Cost-effective Approaches to Attracting Low-Income Countries to International Emissions Trading: Theory and Experiments*

by
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Abstract

The cost-effectiveness of the Kyoto Protocol and any similar non-global treaty would be enhanced by attracting as many new countries as possible to international emissions trading and achieving these additions as soon as possible. This paper focuses on two forms of compensation that can be used to attract poor, risk-averse countries to participate in emissions trading. The theoretical as well as experimental evidence presented here suggests that, if poor countries are more risk averse than rich countries, partial compensation in terms of financial transfers is more cost-effective than relying solely on Assigned Amounts as has been the case so far. In fact, the theoretical argument for cost-effectiveness indicates that large parts of the Assigned Amounts to new participating countries should be replaced by financial transfers. Using money for partial compensation would also reduce the risk for 'hot air' allocations and the ensuing political obstacles to cost-effectiveness that such allocations tend to create.

Keywords: Climate change policy; international emissions trading; cost effectiveness; 'hot air'; experiments

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Introduction

Cost-effectiveness is a crucial as well as a likely requirement for agreements on international climate change policy, especially those aimed at substantial reductions in greenhouse gas (GHG) emissions. This is also borne out in the wording of the Framework Convention of Climate Change and, in particular, the Kyoto Protocol (KP); see UNFCCC (1992) and UN (1997). Regardless of whether the KP will take effect as it stands or be renegotiated, international emissions trading (IET) is likely to be a dominant instrument for cost-effective reductions in aggregate emissions. The pioneering set of trader countries may be small, at most 38 in the present version of the KP, which comprises mainly rich OECD countries and economies in transition, the so-called Annex B countries.[1] Even though this set might cover several of the major emitters and therefore a significant share of the global level of emissions, low-cost abatement options in developing countries would not be available to help minimize the costs of global emissions reductions, except to the extent made possible by the Clean Development Mechanism (CDM) of the KP. The cost-saving capacity of this mechanism may not be large, however. Monitoring problems and the resulting high transaction costs would effectively exclude 'small emission abatement projects' (concerning car use, heating, etc.) that may well dominate the set of cost-effective abatement options.[2]

Therefore, expanding IET by increasing the number of countries committed to stringent emission quotas would, under fairly general conditions, improve the cost-effectiveness of the climate policy, provided that the new countries' Assigned Amounts (AAs) of GHG emissions are not too large.[3] Both this group of countries and the group of pre-existing trader countries

[1] The countries that are allocated Assigned Amounts of GHG emissions and can participate in IET according to the KP are listed in its Annex B.

[2] The CDM allows a committed Annex B country to invest in abatement projects in non-Annex B countries and be credited with (part of) the estimated emission reductions of such projects. A major concern here is that the baseline, needed for estimating a CDM project's contribution to emission reductions, is unobservable. This becomes particularly troublesome since both the host and the investor countries – the two parties likely to have the best information concerning the project and its interdependence with other relevant projects – have incentives to exaggerate the estimates of the emission reductions achieved. It is sometimes argued that these problems can be limited by the use of various kinds of benchmarks. Even if these hopes prove right, the transaction costs are likely to be non-trivial. Since neither monitoring problems (for carbon emissions) nor transaction cost of the same order of magnitude exist for IET and since IET comprises all abatement measures, not only those of large projects, having non-Annex B countries committed to AAs and hence, having IET replacing CDM, would enhance the cost-effectiveness of the climate change policy.

[3] Adding more participants would not only make their low-cost abatement options available for emission reductions, it would also tend to reduce the scope for 'carbon (or GHG) leakage', *i.e.*, reduce migration of GHG emitting production to countries not committed to emission constraints. Furthermore, adding more participants in IET is likely to affect ordinary trade and hence, the countries' terms of trade. In what follows, we will abstract from effects on GHG leakage and terms of trade.

stand to gain from the increased cost-effectiveness of including additional countries in IET.[4] It is important to note that if the set of participating countries is not expanded at the earliest possible occasion, part of the gains in cost-effectiveness is lost forever. The reason is, of course, that those low-cost emission reductions already feasible during a first conceivable commitment period then cannot be used during that period.

Another potential cost-effectiveness reason why non-Annex B countries should join IET as early as possible concerns the fear that, in the context of the present KP, dominant agents such as the US as a buyer or Russia as a seller could try to distort trade to their advantage. For example, Russia might use its market power to withhold supply, thereby increasing the prices of assigned amount units (AAUs). If so, increasing the number of (large) traders would also tend to reduce such risks. Furthermore, additional traders and larger transaction volumes might make it more likely that an efficient AAU exchange would be introduced to replace a system of bilateral trading where transaction costs are higher and market transparency lower (Bohm, 1999).[5]

In the present version of the KP, the AAs of the individual signatories are such that the (*ex post* IET) net costs of the aggregate emission reductions will be borne by the rich countries. The AAs of the poorer signatories – so far only countries in transition to market economies – are large enough to almost ensure that these countries are at least fully compensated by AAU sales. However, for the poorer members of this pioneering set of trader countries, the uncertainty of net gains from this novel kind of trading may be particularly worrisome. This may be a reason why the compensations required for their participation were set at a high level. It is a common belief that, in the present version of the KP, economies in transition such as Russia and Ukraine have been allotted surplus units or so-called hot air, *i.e.*, AAs that exceed, perhaps by far, their prospective business-as-usual (BAU) emissions level. If so, emissions trading might well more than compensate them.[6]

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[4] For an illustration of a case where the pre-existing 'signatories' of an emission-reducing IET treaty were taken to comprise only countries in Western Europe and where an increased cost-effectiveness of such a treaty were attained by the participation of fully compensated countries in Eastern Europe and the Former Soviet Union, see Bohm and Larsen, 1994.

[5] It should be noted that if AAUs are traded on an exchange (a double auction), buyer or seller withholding is unlikely to be used in final trading and if so, market power would not lead to market inefficiency (Carlén, 1999). This, however, may not address the conventional wisdom or the concern as perceived by potential trader countries that the market power problem can be kept at bay only by increasing the number of traders.

[6] Article 17 of the KP allows for an introduction of binding constraints on IET, the effect of which would be to reduce the cost-effectiveness of the agreement. The EU and some non-Annex B countries wish to specify the contents of Article 17 of the Protocol so as to remove the expected 'over-compensations' by imposing constraints on the sales by economies in transition and on the purchases by other countries. This is so in spite of the fact that such 'hot air' allocations were accepted by all Parties to the Protocol and may have been the best deal the Parties could have reached in Kyoto, *i.e.*, that the Parties concerned would not have accepted any lower, no 'hot-air' AAs (Bohm, 1999, Baumert *et al.*, 1999, p.7).

The gain in cost-effectiveness from adding countries to the treaty could be used either to achieve the aggregated emission reduction of the KP at a lower cost or to increase the overall emission reduction, given the aggregate compliance cost of the original KP, or some combination thereof. However, new participants can be expected to be unwilling to accept an agreement that is certain to let pre-existing (rich) signatories get away with a reduction in their commitment costs. Moreover, given that the emission reductions of the KP are generally taken as only a first step, there is little risk of overshooting the relevant climate policy target. Hence, a perhaps more likely target for a cost-effective policy agreement would be one that maximizes aggregate emission reductions given that (a) total costs, all borne by the pre-existing signatories, were kept at the level implied by the KP, and (b) the additional countries are allotted AAs that keep them fully, but barely, compensated.

Compensation to new participants in IET is typically taken to be made in terms of sufficiently large AAs, as was the case for the economies in transition in the KP. In this paper, we ask whether this is indeed the most cost-effective method. More specifically, we address the question of whether this is true for poor, risk-averse, potential new participants in IET.

The paper is divided into two parts; the first concerned with theory and the second with an experiment to test the propositions derived from theory. The reason for complementing the theoretical analysis with an experimental evaluation is twofold. First, results from Experimental Economics have indicated that experimental data do not always support even well-established theoretical predictions. This is particularly true for theories of decision making under uncertainty based on the expected utility hypothesis, possibly relevant in the present context. Second, with respect to issues related to the choice of policy design (as here), policy makers may not be very impressed by results from theory alone. Then, in the absence of empirical data (as here), experimental data that lend support to theoretical results – to the extent they turn out to do so – would make the case clearer.

The paper is organized as follows. Section 1 provides an analytical point of departure by showing how a maximum of participants would produce a cost-effective win/win option in a case of perfect information. In Section 2, we identify compensation options for attracting poor countries as participants in IET under uncertainty (2.1) and compare compensation for risk taking in terms of extra AAs with compensation in terms of financial transfers (2.2-3). This comparison was subjected to an experimental test reported in Section 3. Some discussion and qualifications are offered in Section 4 and our main conclusions are summarized in Section 5.

1. The certainty case

To begin with, we assume that there are no binding political barriers or lack of information which, alone, would prevent a country from engaging in negotiations that might lead to an expanded IET treaty at the earliest possible date. Traders can be either governments and/or firms (legal entities), to whom IET has been devolved by governments that have allocated, in one way or another, their AAs as permits to firms. Furthermore, we assume that all IET is carried out on a perfectly competitive market. Moreover, to simplify the discussion we assume insignificant income effects and zero transaction costs. Given this, changes in net profits as a result of the opening up of IET would not alter the countries' demand for commodities whose production would generate carbon/GHG emissions and hence, leave their marginal-abatement-cost (MAC) functions unchanged. This means that, for a given sum of AAs, the efficient abatement distribution between countries (the point where their MACs are equal) remains the same regardless of how the sum of AAs initially was allocated among the countries (*cf.* Montgomery, 1972).

In this section, we show how a fully cost-effective and Pareto superior version of a non-global IET treaty could be designed under certainty, when an additional country or group of countries, called 'country' AC, joins a set of industrial countries already committed to AAs and IET, called 'country' IC. In the case of perfect foresight, where all marginal abatement costs are assumed to be commonly known, the minimum AA required by AC for participating in IET is such that the value of profit maximizing sales of AAUs equals AC's abatement costs (*plus* some minimum incentive amount, of course, henceforth not explicitly paid attention to).[7] This situation is illustrated in Figure 1, where

i) IC (AC) emissions are counted from the left (right) axis to the right (left) and the width of the open box represents the aggregate AAs of the two Parties
ii) Q_i is country i's emissions under BAU, *i.e.*, the country's emissions level in the absence of a climate treaty (i = AC, IC)
iii) MAC_i shows country i's marginal abatement costs, and
iv) Q'_{IC} is the emissions level to which IC is initially committed and at which its MAC equals p_1^e (= the equilibrium price for emissions trading solely among the set of countries constituting IC).

Abatement by AC would set out from AC's BAU emissions level, Q_{AC} in Figure 1, and move to the right at costs shown by MAC_{AC}. Had AC received an AA equal to Q_{AC}, its efficient emission reductions up to some AAU price and hence, its export revenue, would have exceeded its abatement costs. To keep AC barely compensated, AC need not have an AA larger than Q'_{AC}, defined so as to have its abatement export revenues (IC's import

[7] If future AA allocations were expected to be positively related to the size of first-period AAs, an additional reason would emerge for countries to push for first-period AAs being as high as possible. In the following discussion we abstract from this aspect and presume that minimum compensations demanded are based solely on the estimated consequences of IET for the period in question.

expenditures), $p_2^h(Q'_{AC} - Q_2^h)$, equal to the costs of reducing its emissions from Q_{AC} to Q_2^h. In this situation, shown in the Figure, the resulting trade gains would be shared by the two countries as indicated by G_{IC} and G_{AC}.

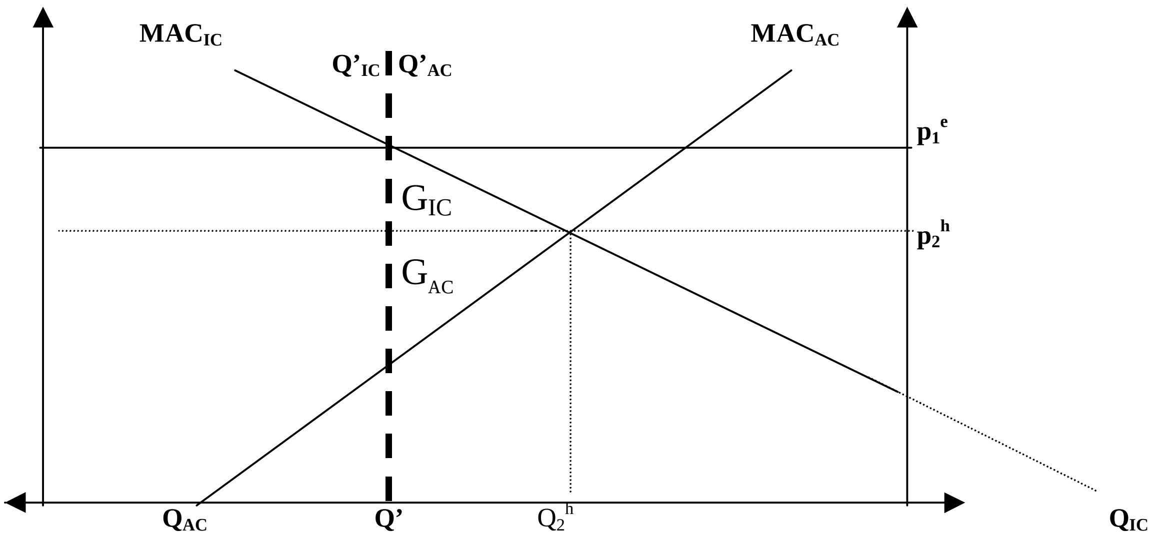

Figure 1[8]

What is shown in Figure 1 can be seen as a hypothetical first step towards an AA allocation, where the aggregate emissions level is minimized, given that IC's costs (*ex post* IET) equal those of the pre-existing climate treaty and AC is held fully compensated. Then, in a hypothetical second step, the formerly agreed Q'_{IC} must be reduced to a quantity that eliminates IC's profits in terms of GDP, thus reducing the width of the open box and shifting the MAC_{AC} curve to the left. This has to take into account that the AAU price now goes up, which makes AC's profits increase at Q'_{AC}. Then, in a third step, to keep AC barely compensated, its AA has to be reduced, which further increases the AAU price, and in turn calls for an increase in IC's AA, etc. up to the AA allocation, where IC and AC are barely compensated at an equilibrium price equal to p_2^e (see Figure 2). At this allocation, (i) AC's zero-gain AA equals Q_{AC}'' ($< Q_{AC}'$ since $p_2^e > p_2^h$) and (ii) IC's gain from the reduced equilibrium AAU price (from p_1^e to p_2^e) is neutralized by IC accepting an AA equal to Q_{IC}''

[8] Although, in the absence of a climate treaty, some countries may want to reduce emissions on their own – especially relevant, perhaps, for large countries – this is not explicitly observed in Figures 1 and 2.

(which contributes to the leftward shift of MAC_{AC} by a’ in this Figure), see the two shaded areas. See Appendix A 1.1 for a formal derivation of these results. [9]

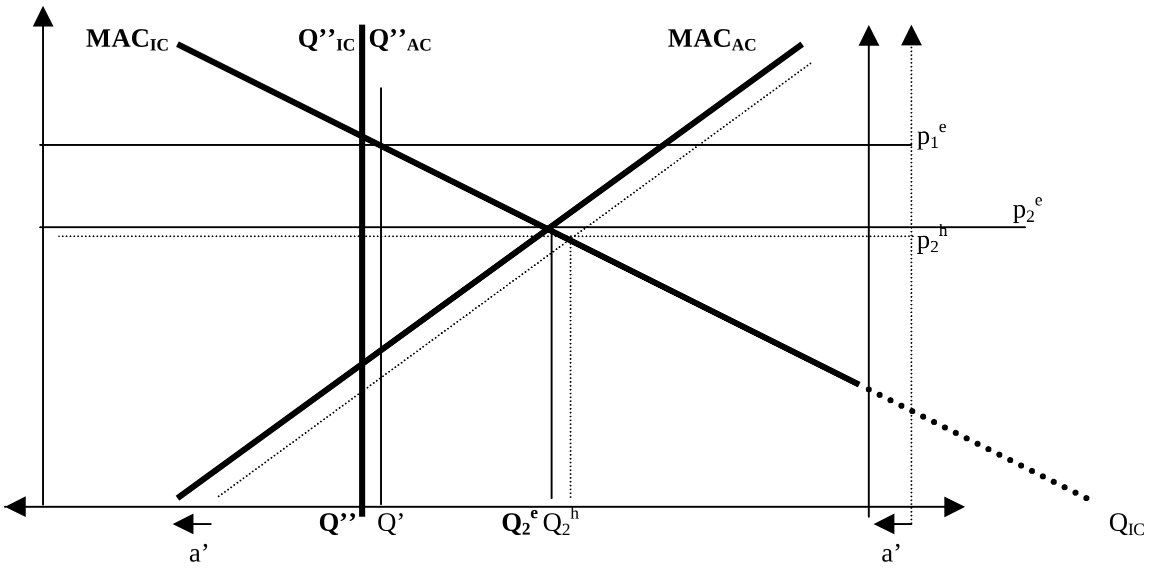

Figure 2

2. Compensation for uncertain trade gains: theory

2.1 Compensation options

Introducing uncertainty concerning MACs and hence, concerning AAU prices, exposes the Parties in an IET agreement to risk taking. A basic assumption here is that AC is risk averse

[9] By presuming common knowledge about the Parties’ MACs, this case may not be too far from a conceivable real-world case. Few countries can be expected to accept joining IET without doing their best to estimate their own MACs as well as the expected market price for emissions trading. To compute this price for a first commitment period, a country would essentially have to try to estimate the other countries’ MACs and hence the aggregate net excess supply or demand confronting it. Each additional country would also need to evaluate the implications of proposed AA allocations between itself and other countries. This establishes a clear motive for all potentially additional countries to estimate the other countries’ MACs. As a result of national efforts as well as those of international organizations, estimated MACs of most of the countries involved can thus be assumed to be common knowledge among all countries considering whether to participate in an enlarged IET treaty for an upcoming commitment period.

and significantly more so than IC. To simplify, we assume that IC is risk neutral and AC risk averse. [10]

The discussion in this section and in Section 3 addresses the issue of a cost-effective design of compensating AC for its risk aversion and specifically whether the traditionally assumed form of compensation, *i.e.,* in terms of AAs only, is indeed a cost-effective option also in the case of risk or uncertainty (the two terms used interchangeably in what follows). The AAU price uncertainty confronting AC would be reduced if IC offered AC a price stabilization scheme, *e.g.,* an AAU price floor. This is akin to measures that have occasionally been used to reduce income risks due to price fluctuations on primary commodities (see Newbery and Stiglitz, 1981). An even more ambitious option would be to eliminate price uncertainty altogether for AC by establishing a long-term contract according to which IC buys whatever is offered by AC at an agreed price. (A different design of such contracts is discussed in Section 4.1.)

Another approach to compensating for uncertainty is suggested in Philibert (1999), where an IET treaty is designed so as to reduce the effect of uncertainty for developing countries to a worst case outcome of zero gains. This design amounts to giving developing countries the option of either (i) engaging in IET, if they expect to gain from AAU sales, then being committed to the AAs they have conditionally accepted, or (ii) simply abstaining from participating in IET and then no longer being committed to their AAs. A version of this approach is discussed below.[11]

Here, we focus on financial transfers as a form of compensation for risk aversion that can be fairly easily compared to the 'traditional' one. To begin with, the latter option will be described as giving AC an additional amount X of AAUs on top of a basic AA allocations sufficient for a risk-neutral country, *i.e.,* an AA that would make its expected net gains of joining the treaty equal to zero. The former option amounts to replacing X by a financial transfer (M).[12] We assume that AC obtains trade revenues as well as any financial transfer at

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[10] The fact that poor people may be taken to be more risk averse than rich people does not necessarily carry over to governments of poor and rich countries. For example, if governments are dictatorial or under some kind of extreme pressure, their behavior may be characterized by strong preferences for risk taking. Still, the discussion here will be based on the assumption that governments of poor countries are typically and significantly more risk averse than those of rich countries.

[11] Still another way of reducing the uncertainty that confronts AC would be to set the assignment for a growing AC in terms of a maximum carbon (or GHG) intensity for the country's GDP (or even individual sector activity levels) instead of a fixed AA, see Baumert *et al*., 1999. In this way the AA would be endogenized to reflect the uncertainty of the future GDP (or sector activity levels). However, AC would still face uncertainty regarding its own MAC and the AAU price.

[12] This is an option that does not seem to have been discussed in the literature on IET. By contrast, financial transfers have been the obvious and only instrument considered for compensating poor countries when international carbon taxes or harmonized domestic carbon taxes are discussed.

the same point in time, say, at the end of the commitment period, *i.e.,* when AC is found to be in compliance with its AA and seller commitments.[13]

Increasing the distance between the date at which an IET agreement is ratified and that at which the agreement enters into operation raises the participating countries' ability to form real capital in accordance with expected future trading prices. However, there are benefits also from allowing Parties to ratify or leave such agreements at a stage near the start of the commitment period when more is known about the implications of a particular commitment. Improved information of this kind may be particularly valuable for a poor country and may call for a treaty design where AC is allowed to confirm an *early, preliminary* agreement at a late date. Therefore, we will compare the X and M options also for a treaty design of this type.

Observing an alternative to compensating AC by increasing its AA has an additional interest in that it could provide a significant potential benefit in terms of reducing the risk for the appearance of a 'hot air' allocation. As noted above, the possibility of allocations containing 'hot air' has spurred some Parties to demand reductions of trade in 'hot air' by introducing constraints on emissions trading (see footnote 6). Such constraints, if binding, would reduce the efficiency of IET. Hence, if compensation for risk aversion were carried out in M instead of X, the risk for 'hot air' allocations and the introduction of such constraints would be smaller.

2.2 Comparing compensation options

Introducing uncertainty and AC risk aversion, the targeted outcome of minimum aggregate reservation emissions (as illustrated in Figs. 1 and 2) is transformed into one of a minimum compensation (in X or M) to AC and a minimum AA for M = 0, or minimum expected AA value minus M > 0, for IC so that both Parties once again are indifferent (to their GDPs *status quo ante*). A financial transfer M would have to come explicitly from IC. Given an AC reservation M' > 0, IC would not accept an AA as small as that when M = 0. Other things equal, its AA would then have to be increased by an amount X', the expected value of which equals M'. Since AC is risk averse, simple theory suggests that AC would prefer the certain amount M' to the uncertain X'. If so, a larger aggregate emission reduction can be attained under M' than under X'.

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[13] This is a design of seller liability that has been discussed in the literature. It requires, if need be, that AC finances costly abatement measures by loans, *e.g.*, from organizations like the World Bank, possibly using AAU exports made or agreed financial transfers as collateral. It also requires, of course, that IC cannot decide unilaterally whether to pay or not. For example, IC would have to credit an account, kept in escrow until AC is found in compliance, (a) for its AAU imports when trade occurs and (b) the agreed (discounted) M before the start of the commitment period.

A number of uncertain factors, such as future economic activities, technologies and exogenous factors influencing fossil fuel prices, are likely to affect the slope and location of the MAC curves of the countries participating in IET and hence, contribute to making their net gains from participating uncertain. The reasons for the uncertainty is not important here, but, to fix ideas, we view uncertainty as if it were determined by an uncertain exogenously determined oil price which affects only the location, but not the slope, of the MAC curves. In effect, we assume that the uncertainty involved is expressed as a commonly known (normal) probability distribution of the resulting equilibrium AAU price when AC participates in IET. The AA allocation that would make AC's and IC's expected net gains equal to zero is shown in Appendix A 1.2. This basic allocation would be the solution to the problem of minimizing aggregate emissions while keeping both countries barely compensated, given that they were both risk neutral. Introducing risk aversion for AC, AC would need an AA increased by X or a financial transfer, M, to be fully compensated. This would influence AAU prices and reservation asks, eventually revealing an outcome, where both AC and IC are barely fully compensated in the sense defined above. This is illustrated in Appendix A1.3 for a numerical example, which is also the test bed to be used in the experiment.

The objective of the test to be reported is to see whether or not the proposition that a risk-averse AC prefers M to X, given their cost to IC, is supported by the behavior of subjects placed in a position similar to that of AC. The test also includes the above-mentioned treaty design where an agreement on X or M would be preliminary only and would allow AC to reject – at some small but non-trivial penalty as compensation to IC – or finally accept the agreement at a later point in time close to the beginning of the commitment period. Given the character of this treaty design, the minimum AC asks (maximum IC offers) are likely to be at most as high as in the case of the X and M commitments that were mutually binding right from the start; this is so at least if the latter case were equally uncertain. The hypothesis about IC's ranking of its costs for the minimum X and M compensations to AC remains as before.

3. An experiment

3.1 Experimental design

The experimental objective

The experiment is aimed at testing the hypothesis that a financial transfer is more cost-effective than a transfer of AAUs in compensating a risk-averse AC for the uncertainty associated with participating in climate treaties of the kind discussed above. Although the real-world level of such compensations would be determined in negotiations between AC and IC, the experiment does not intend to mimic any form of negotiations between the Parties.

The principal reason is that the generality of the results of such negotiation experiments can be expected to be low. Instead, the route taken here is to create an experimental situation for investigating AC's minimum demands; such demands that are needed in order to ascertain the feasibility as well as the cost-effectiveness of alternative forms of agreements can hardly be observed outside the laboratory. Here, minimum compensation demands are elicited for each type of compensation by giving subjects representing AC incentives to reveal their true minimum compensation levels. As explained below, such incentives were established by letting subjects state their asks for compensation under the so-called Becker-deGroot-Marschak (BDM) mechanism, known to provide incentives for truthful revelation.

As mentioned in the Introduction, experimental testing of theoretical propositions concerning the design of new policies may be needed, in particular when policy makers can be expected to remain unconvinced by theoretical arguments alone. Moreover, for such purposes, a case can be made for using an experimental design that would perform well pedagogically for policy makers. The methodological ambition of the experiment conducted here is to identify and use a context-explicit design for studying the new policy field of IET.[14] The experiment was designed so that (in particular, lay readers of the results could believe that) the subjects were exposed to a real-world-like context and to incentives similar to those that would exist in the real world. The premise is that the noise produced by a 'non-context' that has little meaning for the intended real-world application may confuse the subjects' notion of the purpose of the study and hence distort their responses or that critical readers may believe that to be the case.[15]

The experiment consists of two pairs of tests. In the first (M-X), asks are elicited for compensation in money (M) and, alternatively, in AAUs (X) for a case where it is assumed that there exist objective probabilities of different states of the world. In the second test (M^{prel}-X^{prel}), subjects ask for compensation in a situation where they only have access to estimates of the likelihood of different states of the world, but have the option to withdraw from the negotiated treaty at a later stage when better information would be available.

[14] In earlier tests, attempts have been made (a) to find appropriate experimental designs for evaluating the cost-effectiveness of government trading among a small set of similar countries, using real government-appointed traders and incentives other than money (Bohm, 1997a; Bohm and Carlén, 1999), and (b) to identify a subject type and appropriate incentives likely to deliver some insights into the pre-Kyoto attitudes of developed as well as developing countries with respect to joining an IET protocol (Bohm, 1997b).

[15] The common procedure in Experimental Economics is to use abstract or synthetic, *i.e.*, not context-related, experimental designs. This is also based on an ambition to avoid noise, although of another kind: subjects' attitudes towards context-specific ingredients (such as global warming, government intervention, etc.) could risk making subjects respond in accordance with idiosyncratic valuations irrelevant for the purpose of the study. Our choice of design reflects the judgment that this particular risk, and its possible tendency to bias the responses, is considered to be less troublesome in this case. For a further discussion of context-specific experiments, see *e.g.*, Loewenstein, 1999.

The test bed used here is based on the allocation of AAs proposed in the Kyoto Protocol for the Annex B countries and on available estimates of these countries' BAU emissions levels and marginal abatement costs, see Appendix A2. To fix ideas, it is assumed that all Annex B countries have ratified the Kyoto Protocol and that, some time prior to the first commitment period (2008-12), these countries would invite a large developing country AC (India) to a renegotiated climate treaty. In line with the theoretical discussion in the preceding section, the test bed is based on the assumptions that

i) the Annex B countries act as a single decision maker, IC (i.e., coalitional problems are disregarded),
ii) the market for AAUs is competitive,
iii) the basic AAs in the proposed climate treaty are such that AC's expected net costs equal zero and the IC's expected net costs equal those under the initial climate treaty (the Kyoto Protocol)[16].

As mentioned above, the uncertainty surrounding (future) marginal abatement costs and, hence, AAU prices are taken to stem from uncertain future oil prices only. In the experiment, the oil price could take any of three equally likely values. This means that for each compensation level AC's net gains could take any of three equally likely values. For details about the test bed, see Appendix A1.3.

Experimental context and subject tasks

To avoid having the subject confused about why this test was carried out and specifically why (s)he was placed in the context of reporting his/her minimum compensation levels for participating in, what amounts to, two types of lotteries, the subject was encouraged to regard him/herself as placed in the role of a consultant to the government of a developing country in the situation now explained. Thus, the subjects could either consider what compensation level they would suggest the developing country would ask for with respect to each of the four different compensation mechanisms or disregard this context and simply consider their own willingness to accept to participate in different types of risk taking. With an ambition to use subjects with an educational and intellectual background similar to that of persons who in their future professional life may well be consultants to the government of a developing country, subjects were recruited from a pool of people trained in Economics, at least as graduate students. Each subject was told that (s)he would receive a known fraction ($0.02 per

[16] This formulation is strictly correct only for the M-X case. In the case of M^{prel}-X^{prel}, when only estimates of the likelihood of different states of the world exist, the term "expected" should be read "expected estimated". Having said this, we will use the term "expected" for both cases.

million) of the gains made by the country he/she represented.[17] To prevent that the subjects' behavior would be influenced by knowledge about what country they represented (played against) they were only told that the test bed was based on estimates of the conditions for real, but unspecified, countries. (See the instructions in Appendix B.)

The distributions of the subject's gains for different compensation levels for the M and X tests are stated in Tables M and X, respectively (see Appendix B). In both Tables, the first columns show the compensation levels the subjects could choose among. The Tables are constructed so that for each compensation level (represented by a row in the Tables) the subject's expected total gains are equal for the two compensation forms, hence implying the same costs to IC. However, since the value of AAUs is uncertain in contrast to the value of money, the variance of the subjects' gains for each compensation level is larger under X than under M. In the M and X tests, the compensation level was limited from above by the level where the AC's gains would be non-negative in all states of the world, *i.e.*, the level at which the country and, hence, also the subject would be certain to gain. Since the spread of the net gains is larger under the X mechanism than under the M mechanism, the choice set covered 23 compensation levels in test M and 26 in test X.

In the M^{prel} and X^{prel} tests, where the subjects had the opportunity to withdraw from the treaty at a later point in time, Tables M and X , respectively, give the expected probability distributions at the date of the first decision concerning the minimum compensation for joining the treaty. Since IC would not value a preliminary contract as highly as an unconditional one, the subjects were told that the highest compensation levels they could ask for in the M^{prel} and X^{prel} tests were lower than in the M-X tests, but not by how much. In M^{prel} and X^{prel} tests the three highest compensation levels were omitted from each of the choice sets.

In each round subjects could lose as well as win significant amounts of money, from -\$32 to \$69 (\$65) in the M (M^{prel}) rounds and from -\$32 to \$77 (\$73) in the X (X^{prel}) rounds. Each subject participated in all four rounds. Since the subjects should not be allowed to leave the experiment with less than the show-up fee (\$10), the aggregate maximum loss a subject could make was limited in the following way. At the beginning of the experiment, the subjects were given an initial payment of \$20 each from which any aggregate net loss would be deducted. If losses exceed \$20, the overshooting amount would be remitted. Hence, a

[17] Thus, the incentive schedule induced in the experiment presupposes that the consultant's payoff would be positively related to AC's actual gains. Although a real-world contract between a government and a consultant may not explicitly state such incentives, the consultant's career opportunities (or his/her firm's future success) would likely be believed to be positively related to the (gradual materialization of the) outcome for the country.

subject's actual loss or gain foregone would depend on the outcome in all rounds.[18]

The BDM mechanism was used to provide subjects with incentives to state their true reservation asks. In each test, the procedure was as follows. First, each subject chose a compensation level in Table M (X). Then a buyout compensation level was drawn from a known distribution assigning equal probabilities to each of the compensation levels in Table M (X) (minus the three bottom rows in the M^{prel} and X^{prel} tests). Subjects with asks lower or equal to the buyout level drawn were qualified to sign the treaty and to (implicitly) engage in IET, with a compensation level equal to the buyout level drawn; thus, they were entitled to/bound by the outcomes in the three cells of *the buyout level drawn*. Subjects with asks exceeding the buyout level drawn, would not be qualified to participate and hence, would not make any gains or losses at all. By deviating from his/her true minimum compensation ask, the subject would run the risk of not being fully compensated or of not benefiting from some of the cases where they would be more than compensated.

In total, 32 subjects participated in the experiment: 29 graduate students and three Ph.D's in Economics. Subjects were randomly divided into two groups, A with 15 (there were two no-shows in this group) and B with 17 participants. The two groups participated in the experiment at a thirty-minute interval. Participation in the experiment took about 90 minutes.

Disregarding the availability of qualified subjects and the level of experimental costs, we would have preferred to use a sufficiently large representative sample of such subjects for each of the four options, instead of using the available 32 subjects to elicit reservation asks for all four options. This creates a risk that the stated asks would not be independent of one another. In particular, the order in which the mechanisms were presented to the subjects might play a role, although we have no theory why that would be the case. To detect any such effects, the two groups faced the mechanisms in each pair in different order, M-X and X^{prel}-M^{prel} for Group A and X-M and M^{prel}-X^{prel} for Group B. Since the "prel" versions were to such a large extent based on an understanding of the one-decision-level versions, the order in which the two pairs were tested was not reversed.

The procedural order

One day in advance of the experiment, the subjects were given extensive written instructions, which they were asked to read carefully (to save time the next day) and vital parts of which

[18] This means that the subjects participated in lotteries somewhat less uncertain and with somewhat higher expected values than as explicitly presented to them. Eliminating this effect would have been quite costly in that each subject would have to be given an initial payment of $32 per round. Given a limited experiment budget and the fact that (a) the subjects' expected net gains in each round were positive (for all compensation levels) and (b) as explained below, the subjects had to state their compensation asks for all four mechanisms before knowing their earnings in any of the tests, an initial payment of $20 was deemed high enough to create a situation where the subjects in each round also would take account of the worst outcome.

were repeated orally at the beginning of the experiment. This set of written instructions (see Appendix B) contained

i) an introduction to the climate change problem and the Kyoto Protocol as well as an explanation for why a climate treaty comprising more countries would be more cost-effective than one with fewer countries,
ii) a description of the decision problem facing a developing country that is invited to a climate treaty allowing international emissions trading, in particular the compensation issue,
iii) an explanation of the BDM mechanism to be used and the incentives it gives for truthful revelation of minimum compensation asks,
iv) presentation of the four compensation mechanisms and Tables M and X showing the distribution of the subjects' gains for various compensation levels for the M and X mechanisms, respectively (and the preliminary probability distributions for the M^{prel} and X^{prel} tests) and
v) a suggestion that the subjects should contemplate already in advance their reservation asks under the four mechanisms.

During the experiment the subjects received another set of written instructions for each test in which they were asked to state their minimum compensation requirements.[19]

An individual's attitude towards risk may be influenced by the outcome of a recent exposure to risk. Therefore, the subjects had to state their asks for all four tests before the buyout compensation levels and the states of the world were drawn for any of the four mechanisms. Moreover, before handing over their responses to the conductor of the experiment (not one of the authors), the subjects were given five minutes to check the internal consistency of their responses.

After the responses had been collected, the subjects received the updated information for the M^{prel} and X^{prel} tests (see Tables M^{prel} and X^{prel}). This information stated the real probabilities assumed for the three different states of the world. The implications of this new set of probabilities were such that, for each compensation level, the variance as well as the expectations of the subjects' net gains were significantly smaller than those of the original, estimated probability distribution. Given this new information, subjects were asked to decide whether they wanted to withdraw from any or both of the X^{prel}-M^{prel} options at a cost of $5 per withdrawal, in case it would turn out that they were qualified to sign the treaty and thereby to receive a compensation at least equal to their stated minimum level. This procedural order was motivated by the use of the BDM mechanism. Had the subjects known the actual buyout

[19] These instructions, which relate to each specific ask and include the response forms used, can be obtained from the authors upon request.

compensation level before deciding whether or not to withdraw, their decisions would not have been based upon their minimum compensation requirement, as is the relevant basis for the decisions under study here. Instead, the subjects' decisions would then be based on the buyout levels drawn, which for those qualified could be (possibly substantially) higher than their stated minimum compensation asks.

Finally, a buyout compensation level and a state of the world were randomly drawn for each of the four tests in a fashion that the subjects could witness. As it turned out, the outcomes (buyout level drawn, state of the world; net gain) in Group A were (2, Low;-$30) for M, (17, Medium; $22) for X, (15, Medium; $19) for X^{prel} and (1, Low; -$32) for M^{prel}. In group B, the outcomes were (14, Medium; $18) for X, (21, Low; -$3) for M, (14, Medium; $18) for M^{prel}, and (14, Low; -$15) for X^{prel}. Net of the show-up fee of $10, but including the initial payment of $20, the subjects' total gains came to range from 0 to $61. (Had other buyout levels and states of the world been drawn, the gains could have ranged from 0 to $304.)

3.2 Experimental Results

The M-X choice

The choices made by the subjects in Groups A and B are illustrated in Figures 3 and 4, respectively. As mentioned above, Tables M and X were constructed so that a subject's expected net gains under M and X were equal for a given compensation level, as given by the same row in the two tables. Henceforth, when a compensation level number is referred to, it is given by the million tons column in Table X, 1, 2, … etc.

In both groups, a majority stated asks which far exceeded the lowest level.[20] In Group A, 11 out of 14 and in Group B 15 out of 16 stated asks above the lowest level. Since the lowest level is what a risk-neutral subject would choose, we interpret this to mean that a significant fraction of the subjects, 25 out of 30, behaved as if they were risk averse. Moreover, in both groups, a high (low) first ask – M for Group A and X for Group B – was followed by a high (low) ask for X and M, respectively. However, the mean asks of Group B were clearly higher than those of Group A. This implies that the order in which the mechanisms were presented influenced the level of the asks, in spite of the fact that the subjects were given time to check the internal consistency of their responses before handing them in. Explanations as to why presenting X first led to higher mean asks elude us. But, the importance of testing for a 'starting-point bias' is noteworthy, even without a prior theory as to why the order of presentation order might affect the outcome.

[20] Subjects A15 and B17 behaved in a clearly inconsistent manner in that they revealed risk aversion in one decision pair but risk loving in another. They are therefore omitted from the analysis, with exception for the significance tests below which are reported both with and without these two outliers.

Figure 3. Group A: M and X asks

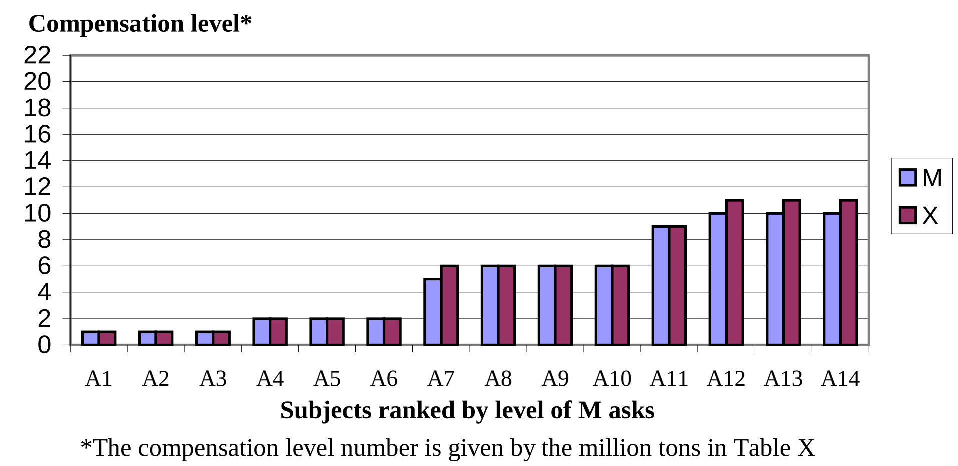
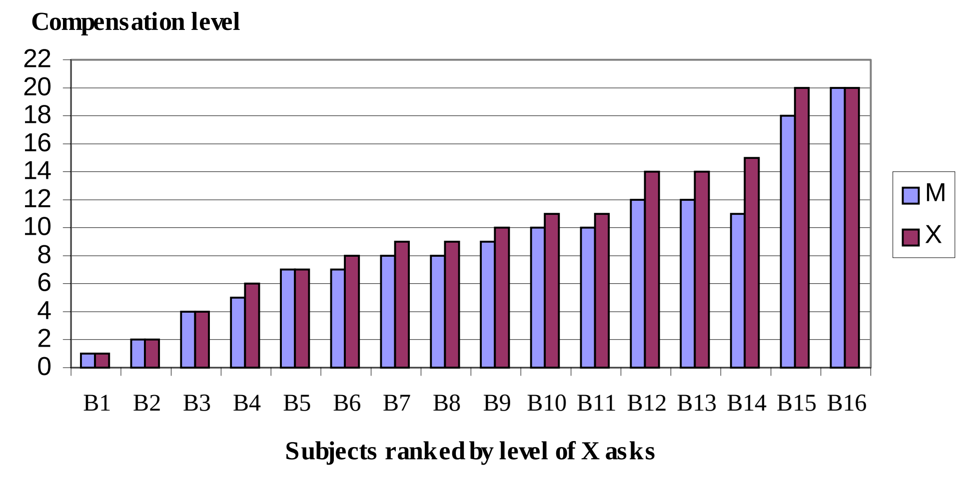


Figure 4. Group B: X and M asks

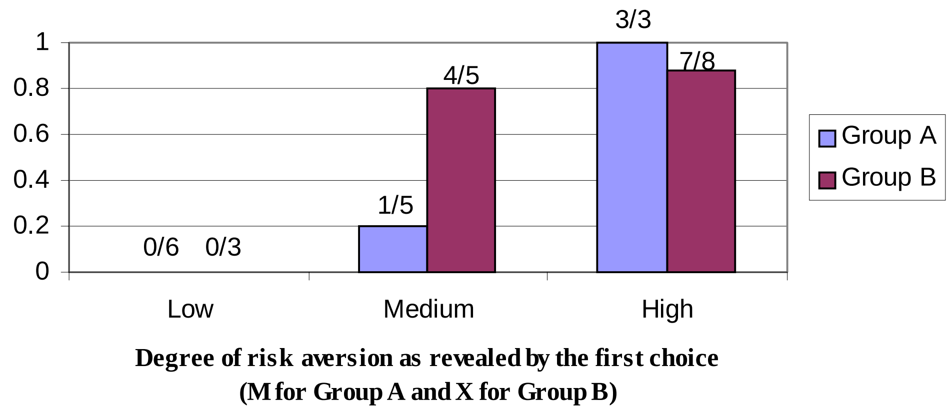


Given that, ideally, independent estimates of the four different asks should have been elicited from four representative subject groups, the observed effects of the order of presentation are an artefact of the experimental design used here. Since the need to elicit all four asks from all subjects was determined by subject availability, a check for possible order effects was required. Given that order effects, which have no meaning for the objective of the test, indeed were observed, the best estimate of the relative performance of the M and X mechanisms would seem to be obtained from the pooled data for the two groups. Despite this, we have chosen to report data both pooled and group-wise.

Although the difference in variance between the outcomes for M and X was modest, a total of 15 of the 30 subjects differentiated their asks for the two mechanisms. All did so in the direction expected for risk-averse decision makers, *i.e.*, with a lower ask under the M mechanism than under the X mechanism. The share of the subjects doing so was higher in Group B than in Group A, 11 out of 16 as compared to 4 out of 14.

To properly evaluate the frequency of differentiated asks, it should be noted that the subjects faced a discrete choice set (the rows in Tables M and X). This may have prevented some subjects with low or modest degrees of risk aversion from differentiating their asks.[21] Thus, it can only be expected that the relative frequency of differentiated asks is higher for subjects with high asks than for subjects with lower asks. Figure 5 shows the relative frequency of differentiated asks for different levels of risk aversion as revealed by the subjects' first choice, *i.e.*, the level of M for Group A and X for Group B. A subject's risk aversion is said to be Low (including zero) if the subject's first choice of compensation level was between levels 1-4, Medium if in the interval 5-9 and High if at least equal to level 10. Note that no subjects who revealed Low risk aversion in their first choice differentiated their asks between M and X, while 10 of the 11 subjects classified as having High risk aversion did so.

Figure 5. Relative frequency of differentiated asks for M and X



[21] Given a continuous choice set, a decision maker for whom the mean-variance approach with constant absolute risk aversion is applicable could find it worthwhile to state a lower ask under M than under X, no matter how small his/her risk aversion was. Since the decision maker here has to choose one of the compensation levels stated in Tables M and X, respectively, (s)he might not find it worthwhile to state differentiated asks. Assuming that the BDM mechanism was successful in eliciting the subjects reservation asks, it can be shown that Tables M and X indicate that this decision maker could find it worthwhile to differentiate his/her asks only if having a risk aversion high enough to call for a compensation level exceeding level 8.

The hypothesis of equal asks under the two mechanisms is rejected in favor of the hypothesis of lower compensation asks under M than under X. P-values are 6.2% for Group A and less than 1% for Group B and the pooled data.[22] Thus, if governments of developing countries are risk averse and would make decisions in the same way as risk-averse subjects did in this experiment, the conclusion is that a monetary transfer is more cost-effective than a transfer of additional AAUs in compensating developing countries for uncertain net gains from joining a climate treaty that allows IET. As mentioned above, the experimental design (especially its discrete choice set) may have induced subjects with low or modest degrees of risk aversion to avoid differentiating their compensation demands between the cases where compensation is given in money and additional AAUs, respectively. Thus, it is tempting to regard the outcome as providing stronger support for the theoretical prediction than the statistical analysis allows.

The M^{prel}-X^{prel} choice

In the first two decision rounds, subjects were asked to choose compensation levels with known probabilities of the different outcomes. In the M^{prel} and X^{prel} decision rounds subjects had to choose compensation levels, given only estimates of the likelihood of the different outcomes, but with an option to annul the contract at a given, fairly small, cost when, at a later point in time, new information would be available.

The asks stated for M^{prel} and X^{prel} are shown in Figures 6 and 7, where subjects are ranked by their first choice, M for Group A and X for Group B. An asterisk denotes that the subject chose to withdraw from the contract after having received the updated information. The picture roughly resembles that of the M and X rounds in that subjects who stated relatively low (high) compensation asks there tended to do so also in the M^{prel} and X^{prel} rounds, although in a much less pronounced fashion. It should be noted that, although the subjects knew less under the M^{prel} and X^{prel} cases, the mean ask is now lower than in the M and X cases. Thus, not surprisingly, it looks as if the option to annul the contract when new information becomes available reduces the compensation required by risk-averse decision makers for entering a climate treaty of the kind investigated.

[22] The Wilcoxon Signed Ranks test was used here. Including the outliers, we cannot reject the hypothesis of equal asks for Group A while the p-values for Group B and the pooled data still are lower than 1%.

Figure 6. Group A: Xprel and Mprel asks

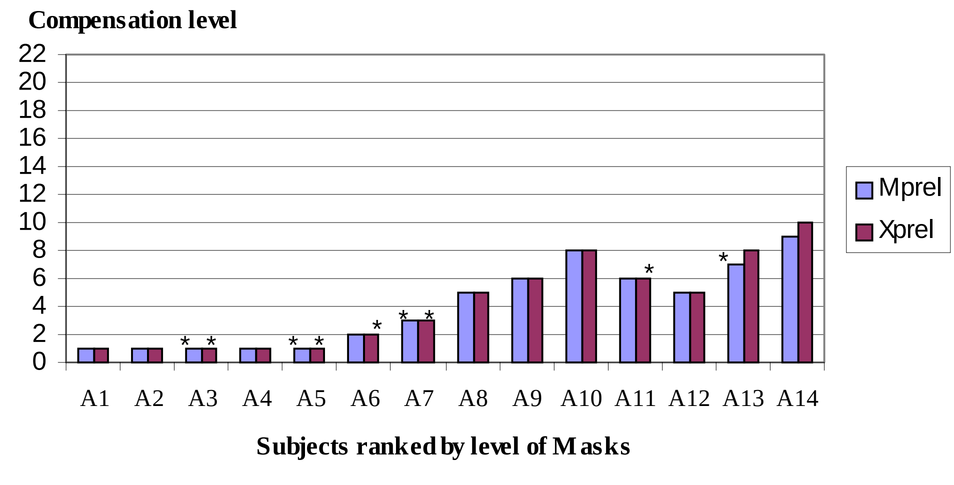


Figure 7. Group B: Mprel and Xprel asks

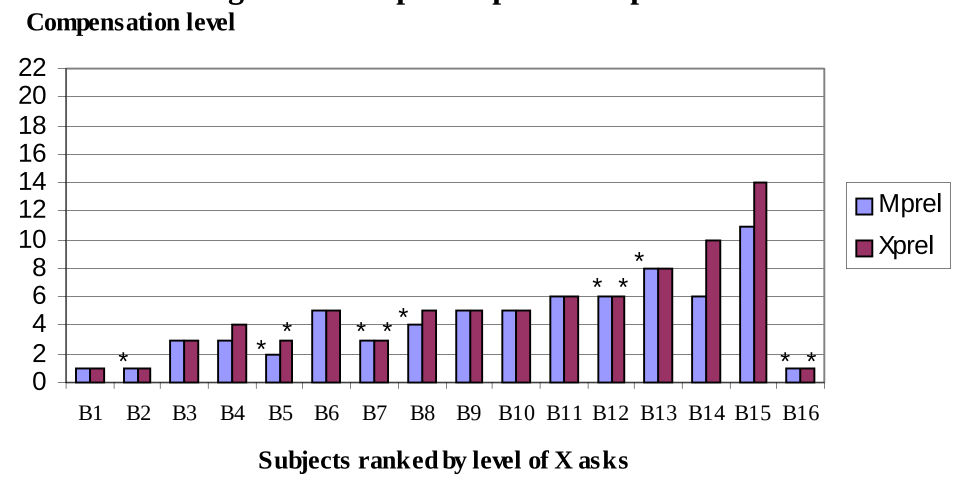
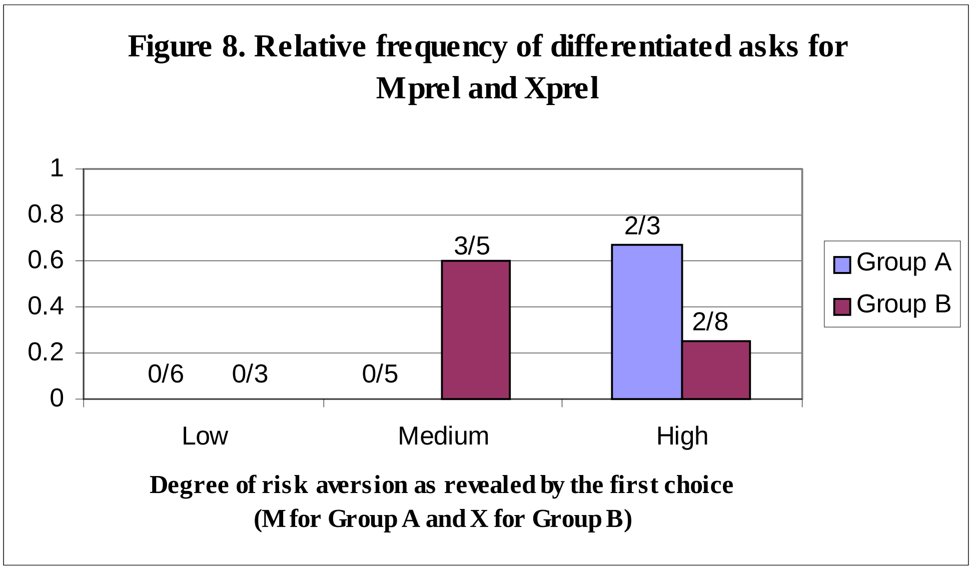


Figure 8 shows the relative frequency of differentiated asks classified by the subjects' first choice in the previous two decision rounds. The frequency of differentiated asks is low, only two in Group A and five in Group B. Taking into account the relatively modest annulment fee ($5 as compared to a maximum loss around $25 for subjects asking for compensation levels 1 - 10) and the fact that the subjects had no given probabilities to base any differentiation on, it is possible that some subjects did not find it worthwhile to contemplate differentiating their asks. The seven subjects who differentiated their asks did so in the direction predicted.



As can be seen from Figures 6 and 7, the withdrawal pattern is irregular and seemingly unrelated to the revealed degree of risk aversion. Recall that compensation levels preliminarily accepted at the first decision point were not renegotiable at the second point, where the expected outcome – as happened here – had deteriorated. Thus, subjects would have to consider what was in store for them next: the expected mean and variance of the gains distribution implied by the BDM mechanism and the unknown cut-off level (see Tables M^{prel} and X^{prel}). Given this implication of using the BDM mechanism and given the lack of any interesting systematic tendency in the withdrawal data, the existence of the second decision – whether or not to withdraw – was unimportant here except for its impact on the first decision – minimum compensation asks for cases where uncertainty is more pronounced and where subsequent withdrawal from the treaty is possible.

The hypothesis of equal compensation asks is rejected in favor of the asks being higher under X^{prel} than under M^{prel} only for Group B and the pooled data. P-values are 12.5% for Group A, 3.1% for Group B and less than 1% for the pooled data.[23] However, as argued above, the relevant observations are provided by the pooled data. Thus, the conclusion is that also in cases where the developing country has to base its decision on *estimates* of the probabilities of different outcomes, but where the developing country has the option to annul the contract when new information becomes available, compensation in money is more cost-effective than compensation in additional quota units.

[23] The Wilcoxon Signed Ranks test was used. Including the outliers, p-values were 7.8% for Group B and 2.7% for pooled data.

4. Discussion and qualifications

4.1. On the extent of replacing AA allocations by financial transfers

Given that cost-effective compensations for the risk aversion of new entrants into IET should be made in terms of M instead of X, the question arises whether it is in fact cost-effective to have financial transfers replace also part of the basic AA_{AC} allocation (denoted q_{AC}^0 in Appendix A.2). The basic AA_{AC} was set so that profit-maximizing trade behavior would make the costs of the expected abatement induced equal to the expected export revenue. Since the marginal AAU thus allocated to AC is expected to be exported and hence, would yield an uncertain net revenue, AC would strictly prefer to have this unit replaced by an additional financial transfer equal to the expected net export revenue of that unit. If IC obtained AC's marginal AAU in exchange for the additional financial transfer to AC, aggregate emissions and hence, the expected competitive AAU price would remain the same. This is a move to which IC is indifferent. Thus, due to the difference in risk attitudes and given the precondition that both Parties should be kept just barely compensated, aggregate emissions could be reduced even further.

Cost-effective moves of this type may be significant, but their extent depends on the characteristics of the uncertainty at hand. For the case analyzed here and the parameters used in the experiment, the cost-effective outcome would be that two-thirds of the expected trade volume (from AC's otherwise basic AA) should be replaced by financial transfers (see Appendix A2). This means that, instead of being allocated a large AA and exporting a substantial part of it to IC, AC would be paid a large money transfer for agreeing to a much smaller AA. The cost-effectiveness of this position implies that, although IC's AA would be larger, aggregate AAs and hence, aggregate emissions would now be smaller. This solution resembles a long-term contract for a large part of AC's emission abatement and amounts to an efficient shifting of risks to the party with the lowest costs of risk bearing.

4.2 IC restraints on cost-effective solutions

Financial transfers by IC and, in particular, the implied shift from small to possibly very large amounts of financial transfers calls for additional considerations. One is that IC may find an explicit financial transfer less palatable than an equally valued transfer implicit in the 'in-kind transfer' of extra AAUs. This may be so, even though, as we have assumed, payments for AAUs bought (with seller liability) as well as payments of an agreed financial transfer are finalized only after the commitment period is over and when AC is found to be in compliance. Second, since IC in actual fact stands for a *group* of Annex B countries, an agreement about the division of compensation payments among these countries may be difficult to negotiate.

And this may be increasingly difficult if the cost-effective amounts of financial transfers become large.

4.3. Factors reducing AC's interest in agreeing to (early) AA commitments

Even though the win/win situation of AC joining IET would seem pretty obvious, non-Annex B countries are often reported to flatly reject doing so in a near future. There is a number of possible reasons why this is so. One is, of course, that some governments simply may not be aware of the potential win/win situation. Another is that they may not believe that such a favorable outcome could be negotiated or implemented in practice. A third reason may be that new potential participants in IET believe they could follow an overall more profitable trajectory, if they initially, *i.e.*, with respect to a first commitment period, refuted all (better-than-*status-quo*) offers, expecting that their co-players would offer deals later that would imply a higher present value of their future trade gains. A final reason, possibly related to those now mentioned, may be found in a preference of potentially additional IET participants to avoid going it alone and therefore to wait until there is large enough support for entering into IET from members of a coalition to which they (want to) belong, *e.g.*, the G 77.

Considerations of the types now mentioned have been disregarded here, where we have focused on the minimum compensations demanded by potentially additional participants in IET, based solely on the estimated consequences of IET for a given 'first' period. But once the principles of that starting point have been clarified, the last two reasons just given – (i) possible benefits to AC from adding pressure on pre-existing trader countries by delaying their entry into an IET agreement, and (ii) constraints imposed by cooperation with other non-Annex B countries – should be addressed and may be found to influence the final AC decisions in real-world negotiations. To repeat, these negotiations concern the middle-ground between the reservation asks by AC and IC and may not lead to a minimization of 'income-compensated' aggregate emission reductions, but more likely to larger than minimum gains in terms of GDP to one or both Parties.

Furthermore, in past negotiations, developing countries have expressed a concern that agreements to sell emission reductions to (governments of) industrial countries, which provide official development assistance (ODA) to them, may reduce the donors' willingness to provide such assistance. This risk remains, of course, in agreements where AC receives a financial transfer, in particular, if large. Reductions in ODA would be hard to ascertain, since the baseline for future ODA is counterfactual. Still, this is another important aspect that will influence AC's position in real-world negotiations.

5. Conclusions

We set out from the observation that a cost-effective climate-change policy at given aggregate costs would mean: (i) that a maximum number of countries should participate in international emissions trading (IET) in the earliest period where commitment is politically possible; (ii) that IET should be unconstrained; and (iii) that the composition of the cap on the GHG emissions of all participating countries should be such that they are given Assigned Amounts (AAs) which are as small as possible. This would amount to a cost-effective design of a policy for attaining the resulting cap on the aggregate emissions of these countries.

Here, we have questioned the cost-effectiveness of the generally presumed process for enlarging the set of participants in IET, which has been to compensate new countries for joining IET solely in terms of sufficiently large AAs. The basic issue investigated was whether the minimum compensation for the risk taking of new countries, when participating in uncertain IET, was less or more costly to the pre-existing trader countries in the Kyoto Protocol (KP) if compensation took the form of financial transfers instead of extra units of AAs.

Given that rich countries, which dominate the trader countries listed in Annex B of the KP, can be assumed to be less risk averse than poor countries, which dominate the group of potential trader countries, we tested the hypothesis that financial transfers would be the more cost-effective of the two compensation instruments. This test had a context-explicit experimental design where graduate students and some Ph.D's in Economics were informed at length about the policy background to the experiment. They were invited to regard themselves as consultants to a developing country and obtain a share of the gains that 'their' country could make when participating in IET. Alternatively, the experimental subjects could simply view themselves as participants in the lottery created by this context. Using the incentive-compatible Becker-DeGroot-Marschak mechanism with significant monetary incentives made it possible to elicit risk-averse subjects' ranking of the reservation asks for the two instruments.

In first part of the experiment, subjects were exposed to uncertainty in the sense that their net outcomes in trade gains plus, where relevant, money transfers could take three different, equally probable values for each minimum compensation level that they could choose. A large majority of the subjects – 26 out of 30 – behaved as risk averters (two subjects were excluded due to clearly inconsistent behavior). Fifteen of the 26 subjects differentiated their asks, stating a lower reservation ask for transfers in money. Among the 11 subjects who revealed high rates of risk aversion, 10 behaved in this way. The null hypothesis of equal reservation asks for compensation in money and in additional AA units was rejected with p-values of less than 1 percent for the data pooled over the two subject groups used.

In the second part of the test, the subjects were exposed to *estimates* of the probabilities of the outcomes in the three states of the world and could withdraw from an agreement at a later stage when better information became available. Here, somewhat fewer subjects revealed risk aversion; moreover, their mean asks were lower. Only 7 out of 30 differentiated their asks, but did so in the direction predicted. Since subjects could choose only among discrete reservation asks, the data may have underreported the extent of differentiation in this as well as the first part of the test. Still, in this part of the experiment as well, a significance test rejected the hypothesis of equal compensation asks with a p-value of less than 1 percent for the pooled data.

If governments are more risk averse in developing countries than in industrial countries, and would make decisions in the same way as the risk-averse individuals did in the experiment, it may be concluded that a monetary transfer is more cost-effective than a transfer of additional AA units to compensate developing countries for uncertain net gains from joining a climate treaty that allows IET. We also observed that it is cost-effective to carry the substitution of money for AA units even further, *i.e.*, by replacing a, perhaps large, share of that part of the AA which is expected to be exported from the new participating countries. It was noted that there are factors, partly unrelated to cost-effectiveness, which could reduce (a) the willingness of pre-existing trader countries to offer ’costless’ compensation to new countries as well as (b) the interest of potential countries to participate in (even profit-generating) IET at an early stage. However, most of these factors would exert a similar influence also on compensations solely in terms of AAs. Thus, the result stands that the use of financial transfers as a compensation instrument would improve cost-effectiveness when attracting additional countries to participate in IET.

This result is important also in the sense that substituting money for part of the AAs to new and poorer countries reduces the risk of so-called ‘hot air’ allocations (allocations larger than the expected business-as-usual level). Such allocations have raised political demands to place binding constraints on IET, which would reduce its cost-effectiveness.

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Appendix A.1 Model and Test Bed

Section 1 of this appendix derives the AA allocation of a cost-effective climate treaty of the kind discussed in the main text when there is no uncertainty regarding the participating countries' MACs. In section 2, uncertainty is introduced and the basic AA allocation is derived, *i.e.*, the allocation that minimizes aggregate emissions while keeping both AC and IC fully compensated, given that they are both risk neutral. Section 3 presents (a) the parameter values used in the experiment and (b) a numerical analysis of the implications of AC being risk averse.

1.1 The certainty case

Let AC's and IC's abatement cost functions be

$$C_{AC}(q_{AC}) = \frac{\beta}{2}(q_{AC}^{BAU} - q_{AC})^2 \quad (1)$$

$$C_{IC}(q_{IC}) = \frac{b}{2}(q_{IC}^{BAU} - q_{IC})^2 \quad (2)$$

where q_i (i=AC, IC) denotes emission levels, BAU stands for business-as-usual, and where $b, \beta > 0$, *i.e.*, MAC functions are linear and increase in abatements. Initially, only IC is committed to an AA ($= \bar{q}_{IC}^{I}$). Under this initial climate treaty total emission reductions (TER) equal $TER^I = q_{IC}^{BAU} - \bar{q}_{IC}^{I}$. IC's cost of attaining its AA amounts to $C_{IC}^{I} = \frac{b}{2}(q_{IC}^{BAU} - \bar{q}_{IC}^{I})^2$. Consider now an IET treaty that comprises IC and AC and gives these countries AAs equal to $\bar{q}_{AC}$ and $\bar{q}_{IC}$. On a perfectly competitive market, AC and IC would abate emissions until their MACs equal the price, and imports of AAUs would equal exports. Letting $*$ denote competitive levels, the competitive equilibrium is thus characterized by

$$\beta(q_{AC}^{BAU} - q_{AC}^{*}) = b(q_{IC}^{BAU} - q_{IC}^{*}) \quad (3)$$

$$\bar{q}_{AC} - q_{AC}^{*} = q_{IC}^{*} - \bar{q}_{IC} \quad (4)$$

Combining (3) and (4) gives

$$q_{AC}^{*} = \frac{\beta q_{AC}^{BAU} + b\,\bar{q}_{AC}}{b+\beta} - \frac{b(q_{IC}^{BAU} - \bar{q}_{IC})}{b+\beta} \quad (5)$$

$$q_{IC}^{*} = \frac{b q_{IC}^{BAU} + \beta\,\bar{q}_{IC}}{b+\beta} - \frac{\beta(q_{AC}^{BAU} - \bar{q}_{AC})}{b+\beta} \quad (6)$$

AC's and IC's net gains of participating in the new climate treaty are $\Pi_{AC} = P(\bar{q}_{AC} - q_{AC}) - C_{AC}(q_{AC})$ and $\Pi_{IC} = C^I_{IC} - C_{IC}(q_{IC}) - P(q_{IC} - \bar{q}_{IC})$, respectively. Competitive net gains equal

$$\Pi^*_{AC} = \frac{b\beta TER}{2(b+\beta)^2}\left[b(q^{BAU}_{IC} - \bar{q}_{IC}) - (b+2\beta)(q^{BAU}_{AC} - \bar{q}_{AC})\right] \tag{7}$$

$$\Pi^*_{IC} = C^I_{IC} - \frac{b\beta TER}{2(b+\beta)^2}\left[(2b+\beta)(q^{BAU}_{IC} - \bar{q}_{IC}) - \beta(q^{BAU}_{AC} - \bar{q}_{AC})\right] \tag{8}$$

AC and IC are assumed to join the new treaty only if $\Pi^*_{AC} \geq 0$ and $\Pi^*_{IC} \geq 0$, respectively. Assuming zero income effects, the AAs that keep AC and IC barely compensated, *i.e.*, $\Pi^*_{AC} = \Pi^*_{IC} = 0$, amount to

$$\bar{q}^c_{AC} = q^{BAU}_{AC} - \frac{b}{2\left[\beta(b+\beta)\right]^{1/2}}(q^{BAU}_{IC} - \bar{q}^I_{IC}) \tag{9}$$

$$\bar{q}^c_{IC} = q^{BAU}_{IC} - \frac{b+2\beta}{2\left[\beta(b+\beta)\right]^{1/2}}(q^{BAU}_{IC} - \bar{q}^I_{IC}) \tag{10}$$

The certain $TER \equiv TER^c$ then equals

$$TER^c = \left(\frac{b+\beta}{\beta}\right)^{1/2}(q^{BAU}_{IC} - \bar{q}^I_{IC}) \tag{11}$$

Since b and β are strictly positive, $TER^c > TER^I$. Moreover, since $\Pi^*_{AC} = \Pi^*_{IC} = 0$, aggregate abatement costs equal C^I_{IC}.

1.2 The case of uncertain abatement costs

Let the uncertain oil price for AC and IC be denoted $\tilde{P}_{oil} = P_{oil} + \varepsilon$, where $\varepsilon \sim N(0, \sigma^2)$. The oil price is assumed to affect only the location of the MAC curves, *i.e.*, the stochastic BAU emissions levels are

$$\tilde{q}^{BAU}_{AC} = F_{AC} - \alpha \tilde{P}_{oil} \tag{12}$$

$$\tilde{q}^{BAU}_{IC} = F_{IC} - a \tilde{P}_{oil} \tag{13}$$

where the intercept F_i, a and $\alpha > 0$. Letting q^{BAU}_i denote the expected BAU emissions level for country i, the stochastic BAU emissions levels can be expressed as

$$\tilde{q}^{BAU}_{AC} = q^{BAU}_{AC} - \alpha\varepsilon \tag{14}$$

$$\tilde{q}^{BAU}_{IC} = q^{BAU}_{IC} - a\varepsilon \tag{15}$$

Inserting (14) and (15) in (1)-(4) and solving for the stochastic competitive emissions levels give

$$\tilde{q}^*_{AC} = q^*_{AC} + \frac{ab - \alpha\beta}{b+\beta}\varepsilon \tag{16}$$

$$\tilde{q}^*_{IC} = q^*_{IC} - \frac{ab - \alpha\beta}{b+\beta}\varepsilon \tag{17}$$

The competitive price equals

$$\tilde{P}^* = \frac{b\beta}{b+\beta}\left(E\left\{TER\right\} - (a+\alpha)\varepsilon\right) \tag{18}$$

yielding the stochastic net gains,

$$\tilde{\Pi}^*_{AC}\left(\bar{q}_{AC}, \bar{q}_{IC}, \varepsilon\right) = \tilde{P}^*\left(\bar{q}_{AC} - \tilde{q}^*_{AC}\right) - C^*_{AC}(\tilde{q}^*_{AC}) \tag{19}$$

$$\tilde{\Pi}^*_{IC}\left(\bar{q}_{AC}, \bar{q}_{IC}, \varepsilon\right) = \tilde{C}^I_{IC} - C^*_{IC}(\tilde{q}^*_{IC}) - \tilde{P}^*\left(\tilde{q}^*_{IC} - \bar{q}_{IC}\right) \tag{20}$$

Expected competitive net gains amount to

$$E\left\{\tilde{\Pi}^*_{AC}\right\} = \Pi^*_{AC} - \frac{b\beta\Omega}{2(b+\beta)^2}\sigma^2 \tag{21}$$

$$E\left\{\tilde{\Pi}^*_{IC}\right\} = \Pi^*_{IC} + \frac{b\gamma_1^2}{2(b+\beta)^2}\sigma^2 \tag{22}$$

where $\Omega = \left[(b+2\beta)\alpha - ba\right](\alpha + a)$ and $\gamma_1 = ba - \beta\alpha$. The variance of AC's net gains equals

$$Var\left(\tilde{\Pi}^*_{AC}\right) = \left(\frac{b\beta\sigma}{(b+\beta)^2}\right)^2\left[\gamma_1(q^{BAU}_{IC} - \bar{q}_{IC}) - \gamma_2(q^{BAU}_{AC} - \bar{q}_{AC})\right]^2 \tag{23}$$

where $\gamma_2 = (b+2\beta)\alpha + \beta a$.[1] Set (21) and (22) equal to zero and rearrange to get

$$\bar{q}_{AC} = q^{BAU}_{AC} + \frac{\beta}{b+2\beta}(q^{BAU}_{IC} - \bar{q}_{IC}) - \frac{b+\beta}{b+2\beta}\left((q^{BAU}_{IC} - \bar{q}_{IC})^2 - \frac{(b+2\beta)\Omega}{(b+\beta)^2}\sigma^2\right)^{1/2} \tag{24}$$

[1]Note for further use below that, if the AAs are such that $\frac{(q^{BAU}_{IC} - \bar{q}_{IC})}{(q^{BAU}_{AC} - \bar{q}_{AC})} = \frac{\gamma_2}{\gamma_1}$, the variance equals zero.

$$\begin{aligned}\bar{q}_{IC} &= q_{IC}^{BAU} + \frac{b}{2b+\beta}(q_{AC}^{BAU} - \bar{q}_{AC}) \\ &\quad -\frac{b+\beta}{2b+\beta}\left((q_{AC}^{BAU} - \bar{q}_{AC})^2 + \frac{(2b+\beta)(2C_{IC}^{I} + \frac{b\gamma_1^2\sigma^2}{(b+\beta)^2})}{b\beta}\right)^{1/2}\end{aligned} \tag{25}$$

Eqs. (24) and (25) define the basic AA allocation $(\bar{q}_{AC}^{0}, \bar{q}_{IC}^{0})$ such that both AC's and IC's expected net gains equal zero; this is the relevant solution when both countries are risk neutral. The expected TER in the case where both AC and IC are risk neutral equals

$$E\left\{TER^0\right\} = (q_{AC}^{BAU} - \bar{q}_{AC}^{0}) + (q_{IC}^{BAU} - \bar{q}_{IC}^{0}) \tag{26}$$

1.3 Compensation to a risk-averse AC for uncertain net gains - a numerical analysis

Assume (a) that AC's risk aversion (r) is constant and independent of income, (b) that IC is risk neutral and (c) that the mean-variance approach is applicable (Mas-Collell *et al.*, 1995). A climate treaty that just barely holds AC and IC fully compensated would then have to satisfy

$$E\left\{\text{AC}'\text{s net gains}\right\} - rVar\left(\text{AC}'\text{s net gains}\right) = 0 \tag{27}$$

$$E\left\{\text{IC}'\text{s net gains}\right\} = 0 \tag{28}$$

When compensated by a financial transfer, AC is given a basic AA equal to $\bar{q}_{AC}^{0}$ and a monetary transfer M financed by IC. Given competitive IET, AC's and IC's net gains then become

$$\tilde{\Pi}_{AC}^{*}\left(\bar{q}_{AC}^{0}, \bar{q}_{IC}^{M}, \varepsilon\right) + M \tag{29}$$

$$\tilde{\Pi}_{IC}^{*}\left(\bar{q}_{AC}^{0}, \bar{q}_{IC}^{M}, \varepsilon\right) - M \tag{30}$$

where $\bar{q}_{IC}^{M}$ is IC's unknown AA such that IC's expected net gains (28) equal zero.

When compensated by AAUs in addition to $\bar{q}_{AC}^{0}$, AC's and IC's net gains become

$$\tilde{\Pi}_{AC}^{*}\left(\bar{q}_{AC}^{0} + q^X, \bar{q}_{IC}^{X} - q^X, \varepsilon\right) \tag{31}$$

$$\tilde{\Pi}_{IC}^{*}\left(\bar{q}_{AC}^{0} + q^X, \bar{q}_{IC}^{X} - q^X, \varepsilon\right) \tag{32}$$

where q^X denotes the extra AAUs transferred and $\bar{q}_{IC}^X$ is such that the expected value of (32) equals zero.

Eqs. (27) and (28) together with (29) and (30) determine the M and the $\bar{q}_{IC}^M$ that minimize aggregate emissions (maximize TER) in the case of money compensation. Eqs. (27), (28), (31) and (32) determine q^X and $\bar{q}_{IC}^X$ that minimize aggregate emissions when compensation is given in terms of additional AAUs.

Below are presented some calculations of the impact AC's risk aversion has on $E\{TER\}$ under the two compensation mechanisms. These calculations are based on a particular set of parameter values, which also provides the test bed to be used in the experiment.[2]

The parameter set consists of available estimates for India (as the AC) and the Annex B countries (as the IC). Expected BAU emission levels (in Mton CO_2) for the year 2010 are taken to be q_{AC}^{BAU}=1,680 and q_{IC}^{BAU}=17,300 (Brown *et al.*, 1997). The Kyoto Protocol gives the Annex B countries an AA (for 2008-12) equal to 94.8 percent of five times their emissions in the year 1990, which amounted to approximately 13,826 Mtons CO_2 (IEA, 1999). In other words, the Annex B countries would have to keep their average yearly emissions during 2008-12 below $\bar{q}_{IC}^I$=13,107 Mtons CO_2. IC's expected yearly average emission reduction amounts to 24 percent. Publicized estimates indicate that Annex B's expected MAC at this yearly target level is about MUSD 85 per Mtons CO_2 (IPCC, 1995). In accordance with these estimates it is assumed that $b = \frac{1}{50}$. For India it is assumed that $\beta = \frac{1}{8}$, *i.e.*, the expected MAC at a 25 percent reduction in emissions 2010 is taken to lie around MUSD 50 per Mton CO_2. In addition, it is assumed that $a = 460$ and $\alpha = 10$.[3] In the experiment, the oil price is taken to be uniformly distributed over \$14, \$15 and \$16 per barrel, whereby $\sigma^2 = \frac{2}{3}$. The competitive AAU price can then vary 10 percent around the expected level of MUSD 77 per Mton CO_2.

In terms of Mton CO_2, these parameters give TER^I=4,193, TER^c=4,516, $\bar{q}_{AC}^0$=1,367, $\bar{q}_{IC}^0$=13,095 and, hence, $E\{TER^0\}$=4,518. Evaluated at the quota allocation $(\bar{q}_{AC}^0, \bar{q}_{IC}^0)$, the variance of AC's competitive net gains increases (decreases) in the compensation given in terms of additional AAUs (monetary transfer).

Here, as well as in the experiment, it is assumed that AC would not

[2]Tables M and X, introduced in Section 3.1, are obtained by evaluating (29) and (31) for the compensation levels given in the first column of the Tables.

[3]Given an oil price in the region of \$15, IC's and AC's elasticities of CO_2 emissions with respect to the oil price are close to those estimated for US/OECD (-0.4) and India (-0.1), respectively (Baker *et al.*, 1995).

reject participating in a lottery where all possible prizes exceed the cost of the ticket. Given the modest variance of the oil price, the compensation levels that guarantee AC non-negative net gains are quite small, whereby for all compensation levels allowed AC's AA is significantly below $E\left\{q_{AC}^{BAU}\right\}$=1,680 Mtons CO_2. So, these assumptions do not allow 'hot air' to arise in this case.

Table A 1 shows, for various degrees of risk aversion, (a) the AAs that would hold AC and IC barely compensated and (b) what the resulting $E\{TER\}$ then would be. Not surprisingly, these calculations show that a risk-averse AC requires a larger compensation (as evaluated by IC) when compensated in terms of additional AAUs than when compensation is given in money. This circumstance results in a smaller $E\{TER\}$ under X than under M. Moreover, the larger AC's risk aversion is, the larger is the difference between $E\{TER\}$ under the two compensation mechanisms.

Table A 1. Expected aggregate emission reductions in Mtons CO_2 for M and X and for various degrees of risk aversion (r)

			M				X	
r		$\bar{q}_{IC}^{M}$	$\bar{q}_{AC}^{0}$	$E\left\{TER^M\right\}$		$\bar{q}_{IC}^{X} - q^X$	$\bar{q}_{AC}^{0} + q^X$	$E\left\{TER^X\right\}$
0		13,095	1,367	4,518		13,095	1,367	4,518
.0001		13,098	1,367	4,515		13,095	1,370	4,515
.0002		13,100	1,367	4,513		13,095	1,373	4,512
.0003		13,103	1,367	4,510		13,095	1,376	4,509
.0004		13,105	1,367	4,508		13,095	1,379	4,506
.0005		13,108	1,367	4,505		13,094	1,382	4,503
.0006		13,111	1,367	4,502		13,094	1,386	4,500
.0007		13,113	1,367	4,500		13,094	1,390	4,496
.0008		13,115	1,367	4,498		13,093	1,394	4,493
.0009		13,118	1,367	4,495				

Note that for the small oil price range chosen here, the difference between $E\left\{TER^M\right\}$ and $E\left\{TER^X\right\}$ is small, but represent maximum annual values of the order of MUSD 400.

Appendix A.2 Further Reductions of AC's Assigned Amount

As stated in Appendix A 1.3, a cost effective climate treaty that gives AC an AA ($\bar{q}_{AC}^{0}$) such that AC's expected net gains equal zero and keeps AC just barely compensated by means of a money transfer must satisfy (27) and (28) where the competitive net gains are given by (29) and (30). The question to be analyzed here is whether it is cost-effective to replace also part of $\bar{q}_{AC}^{0}$ by a financial transfer.

Consider the case where a marginal unit of $\bar{q}_{AC}^{0}$ is transferred to IC and AC instead is given a money transfer equal to the expected export value of this marginal unit. Given a competitive IET market, the expected price depends only on expected TER, not how a given sum of AAs are allocated, see (18). Therefore, this exchange of money for AAs does not change the expected AAU price, hence (28) still holds. However, (27) will no longer hold. To see this, differentiate the left hand side of (27) with respect to M, $\bar{q}_{AC}^{0}$ and $\bar{q}_{IC}^{M}$ to obtain

$$dE\left\{\tilde{\Pi}_{AC}^{*}\left(\bar{q}_{AC}^{0},\bar{q}_{IC}^{M},\varepsilon\right)\right\}+dM-r\left(\frac{\partial Var(.)}{\partial\,\bar{q}_{AC}}d\,\bar{q}_{AC}+\frac{\partial Var(.)}{\partial\,\bar{q}_{IC}}d\,\bar{q}_{IC}\right) \qquad (33)$$

Since the change in expected export revenues equals the change in monetary transfers, the two first terms in (33) add up to zero. Given the parameter set presented above, $\frac{\partial Var(\bar{q}_{AC}^{0},\bar{q}_{IC}^{M},\varepsilon)}{\partial\bar{q}_{AC}}>0$ and $\frac{\partial Var(\bar{q}_{AC}^{0},\bar{q}_{IC}^{M},\varepsilon)}{\partial\bar{q}_{IC}}<0$. So, given the fact that $d\,\bar{q}_{IC}=-d\,\bar{q}_{AC}>0$, the expression within parenthesis in the third term of (33) is negative. Since $r>0$, we have that replacing a marginal unit of $\bar{q}_{AC}^{0}$ by a financial transfer (equal to the expected marginal export revenue foregone) improves AC's situation. Hence, starting from $(\bar{q}_{AC}^{0},\bar{q}_{IC}^{M})$ it is possible to further increase $E\{TER\}$ while keeping both AC and IC fully compensated.

This raises the question of how far it is worthwhile to replace units of $\bar{q}_{AC}^{0}$ by money transfers. This problem can be formulated as

$$\max_{\bar{q}_{AC},\bar{q}_{IC}} E\{TER\} = (q_{AC}^{BAU}-\bar{q}_{AC})+(q_{IC}^{BAU}-\bar{q}_{IC}) \qquad (34)$$
$$s.t.\ (27)\text{ and }(28)$$

Use (28) to eliminate M in (27). Then, the Lagrangian becomes

$$\pounds=\{TER\}-\lambda\left[E\left\{\tilde{\Pi}_{AC}^{*}(.)+\tilde{\Pi}_{IC}^{*}(.)\right\}-rVar\left(\tilde{\Pi}_{AC}^{*}(.)\right)\right] \qquad (35)$$

The solution to this problem is $\bar{q}_{AC}$=1,153 and $\bar{q}_{IC}$=13,309. It is noteworthy that this solution is independent of AC's degree of risk aversion. The reason is that, for this allocation of AAs, the variance of AC's net gains equals zero. $E\{TER\}$=4,518 Mtons CO_2, which equals $E\{TER\}$ when AC is risk neutral. Thus, expected competitive emission levels and prices are the same in these two cases. However, the allocation of AAs to AC and IC in the case of a risk neutral AC amounts to $\bar{q}^0_{AC}$=1,367 and $\bar{q}^0_{IC}$=13,095. In other words, AC's exports of AAUs are considerably higher in the case of risk neutrality than in the case of risk aversion (310 compared to 96 Mtons CO_2). So, by replacing AAUs expected to be exported at an uncertain price level with certain money transfers it is possible to transfer risk taking from the risk-averse AC to the risk-neutral IC, thereby attaining the same expected TER as when both parties were risk neutral.

Appendix B Instructions

(Written instructions distributed in advance.)

Introduction

A. International Greenhouse Gas Emissions Trading

The experiment you will participate in investigates the cost-effectiveness of certain options for international climate change policy. More precisely, the experiment involves a test of four different mechanisms to increase the number of countries committed to stringent targets for the emissions of so-called greenhouse gases (GHGs), i.e., gases that restrict heat radiation from the earth.

> ***Background:*** *The growing concentration of GHGs in the atmosphere implies a risk of an increase in the average global temperature. Such a climate change, if large, may give rise to rather drastic consequences such as a higher sea level, changes in the wind and sea currents, reduced food production and desertification. Some of these changes may directly or indirectly result in large population movements. All countries may not be affected to the same extent; some may even gain from an increase in the temperature.*
>
> *The single most important GHG is carbon dioxide (CO_2). CO_2 is emitted to the atmosphere mainly through combustion of fossil fuels. There exists no economically feasible technique to separate CO_2 from other emissions of fossil fuel combustion. Thus, in order to prevent climate changes the use of fossil fuels would have to be reduced. A specific feature of GHGs is that their effect on the global climate does not depend on where the emission source is located.*
>
> *It has been debated among scientists whether or not there is a man-made risk for global warming. Here, we just assume that a number of governments have decided to limit the global GHG emissions.*

At the UN conference on environment and development in 1992 in Rio de Janeiro, the so-called Climate Convention was adopted by more than 180 countries. Its objective is to stabilize the concentration of GHGs in the atmosphere at such a level and within such a time frame that the above-mentioned changes will not be drastic and that the ecological systems can adjust more slowly. In December 1997, a large number of the world's nations gathered in Japan to negotiate over country-specific GHG emission targets or quotas for the industrialized (so-called Annex B) countries – the OECD-countries and the economies in transition – for a first commitment period of 2008-12. The outcome is known as the Kyoto Protocol, which is signed but not yet ratified by a sufficient set of countries. If it is, the signatories would be assigned the country-specific emission targets (quotas) stated in the Protocol and have the opportunity to engage in so-called international emissions trading (IET).

IET is expected to ensure a minimum level of cost-effectiveness in the countries' aggregate attempts to reduce the emissions of GHGs. In such trading, each high-cost country that has committed itself to a certain stringent CO_2 emissions level (we forget about other GHGs here) may attain its commitment level at a lower cost by importing emission abatements from signatory countries with lower abatement costs. So, instead of making all emission abatement at home, a country can pay others to do part of it. By such transactions exporting countries transfer parts of their emission quotas to importing countries whereby the total emissions of all signatory countries remain constant. With a large number of trading countries a single market price is likely to be established. A country would gain by purchasing emission reductions as long as its own marginal abatement costs (MACs) exceed the market price. Similarly, a low-cost country would make trade gains by exporting emission abatements for which the country's MACs fall short of the market price.

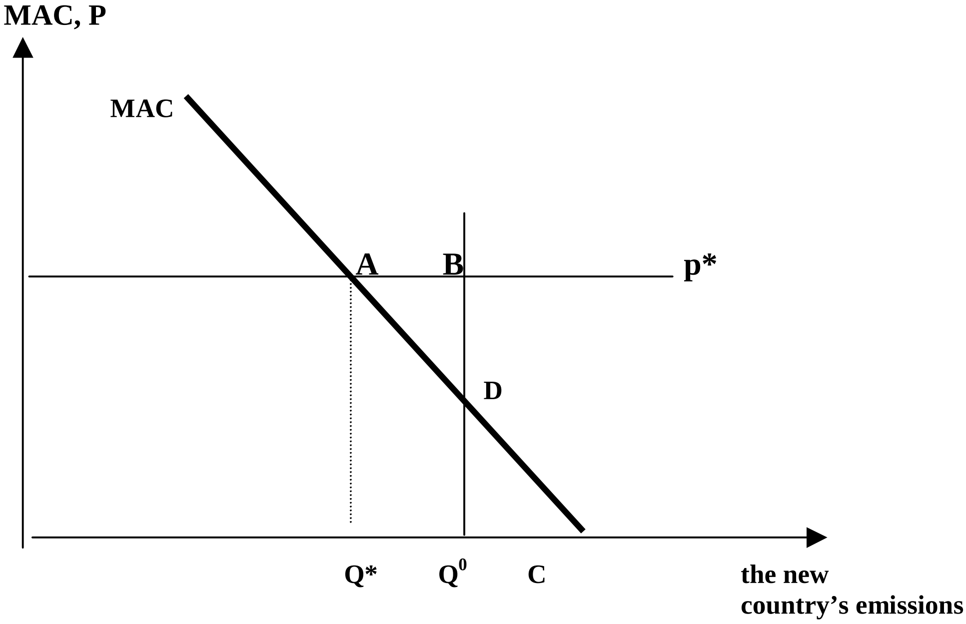
B. More trader countries mean lower GHG emissions at constant costs

The larger the number of participating trader countries, the more low-cost abatement options will be made available for cost-effective global emission abatements. It is therefore in the collective interest of the initial set of trader countries, which have agreed that reducing GHG emissions is better than not reducing them, to invite more countries to commit themselves to stringent CO_2 emissions levels (quotas) and participate in IET. Such new countries would have to come from the group of developing or middle-income countries. We assume that participation of such countries would require them to be kept at least fully compensated.

To simplify, we will regard the pre-existing signatory countries, when analytically practical, as one country only. We assume that this 'umbrella country' will have to reduce its emission quota enough to avoid making any gains from the addition of a new country which otherwise would be unlikely to accept to join the new climate treaty. This means that the abatement cost reductions made possible by a new country joining the group of emission traders would not benefit anyone directly. But it would benefit the global environment by minimizing emissions for given aggregate commitment costs. Since governments have expressed that they, other things equal, prefer a lower risk of global warming to a higher, they would all benefit in this 'indirect' fashion.

Excursus on the new country's commitment costs*: In the absence of a climate treaty the new country emits C. If the new country commits itself to an emission quota Q^0, it incurs (unavoidable) abatement costs equal to the area Q^0DC (see Fig. 1). However, since the treaty allows emissions trading, the new country can make trade gains by selling emission reductions. On a competitive* *market, the country would maximize its trade gains by selling emission reductions up to the point where its MAC equals the price level. Given a price p*, profit maximizing sales equal* Q^0*-Q* units, which implies sales revenues equal to Q*ABQ*^{0} *and additional abatement costs equal to Q*ADQ*^{0}*. Hence, trade gains equal ABD. Thus, given a choice of* Q^0 *such that trade gains (ABD) equal unavoidable abatement costs (*Q^0*DC), the commitment costs for the new (seller) country – unavoidable abatement costs minus trade gains or sales revenue minus total abatement costs – will be zero.*

Figure 1 **Illustration of a new country's commitment costs**



Even after the buyer countries have adjusted their commitments so as to keep their commitment costs constant, the addition of a new trader country would imply a reduction of the market price. Since pre-existing seller countries then would lose, they would likely demand to be compensated. To avoid explicitly dealing with this complication of buyers and sellers among the pre-existing signatory countries having to be treated differently, we regard them, as was mentioned above, analytically as one 'umbrella' country whose emissions target has to be reduced. Thus, the bottom line would be an outcome where a new (relatively) poor country as well as the umbrella country would have been fully compensated with respect to the status quo ante.

C. Compensation under uncertainty

If the MACs and the price level for trade in emission quota units were known with certainty, it would be straightforward to calculate the minimum quota Q^0 that would imply zero commitment costs for a new trader country, while holding the commitment costs of the umbrella country constant. Since we now have to observe that MACs and the price level are not known with certainty, we assume that the proposed new treaty is such that

(a) Q^0 is set at a level where the expected commitment costs of the new country equal zero, given a known probability distribution of MACs and price levels (see further below), and

(b) the expected commitment costs of the umbrella country (= the pre-existing signatory countries) are held constant. (Commitment costs for the umbrella country = abatement costs *plus* expenditure for import of emissions quota units.)

Due to uncertainty about MACs and hence, quota prices, actual commitment costs for a new (seller) country may be higher or lower than the expected zero. That is, by committing itself to the climate treaty the new country runs a risk of making losses, something it may want to be compensated for. In this experiment we will test four different mechanisms to compensate a poor country for this risk. Given a specific compensation mechanism, the compensation level is determined in a bargaining process between the pre-existing signatory countries and the new country.

If a compensation level is agreed upon, the new country commits itself to the specified emission level, is credited the compensation and engages in IET (then at known marginal abatement costs).

D. Your role in the experiment

Your role can be viewed as that of a consultant to a poor country that is faced with an option to commit itself to a certain level of CO_2 emissions, Q^0, and participate in IET. More specifically, we assume that some time before 2005, your client government – called 'your country' or simply 'you' here – will be asked to specify the minimum compensation level at which it would want to use this option. We assume here that your client accepts your proposal. If the proposed compensation level were accepted also by the pre-existing signatory countries – which is found out from a process detailed below – you(r government) would be able to participate in emissions trading with countries that have higher MACs. If so, your sales of emission reductions during 2008-12 would be determined by the relevant state of the world, which will be drawn from a known probability distribution. (The underlying data for the tests presented here are based on estimates of future emissions levels and MACs of real countries as found in the literature.)

By participating in this experiment you will be able to earn money. In addition to the show-up fee of $10, you will be given an initial payment of $20. You may lose this initial payment, or part of it, if you choose to take certain risks. Or, at the other extreme, you may gain money

-- (a) an amount according to the accepted level of compensation and (b) trade gains from exporting emission reductions below Q^0.

Below you find (i) a description of how the negotiations over the compensation level is mimicked in the experiment and (ii) instructions for the four tests you will participate in. Please, read these instructions carefully and take time to consider the questions posed there. If you do, the meeting tomorrow will run smoother and faster.

E. Negotiations concerning the compensation level

In real-world international negotiations it might have paid your country to present the other side with a compensation requirement that is much higher than its true minimum ask. In the experiment, however, the transfer is determined in a different fashion. You will be asked to state your truly smallest compensation amount in a situation, where it does not pay you to give a distorted response. The reason is that, in this experiment, a value is drawn randomly from a known distribution where all values between an upper and a lower bound appear with the same probability; you will get a fixed share of the value drawn if it is equal to or higher than your ask, otherwise nothing and you will be excluded from participating in emissions trading.

> ***Basic principle:*** *Compensations will be in money or in quantities of a marketable commodity. Assume here that you are invited to participate in trading with this commodity, that your true minimum money compensation was 10 MU (monetary units) and that you stated your ask as something higher, say 15 MU. This would imply that if a value between 11 MU and 14 MU were drawn, you would end up foregoing a gain of 1 - 4 MU and be excluded from trading. Had you stated your true minimum compensation amount, you actually would have avoided that. Hence, it is not in your interest to state a higher requirement than your true minimum compensation amount. Assume now that you stated your requirement as 5 MU. This would certainly mean that you would increase your chances of being qualified for trading. But if a value were drawn between your true minimum and 5 MU, say 7 MU, you would get 7 MU as your compensation. This is obviously below what you feel is required to keep you fully compensated. So, it does not pay you to state a lower requirement than your minimum acceptable requirement. By replacing the amounts in MU above by quantities in a marketable commodity, the incentive argument will remain the same.*

This mechanism (the Becker-deGroot-Marshak mechanism) is known to provide incentives for truth revelation in a context of the type relevant here. The reason is that the ask you state can only affect your chance of 'winning', but not the amount you win in any positive direction. By deviating from your true minimum, you run the risk of not being fully compensated, or of not benefiting from some of the cases where you would be more than compensated.

This is not to say that it will be easy to make up your mind about what your minimum acceptable compensation is, only that it *is not in your interest* to respond by consciously deviating from your best estimate of your minimum acceptable compensation.

Test M: Money compensation

Assume that your country is asked to commit itself to an annual CO_2 emissions volume of $Q^0 = 1\ 367$ Mtons for the period 2008-12. As indicated above, your country's cost curve as well as those of the pre-existing signatory countries are not known with certainty, something that implies an uncertain market price for emissions trading. Your country's emissions quota Q^0 has been determined so that your country's expected commitment cost is equal to zero. (If needed for a proper understanding, check Figure 1 for p* and MAC equal to their expected values.)

The uncertainty your country faces regarding abatement costs and price is such that there exists three equally likely states of the world: Low, Medium and High. If you want your country to be compensated for the risk associated with committing itself to the proposed climate treaty and therefore require a strictly positive expected value, you can ask for a *minimum financial transfer (M) to your country*. Note that the higher your requirement, the lower the chance that your requirement will be accepted. If your country's requirement is accepted, your consultancy fee equals a fixed share of your country's total gains, defined as its compensation received *plus* trade revenue *minus* abatement costs.

Since the trade itself, given the relevant costs and hence prices, is pretty straightforward, we take for granted that it is carried out to the point where MACs equal price. Therefore, we describe in Table M the three possible outcomes directly in terms of your total personal gains for each compensation level. As you can see, each compensation level is associated with a unique distribution. The reason is that the more the pre-existing signatory countries pay as compensation to your country, the less they are required to reduce their emission quotas which in turn will affect the total gains distribution. Note that Table M shows the end result in terms of your personal gains (your share of your country's total gains).

Example: *Consider Table M. Assume that the buyout compensation value drawn is $1,168 million. Then, those who have stated compensation asks lower or equal to this amount receive their share of this compensation amount and are committed to the initial emission quota* Q^0 *and qualified to engage in IET. Assume now that the state of the world drawn is Medium. Then, all those who qualified for IET receive $19. Had instead Low been drawn, those qualified would have made a personal loss equal to $11., which would have been subtracted from the initial payment of $20. Finally, had the state of the world been High, those qualified would have gained $57.*

Tomorrow, you will be asked to state what your country's minimum required financial transfer (M) is. A compensation level equal to zero is not regarded as an acceptable outcome here. The shaded row in Table M is only for illustration. Therefore, the buyout compensation range is $78 million – $1,792 million, where each value has the same probability to be drawn (1/23.) Then, we will make the draw. We suggest that you consider already now what minimum compensation amount you would request.

When considering your response you may find it fruitful to proceed as follows. Once you have arrived at a tentative response, test it by moving 'one step down', i.e., check what a somewhat lower compensation amount would mean for you. If the one-step-further-down amount seems acceptable, keep that value in mind as your new tentative response, and repeat the test for another step down until you reach your true minimum compensation level. Remember that an "unnecessarily" high requirement only adds a risk that you will not receive any compensation and not qualify for trading. So, it is in your interest to identify and state your minimum compensation level.

Test X: Extra quota compensation

An alternative mechanism to compensate a country for committing itself to a climate treaty is to let the country specify its required *minimum addition to* Q^0, *the proposed initial emission quota*. Such an addition, if larger than zero, means that your country would be able to sell larger volumes of emission reductions. This increment in your country's emissions quota replaces the money compensation transfer (M) funded by the pre-existing signatory countries in the preceding test. Thus, here, the additional quota (X) will be transferred from these countries. Thus, any addition to your country's quota would be at the expense of the pre-existing trader countries. The larger the X that these countries would have to give to your country, the less their trade gains would be and – given the requirement that their commitment costs should remain the same – the less they would be required to reduce their emission quotas. This means that the larger your X, the lower the price level will be. Thus, just as in the case of compensation in money, there is a different distribution of your personal gains for every compensation level, see Table X.

Everything is the same as in the preceding test, except that compensation now works through your country's required addition to Q^0 instead of its required money compensation.[1]

[1] When comparing the two mechanisms, note also that payments in both cases are made at the same point in time: In a real-world case, the country's money compensation as well as its sales revenue can be assumed to be kept in escrow until the country is found to be in compliance with the treaty at the end of the commitment period. In the experiment, your personal gains will be paid in out at the same time for both the M and the X cases.

In this new test, compensation in terms of X will be determined by the value drawn from the range 1-26 Mtons CO_2.

Tomorrow, you will be asked what your country's minimum volume of additional quota (X) is, given that each amount from 1-26 Mtons CO_2 has the same probability to be drawn (1/26). Again, incentives are provided for you to give a response that reveals your true minimum compensation required. Once the buyout level has been drawn from the buyout compensation range, your country will receive an extra quota equal to the level drawn, provided that your demand did not exceed the buyout compensation level drawn.

We ask you to consider already now what your minimum compensation request would be in terms of additional quota units, given the information in Table X. Again, consider your answer as tentative only until you have checked it against a value one step down in the same fashion as was suggested above.

Test X^{prel}

The two remaining tests are variations of the two mechanisms we have now dealt with. Both involve a chance for your country to back out from the agreement at a given point in time closer to that when trade is about to start. The option to back out at this later stage allows your country to make its final decision at a date when new and more accurate (= lower variance) information about costs and prices, *i.e.*, about possible total gains, is likely to be available. For you as a participant in this test, a withdrawal would be at a cost of $5.

Note that this new test refers to a situation that differs from that of the preceding two tests. There, uncertainty (concerning 2008-12) was taken to be fully described by three states and their probabilities. In this new test, the information about the future that is available at the time of the negotiations (say, 2005) amounts to an estimate only and does not completely describe the existing uncertainty. Instead, such a description is now taken to exist only at a later stage (say, late 2007), when your country can make its final decision whether to remain onboard or not.

The pre-existing signatory countries, which now cannot be sure of the provision of additional low-cost options for future purchases of emission reductions, will not find contracts of this new type, which involves compensation in terms of additional quota units, as valuable as those concerning the preceding one, the X compensation. Therefore, they will not be willing to offer equally high compensation levels in this new case, X^{prel}.

Then, another difference between this test and the preceding one is that the upper bound to the buyout compensation range now will be lower, but how much lower will not be revealed. Thus, Table X above is relevant also in this new test to the extent that it indicates your estimated gains at different additional quota levels with the exception for a deleted unknown number of rows from the bottom reflecting the now reduced buyout compensation range. Again, it is your minimum compensation level you are asked to state. You are confronted with exactly the same type of incentives to respond truthfully as before.

So, the question is “what is the minimum additional quota you need in order to be fully compensated, given that you will be able to annul the contract at a cost of $5 at a time just before trading is about to start, given the information about the uncertainty that is available then”. Test your preliminary response against smaller additional quota values to check what your true minimum requirement is.

Tomorrow, after you have responded and then after you have received updated information about the distribution of your personal gains, you will be asked whether you want your country to keep, or withdraw from, the X^{prel} contract previously established.

Test M^{prel}

The final test refers to compensation in terms of a money transfer but with the same possibility to withdraw as in the preceding test. Table M above is relevant also in this new test to the extent that it indicates your gains at different compensation levels, except for a deleted unknown number of levels/rows from the bottom reflecting the reduced buyout compensation range. As in the preceding test, this range is reduced as a result of the fact that the pre-existing countries won’t be as keen on offering compensation here as in the M case where you could not withdraw at a later stage.

The question now is “what is the minimum amount of money, M^{prel}, you need in order to be fully compensated, given that you have the option to annul the contract at a cost of $5 at a later date when you will have new information.”

Test your preliminary response against smaller amounts of compensation in money to check what your true minimum requirement is.

Tomorrow, after you have responded and then after you have received updated information about the distribution of your personal gains, you will be asked whether you want your country to keep, or withdraw from, the M^{prel} contract previously established.

REMEMBER …

- you are assumed to be a consultant to a poor country that wants to be compensated for participating in international emissions trading with uncertain benefits
- you are asked to state the minimum level of compensation for four different compensation mechanisms
- you have no incentives to deviate from your true estimate of the minimum compensation required (check the Becker-DeGroot-Marschak mechanism)
- your incentives are formed by the fact that you get a share of your country's compensation and its efficient emissions trade
- your country is accepted as a trader and you receive your payoffs, contingent upon the state of the world, if your stated minimum compensation requirement at most equals the acceptable compensation drawn from the uniform probability distribution over the values given in the first column of the relevant tables
- your payoffs are determined by a random draw of one of three states of the world

DON'T FORGET TO OPEN THE ATTACHED TABLES!

Table M. **Your payoffs at different M compensation levels in the three states of the world, $**

Your country's M compensation, $ Million	Your payoffs in states of the world			Your payoffs'	
	High 1/3	Medium 1/3	Low 1/3	Expected value	Variance
0	36	-2	-33	0	804
78	37	-1	-32	**2**	**803**
156	39	1	-30	**3**	**803**
234	40	2	-29	**4**	**802**
312	42	3	-28	**6**	**801**
389	43	5	-26	**7**	**800**
467	45	6	-25	**9**	**799**
545	46	8	-23	**10**	**799**
623	47	9	-22	**12**	**798**
701	49	11	-20	**13**	**797**
779	50	12	-19	**15**	**796**
857	52	14	-17	**16**	**795**
935	53	15	-16	**17**	**795**
1013	55	17	-14	**19**	**794**
1091	56	18	-13	**20**	**793**
1168	57	19	-11	**22**	**792**
1246	59	21	-10	**23**	**791**
1324	60	22	-8	**25**	**790**
1402	62	24	-7	**26**	**790**
1480	63	25	-5	**28**	**789**
1558	65	27	-4	**29**	**788**
1636	66	28	-3	**31**	**787**
1714	67	30	-1	**32**	**786**
1792	69	31	0	**33**	**786**

(The table contains errors in rounding off.)

Table X. **Your payoffs at different X compensation levels in the three states of the world, $**

Your country's X compensation, Million tons	Your payoffs in states of the world			Your payoffs'	
	High 1/3	Medium 1/3	Low 1/3	Expected value	Variance
0	36	-2	-33	0	804
1	38	-1	-32	**2**	**811**
2	39	1	-31	**3**	**818**
3	41	2	-29	**4**	**824**
4	42	3	-28	**6**	**831**
5	44	5	-27	**7**	**838**
6	46	6	-26	**9**	**845**
7	47	8	-24	**10**	**852**
8	49	9	-23	**12**	**859**
9	50	11	-22	**13**	**866**
10	52	12	-20	**15**	**872**
11	54	14	-19	**16**	**879**
12	55	15	-18	**17**	**886**
13	57	17	-16	**19**	**893**
14	58	18	-15	**20**	**900**
15	60	19	-14	**22**	**908**
16	61	21	-12	**23**	**915**
17	63	22	-11	**25**	**922**
18	65	24	-10	**26**	**929**
19	66	25	-9	**28**	**936**
20	68	27	-7	**29**	**943**
21	69	28	-6	**31**	**951**
22	71	30	-5	**32**	**958**
23	73	31	-3	**33**	**965**
24	74	32	-2	**35**	**973**
25	76	34	-1	**36**	**980**
26	77	35	0	**38**	**987**

(The table contains errors in rounding off.)

UPDATED INFORMATION (previous estimates in parenthesis)

Table M^{prel}. Your payoffs at different M compensation levels in the three states of the world, $

Your country's M compensation, $ Million	Your payoffs in states of the world			Your payoffs'	
	High 1/10	Medium 5/10	Low 4/10	Expected value	Variance
0	36	-2	-33	(0) **-11**	(804) 458
78	37	-1	-32	(2) **-10**	(803) **458**
156	39	1	-30	(3) **-8**	(803) **457**
234	40	2	-29	(4) **-7**	(802) **457**
312	42	3	-28	(6) **-5**	(801) **456**
389	43	5	-26	(7) **-4**	(800) **456**
467	45	6	-25	(9) **-2**	(799) **455**
545	46	8	-23	(10) **-1**	(799) **455**
623	47	9	-22	(12) **0**	(798) **454**
701	49	11	-20	(13) **2**	(797) **454**
779	50	12	-19	(15) **3**	(796) **454**
857	52	14	-17	(16) **5**	(795) **453**
935	53	15	-16	(17) **6**	(795) **453**
1013	55	17	-14	(19) **8**	(794) **452**
1091	56	18	-13	(20) **9**	(793) **452**
1168	57	19	-11	(22) **10**	(792) **451**
1246	59	21	-10	(23) **12**	(791) **451**
1324	60	22	-8	(25) **13**	(790) **450**
1402	62	24	-7	(26) **15**	(790) **450**
1480	63	25	-5	(28) **16**	(789) **449**
1558	65	27	-4	(29) **18**	(788) **449**
1636	66	28	-3	(31) **19**	(787) **448**
1714	67	30	-1	(32) **21**	(786) **448**
1792	69	31	0	(33) **22**	(786) **447**

(The table contains errors in rounding off.)

Table X^{prel}. Your payoffs at different X compensation levels in the three states of the world, $

Your country's X compensation, Million tons	Your payoffs in states of the world			Your payoffs'	
	High 1/10	Medium 5/10	Low 4/10	Expected value	Variance
0	36	-2	-33	(0) **-11**	(804) 458
1	38	-1	-32	(2) **-10**	(811) **462**
2	39	1	-31	(3) **-8**	(818) **466**
3	41	2	-29	(4) **-7**	(824) **470**
4	42	3	-28	(6) **-5**	(831) **474**
5	44	5	-27	(7) **-4**	(838) **478**
6	46	6	-26	(9) **-2**	(845) **482**
7	47	8	-24	(10) **-1**	(852) **486**
8	49	9	-23	(12) **0**	(859) **490**
9	50	11	-22	(13) **2**	(866) **495**
10	52	12	-20	(15) **3**	(872) **499**
11	54	14	-19	(16) **5**	(879) **503**
12	55	15	-18	(17) **6**	(886) **507**
13	57	17	-16	(19) **8**	(893) **511**
14	58	18	-15	(20) **9**	(900) **515**
15	60	19	-14	(22) **10**	(908) **520**
16	61	21	-12	(23) **12**	(915) **524**
17	63	22	-11	(25) **13**	(922) **528**
18	65	24	-10	(26) **15**	(929) **532**
19	66	25	-9	(28) **16**	(936) **536**
20	68	27	-7	(29) **18**	(943) **541**
21	69	28	-6	(31) **19**	(951) **545**
22	71	30	-5	(32) **21**	(958) **549**
23	73	31	-3	(33) **22**	(965) **554**
24	74	32	-2	(35) **23**	(973) **558**
25	76	34	-1	(36) **24**	(980) **562**
26	77	35	0	(38) **26**	(987) **567**

(The table contains errors in rounding off.)