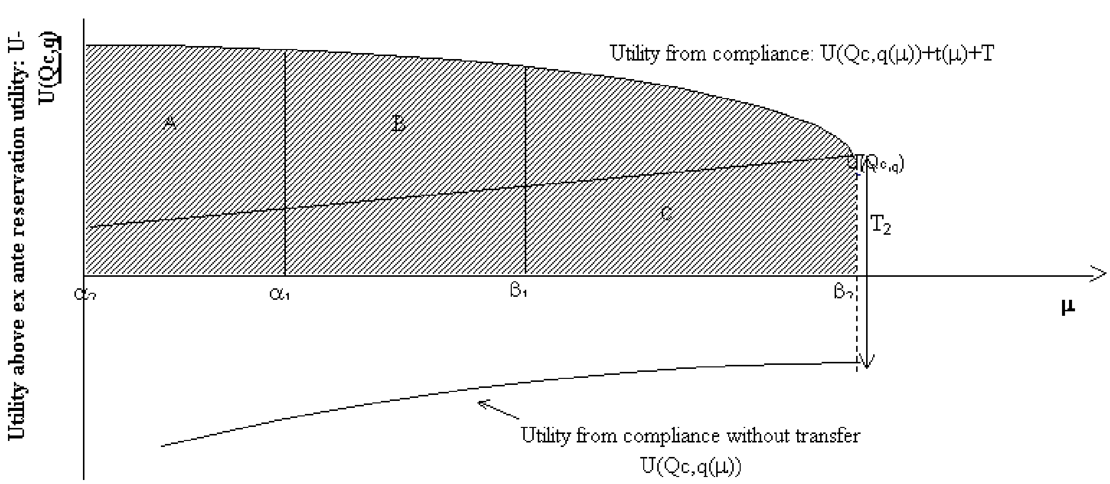
$$\mathbf{T_2 = U(Q_c, \underline{q}(\beta_2), \beta_2) - U(Q_c, q(\beta_2), \beta_2)} \qquad \textbf{(6.6)}$$

$$\mathbf{K_2 = \int_{\alpha_2}^{\beta_2} \Big[U(Q_c, q(\mu), \mu) - \int_{\mu}^{\beta_2} U_3(Q_c, q(s), s)ds + T_2 - U(\underline{Q_c}, \underline{q}(\mu)) \Big] dF_2(\mu)} \qquad \textbf{(6.7)}$$

Lemma 6.1: ***$U_1(1) < U_1(2)$ i.e. 1 will not accept its own optimal contract when another contract optimal for a higher risk entrant is also offered.***

Proof: See Appendix 3

Figure 9 Contract for High Variance Actor



$K_2 = A + B + C$

The surplus above reservation utility to the low variance actor from taking the high variance contract is equal to:

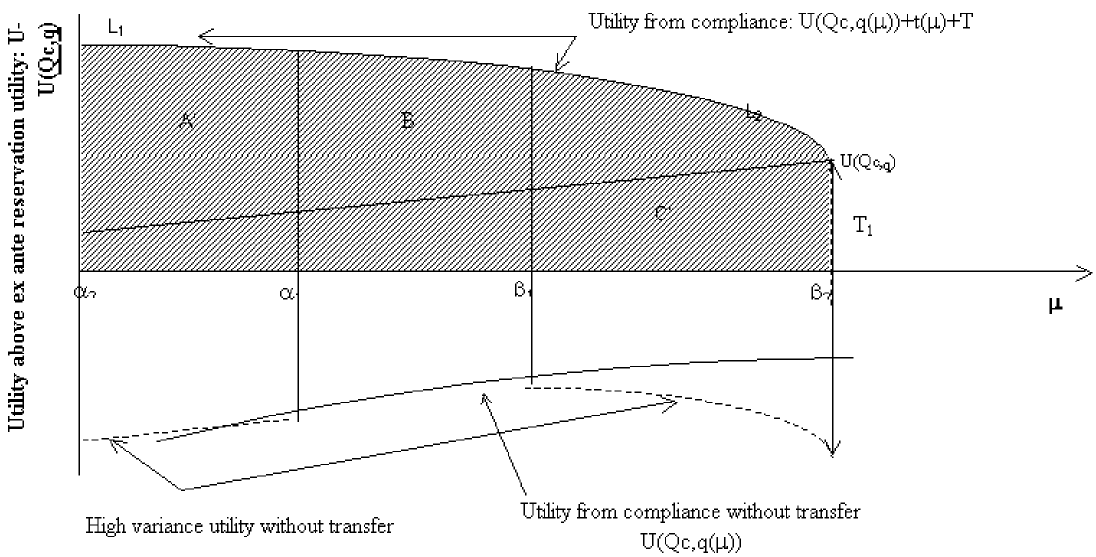
$$B\,\frac{(\beta_2 - \alpha_2)}{(\beta_1 - \alpha_1)} + K_2 = M > 0$$

The structure of rewards in the efficient contract are concave, this means that the lower variance actor receives a higher payoff than the high variance actor. The contract is designed to extract the entire surplus from the high variance actor so the low variance actor gets a positive surplus from this contract. In contrast, the low variance contract is designed to provide the low variance actor with no surplus above its reservation payoff.

Thus if ex-ante optimal, surplus extracting contracts are offered for all different levels of variance, the low variance actors will choose the high variance actors' contracts. This is true for every different level of variance.

Lemma 6.2: The high variance type will prefer contract (2) to contract (1).
Proof: See Appendix 4

Figure 10 Contract for low variance actor with payoffs for high variance that chooses this contract.



The low variance contract is designed not only to provide efficient incentives to low variance types and extract their surplus above the reservation value but also to ensure compliance by any high variance type who chooses this contract, regardless of their actual cost realization. This is done by raising the payment T_1 that is received for compliance and raising K_1 to compensate. Figure 10 shows that this induced compliance in the tails of the distribution means that the high variance actor will have an inefficient level of production and therefore a lower payoff. Not only do they prefer their contract to that of the low variance actor because the level of $K_i - T_i$ is higher, but also they lose efficiency relative to their contract. This inefficiency does not affect the low variance actor due to the assumption of uniformity. Under any other distribution there would be some inefficiency loss to the low variance actor but the result would still hold.

Lemma 6.3: It is possible to change the contract for the low variance entrant (1) to induce them t enter without making the high variance entrant choose the low variance contract.

This is equivalent to establishing that the Spence Condition (Spence 1974) holds where the signal is the choice of contract.

Proof:

Define $U_1(2) - U_1(1) = M$. If the level of K associated with the low variance contract is lowered by the amount M (i.e. their premium is lowered), the low variance actors will be indifferent between the two contracts. The question is whether the high variance actor will now want to choose the low variance contract with the additional M.

Show that $U_2(2) - U_2(1) > M$

Proof : See Appendix 5

Decreasing the payment by M accounts for the effect of concavity on the difference in reward to the low and high variance actors. If the high variance actors were able to have an efficient contract when they choose the low variance contract they would be indifferent between the low variance contract with the additional payment M and their own contract. However, the inefficiency at the tails of the contract (L_1, and L_2) means that their payoff from their own contract is still superior.

In Figure 10, $K_1 = B$. The loss to the high variance actor from choosing this contract rather than their own is:

$$A' + B + C' - B \frac{(\beta_2 - \alpha_2)}{(\beta_1 - \alpha_1)} = M + L_1 + L_2$$

Therefore it is possible to reduce the payment of the low variance contract K_1 by M and still induce the high variance actors to accept their own contract. If there are more than two possible levels of variance, e.g. $\sigma_A < \sigma_B < \sigma_C$, a set of contracts which separate B from A, and C from B will also separate C from A.

<u>Claim</u>: The local necessary conditions are globally sufficient.

Lemmas 6.1, 6.2 and 6.3 are true for all values of $B_2 - \beta_1$, and hence $\alpha_1 - \alpha_2$ and σ. Therefore it is possible to separate potential entrants on the basis of their variance and the separation is global.

Problem (26) is equivalent to the following problem.

$$\max_{Q_c,\, q(\mu|\sigma)} \int_\sigma \int_\mu V(Q_c, q(\mu|\sigma)) + U(Q_c, q(\mu|\sigma), \mu)\, dF(\mu|\sigma) - \int_{\sigma}^{\sigma'} m(\sigma)\, dG(\sigma) \qquad \textbf{(6.8)}$$

s.t. (i) $q'(\mu|\sigma) < 0 \quad \forall \mu,\sigma$

$t(\mu|\sigma)$, and $T(\sigma)$ are defined as in contract (1) where β_2 is the β for the highest variance type. $K(\sigma)$ is as defined in (1) but has an additional term $-M(\sigma)$. $M(\sigma) = 0$ for the highest variance type. For a continuum of contracts the $M(\sigma)$ will be an integral over the M necessary to separate each level of variance. They are all defined for the level of σ in the contract chosen in the first stage of the game.

As in the ex ante contract in section 4.1, the levels of q are chosen efficiently conditional on the level of Q_c. Q_c is chosen inefficiently because it is chosen to maximize ex-ante surplus when σ and μ are not known. Again, the entrants do not receive any expected surplus from the second stage of the game although ex-post they can make a profit or a loss. However, because the set of contracts must separate between entrants with different levels of variance in cost, the low variance entrants will receive a surplus equal to M.

M may vary with Q_c and $q(\mu)$. If it does the core may distort these to minimize the surplus it has to provide in order to separate the non-core actors by their variance.

6.2 Pooling Contract

Claim: In this case with a uniform distribution, a pooling contract leads to same level of efficiency and distribution of surplus as the separating contract.

If the Core chooses to offer a pooling contract it must decide the highest level of variance it is willing to accept in an actor. It will then offer one contract that is efficient and extracts the entire surplus from the highest variance actor. All actors with lower variance will accept this contract and receive a surplus equal to $M(\sigma_i, \sigma')$. Higher variance actors will not accept.

The reason that the pooling and separating contracts yield identical outcomes in this situation is that the distributions are defined over different supports so that the optimal contracts, when designed to ensure compliance for all cost levels ex post, automatically provide higher risk to higher variance entrants who pretend to be lower variance. Thus the separating contracts are efficient with respect to $q(\mu)$, as is the pooling contract. The only difference between the two arises if there is some value to the core (and no disadvantage to the non-core) of being able to identify the level of variance of the entrants they have contracted with.

If the distribution of costs were not uniform, and the two distributions had the same support, to separate the non-core entrants by variance it would be necessary to pool some levels of μ at the tails of the distribution in the low variance contract to reduce the payoff to extreme cost realizations and hence raise the risk of the low variance contract. This would lead to less separation and some inefficiency for the low variance type in a way analogous to the under-insurance result of Rothschild and Stiglitz (1977).

7 Policy Implications and Directions for Future Work

7.1 Implications for International Agreements

The most efficient contracts are written before private information exists. If there is private information, production by the agent may be distorted to reduce the cost of writing a contract to reveal the costs of each agent. Regardless of who writes the contract it is in the interests of both principal and agent to write the most efficient contract because this maximizes the amount of surplus that they can bargain over.

If there are some countries with strong bargaining power that have to be highly paid to encourage them to participate they should be paid through ex ante lump sum transfers rather than through preferential treatment in the transfer function because the latter approach induces inefficiency. For example, the larger developing countries were the most powerful negotiators of the London Amendments. They should not have been rewarded through more power over the distribution of Multilateral Funds or more approved projects. It may be however that these things occurred for reasons other than their credible threats not to participate.

If the contract is written after private information arises there will be incentives to contract for underproduction for high cost countries to minimize the difference in payments between the different cost types. This is to the advantage of the core countries if they have to pay a minimum amount to high cost countries to ensure participation and separate lower cost countries from the high cost. If the non-core were writing the contract, this would maximize the payments to the higher cost countries when the lowest cost country must have a contract that is worthwhile for the core to implement. This is a standard distortion in screening and signaling models.

The issue of when to write a contract is particularly relevant for dealing with global climate change where there is currently a great deal of uncertainty about the costs and benefits of different countries. If a contract can be determined now when countries' information positions are more equal it could be possible to make all countries better off. More information can make negotiation more difficult.

The ability of countries to make commitments is important for efficiency. In this paper we have assumed that the core countries are more able to make binding commitments than the non-core. The strategic use of institutions may make commitments more binding. For example, in our model the core need to be able to commit to provide the transfers as agreed after the non-core have signed the agreement and made any up front payments. This may be easier to ensure if the funds are given to an international fund with a structure designed to implement the transfers. In the contracts, as designed, there is no problem with commitment by the non-core because their contracts are incentive compatible ex post.

The ability of the non-core to make transfers when they sign the contract may be important for efficiency if the core has a lot of bargaining power. If the size of the transfers is a constraint, the core may exercise its bargaining power by changing its own production or the transfer schedule in inefficient ways. An alternative to high ex ante transfers is to use punishments rather than rewards to induce compliance ex-post. This route is fairly weak and diffuse internationally but can be used to a limited extent.

The analysis above assumes that it is possible to write contracts that offer different rates of payment and different quantities of production for different countries. The institutions used to implement this agreement may affect the flexibility of the transfer function. Frequently international agreements require uniform production targets because symmetry appears fair. These agreements are unlikely to be efficient. It may also be difficult to provide different levels of subsidy to different developing countries that are competing for what is often seen as aid dollars.

The issue of flexibility in payments and production will be particularly critical in dealing with global climate change where the efficient levels of abatement are likely to differ vastly across countries in an ongoing way. In contrast, in the ozone depletion case there may have been large differences in costs of abatement but the long run goal is phase out so all countries will ultimately have the same level of production.

Section 6 has shown that (under strict assumptions) it is possible to pool countries with different variance without an efficiency loss. It also showed that if global participation is not an immediate goal, it is possible to write a contract that only lower variance countries will accept and thereby minimize the variance in compliance levels. This might be useful if there were some fixed cost per participant in the agreement. It is also possible to separate countries according to their variance without efficiency loss. This contract has the same efficiency and distribution as the pooling contract but provides information that may be useful.

The potentially high costs of separating countries on the basis of cost makes it clear that efforts to reduce the amount of private information are valuable for efficiency. Of course once countries have private information it is valuable to them so it is difficult to reveal. Revealing information may be easier under some institutional forms than others. A tradeable rights market will provide more incentives to use information bilaterally but will not necessarily increase the amount of common knowledge. The provision of verifiable information may be made a prerequisite for participation as in the London Amendments to the Montreal Protocol. This reduces the problem but does not eliminate it. The difficulties experienced in getting even basic information on production and consumption of ODSs suggest that private information is going to continue to be a major issue.

7.2 DIRECTIONS FOR FUTURE RESEARCH

There are 4 major areas where this work could immediately be extended. First, it could be extended to deal with multiple non-core actors. This introduces interactions between the production of one non-core actor and the incentives of another. The more is expected to be produced in total, the harder it is to induce production on the margin. The uncertainty in total output due to variance in the distribution of costs of one actor can also affect other actors' incentives. If they are sufficiently risk averse, the uncertainty could increase their incentives to produce as a form of insurance.

If the costs of different non-core actors are correlated then "yardstick competition"[8] can be used to remove the aggregate shocks from cost realizations and hence reduce the importance of the private information.

An extension that would have a more fundamental effect would be the recognition that this is not a one period game. In a dynamic setting with the possibility of renegotiation actors will strategically choose not to reveal their information. This leads to dynamic adverse selection games where agents choose not to reveal information immediately because this reduces their payoffs in later periods and therefore the principal has to design contracts to take this into account.[9] The final extension which is taken up in the context of institutional choice in Kerr (1995) is to relax the assumptions of binding contracts, and observable output.

[8] See Baiman and Demski (1980) and Holmström (1982)

[9] See, for example Fudenberg, Holmström and Milgrom (1990) , Crawford and Sobel (1982)

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APPENDIX 1 PROOF OF CLAIM 5.1

Local Necessary and Sufficient Conditions

(i)' is the derivative of the left hand side of (i) with respect to $\hat{u}$. This must be equal to zero at $\hat{u} = \mu$. For sufficiency, the second derivative must be negative. Because (i) is true for all μ it is an identity and its derivative is zero. The second derivative with respect to $\hat{u}$ is:

SOC: $- q'(\mu)\ \partial/\partial\mu\ (a - bQ - cq - \mu) < 0$

because $\partial/\partial\mu\ (a - bQ - cq - \mu) = (-b - c)q'(\mu) - 1 < 0$

[$q'(\mu) < 0$ from first order conditions for Problem (5.2)]

Global Sufficiency

$[a - bQ(\hat{u}) - cq(\hat{u}) - \mu]\ q'(\hat{u}) + t'(\hat{u}) = A$

A is the change in utility with an increase in $\hat{u}$.

$\partial A / \partial \mu = - q'(\hat{u}) > 0$ i.e. A is non-decreasing in μ. $A(\hat{u} = \mu) = 0$

Therefore if $\hat{u} > \mu$, A is negative and the entrant can raise its utility by decreasing $\hat{u}$. Conversely, if $\hat{u} < \mu$ A is positive and the entrant will increase its $\hat{u}$.

APPENDIX 2 PROOF OF CLAIM 5.2

Integrate (i)' with respect to μ to find $t(\mu)$. This gives (5.3) where T+ K is the constant of integration.

T must be chosen to satisfy the ex-post participation constraint. If $U(Q_c,q(\beta)) + t(\beta) = U(Q_c, \underline{q}(\beta))$ and $\partial [U+t(\mu) - \underline{U}] / \partial \mu < 0$ then (5.4) means that (ii) is satisfied for all $\mu \in [\alpha,\beta]$.
$\partial [U+t(\mu) - \underline{U}] / \partial \mu = - q + \underline{q} < 0$

K must be chosen to satisfy the ex-ante participation constraint. Ex-post, the utility of the entrant is:

$$U(\mu) = U(Q_c,q(\mu),\mu) + \int_{\mu}^{\beta} -U_3 [Q_c, q(s), s]ds + T - K$$

Integrating this over μ we get the value of K (5.5).

APPENDIX 3

$$U_1(1) = \int_{\alpha_1}^{\beta_1} \underline{U}(Q_c, \underline{q})\, dF_1(\mu)$$

$$U_1(2) = \int_{\alpha_1}^{\beta_1} U(Q_c, q(\mu), \mu) \;+\; \int_{\mu}^{\beta_2} -U_3(Q_c, q(s), s)ds + T_2\, dF_1(\mu)$$

$$- \int_{\alpha_2}^{\beta_2} U(Q_c, q(\mu), \mu) - \underline{U}(Q_c, \underline{q}) + \int_{\mu}^{\beta_2} -U_3(Q_c, q(s), s)ds + T_2 dF_2(\mu) \quad [= K_2]$$

$$U_1(1)-U_1(1) = \int_{\alpha_1}^{\beta_1} U(Q_c, q(\mu), \mu) - \underline{U}(Q_c, \underline{q}) + \int_{\mu}^{\beta_2} -U_3(Q_c, q(s), s)ds + T_2\, dF_1(\mu)$$

$$- \int_{\alpha_2}^{\beta_2} U(Q_c, q(\mu), \mu) - \underline{U}(Q_c, \underline{q}) + \int_{\mu}^{\beta_2} -U_3(Q_c, q(s), s)ds + T_2\, dF_2(\mu)$$

$\partial(U+t(\mu) - \underline{U})/ \partial\mu > 0$ and $\partial^2(U+t(\mu) - \underline{U})/ \partial\mu^2 < 0$ so the function over which the integral is taken is concave. Therefore, because the first term is an integral over a smaller range with the same mean, it is larger than the second term and the whole expression is positive.

APPENDIX 4

$$U_2(2) = \int_{\alpha_2}^{\beta_2} \underline{U}(\underline{Q}_c, \underline{q}) \, dF_2(\mu)$$

$$U_2(1) - U_2(2) = \int_{\alpha_1}^{\beta_1} U(Q_c, q(\mu), \mu) - \int_{\mu}^{\beta_1} U_3(Q_c, q(s), s)ds + T_1 - \underline{U}(\underline{Q}_c, \underline{q})dF_2(\mu)$$

$$+ \int_{\alpha_2}^{\alpha_1} U(Q_c, q(\mu), \mu) - \int_{\alpha_1}^{\beta_1} U_3(Q_c, q(s), s)ds + T_1 - \underline{U}(\underline{Q}_c, \underline{q})dF_2(\mu)$$

$$+ \int_{\beta_1}^{\beta_2} U(Q_c, q(\beta_1), \mu) + T_1 - \underline{U}(\underline{Q}_c, \underline{q}(\mu), \mu) \, dF_2(\mu)$$

$$- \int_{\alpha_1}^{\beta_1} U(Q_c,q(\mu),\mu) - \int_{\mu}^{\beta_1} U_3(Q_c,q(s),s)ds + T_1 - \underline{U}(\underline{Q}_c,\underline{q}(\mu), \mu) \, dF_1(\mu)$$

$$< \quad 0$$

The integral from α_2 to α_1 is an integral over a function with a negative slope with a first derivative ($- q(\alpha_1)$) equal to that of K_1 at $\alpha_1 = \alpha_2$ but a second derivative which is more negative.

$$U_{33}(Q_c, q(\mu), \mu) - U_{33}(Q_c, q(\alpha_1), \mu) = 0 + 1/(B+b+c)$$

Similarly, the integral from β_1 to β_2 is an integral over a function with a negative slope with a first derivative ($- q(\beta_1)$) equal to that of K_1 at $\beta_1 = \beta_2$ but a second derivative which is more negative.

$$U_{33}(Q_c, q(\mu), \mu) - U_{33}(Q_c, q(\beta_1), \mu) = 0 + 1/(B+b+c)$$

Thus the integral over $F_2(\mu)$ is a concave extension of the integral over $F_1(\mu)$ for low variance actors. Through K_1 they are being forced to pay for the higher utility of the low variance actors yet their payoffs have a greater variance over an identical concave payoff function. Hence the high variance will receive less from the low variance contract than from their own and will prefer their own contract. This is true for all values of σ_1 and σ_2 and hence all levels of variance.

APPENDIX 5

$$U_2(2) - U_2(1) - M =$$

$$- \int_{\alpha_1}^{\beta_1} U(Q_c, q(\mu), \mu) - \int_{\mu}^{\beta_1} U_3(Q_c, q(s), s)ds + T_1 - \underline{U}(\underline{Q}_c, \underline{q})dF_2(\mu)$$

$\alpha_1 \qquad \beta_1$

$$- \int_{\alpha_2} U(Q_c, q(\alpha_1), \mu) \; - \int_{\alpha_1} U_3(Q_c, q(s), s)ds + T_1 \; -\underline{U}(\underline{Q}_c, \underline{q})dF_2(\mu)$$

$$- \int_{\beta_1}^{\beta_2} U(Q_c, q(\beta_1), \mu) + T_1 \; -\underline{U}(\underline{Q}_c, \underline{q}(\mu), \mu)\, dF_2(\mu)$$

$$+ \int_{\alpha_1}\int_{\mu}^{\beta_1} U(Q_c,q(\mu),\mu) \; - \int_{\mu}^{\beta_1} U_3(Q_c, q(s), s)ds + T_1 - \underline{U}(\underline{Q}_c, \underline{q}(\mu), \mu)dF_1(\mu)$$

$$- \left[\int_{\alpha_1}^{\beta_1} U(Q_c, q(\mu), \mu) - \underline{U}(\underline{Q}_c, \underline{q}) + \int_{\mu}^{\beta_2} U_3(Q_c, q(s), s)ds\, dF_1(\mu)\right.$$

$$\left. - \int_{\alpha_2}^{\beta_2} U(Q_c, q(\mu), \mu) - \underline{U}(\underline{Q}_c, \underline{q}) + \int_{\mu}^{\beta_2} -U_3(Q_c, q(s), s)ds\, dF_2(\mu)\right] \quad [M]$$

$$= - \int_{\alpha_1}^{\beta_1}\int_{\beta_1}^{\beta_2} -U_3(Q_c, q(s), s)ds\, dF_1(\mu)$$

$$+ \int_{\alpha_2}^{\alpha_1} U(Q_c, q(\mu), \mu) - U(Q_c, q(\alpha_1), \mu) + \int_{\mu}^{\alpha_1} -U_3(Q_c, q(s), s)ds\, dF_2(\mu)$$

$$+ \int_{\beta_1}^{\beta_2} U(Q_c, q(\mu), \mu) - U(Q_c, q(\beta_1), \mu) + \int_{\mu}^{\beta_2} -U_3(Q_c, q(s), s)ds\, dF_2(\mu)$$

$$+ \int_{\alpha_2}^{\beta_1} \int_{\beta_1}^{\beta_2} -U_3(Q_c, q(s), s)ds\, dF_2(\mu)$$

$$= \int_{\beta_1}^{\beta_2} U(Q_c, q(\mu), \mu) + \int_{\mu}^{\beta_2} -U_3(Q_c, q(s), s)ds$$

$$- \quad U(Q_c, q(\beta_1), \mu) - \int_{\beta_1}^{\beta_2} -U_3(Q_c, q(s), s)ds\, dF_2(\mu)$$

$$+ \int_{\alpha_2}^{\alpha_1} U(Q_c, q(\mu), \mu) - U(Q_c, q(\alpha_1), \mu) + \int_{\mu}^{\alpha_1} -U_3(Q_c, q(s), s)ds\, dF_2(\mu)$$

$$> 0$$

If $\beta_1 = \beta_2$ then the first two lines are zero. The change in the term inside the first integral as β_2 increases from β_1 and hence μ increases is:

$$- q(\mu) + q(\beta_1) > 0$$

Clearly as the limits of the integral increase the change is also positive because the value of the term in the integral increases from 0. The final line is positive because the last term in the integral is the marginal transfer which is globally sufficient to separate the different types ex post whereas the second term is the utility from pretending to be a $\mu = \alpha_1$ type.