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Trading Flexibility for Predictability — Differential Emission Dynamics and the Formation of Common Carbon Markets

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Abstract

The Kyoto Protocol was a success in the sense that it established legally binding commitments to reduce carbon emissions for a very specific set of actions and a specific set of countries — emission reduction of Annex B sources (mainly combustion of fossil fuels) in industrialized countries. However, the Protocol failed to establish a comprehensive set of markets of full geographic (all countries) and full structural coverage (all sources of GHGs). In this paper, we argue that it is mainly the economic and technological dissimilarity between carbon systems (e.g., country specific fossil fuel emissions, regional terrestrial methane fluxes to the atmosphere) that impede the formation of a single global GHG market covering all sources. It appears that the international realpolitik requires second best (worst) solutions in order to be agreeable to all potential parties. This paper discusses a methodology of developing such a solution by forming Common Carbon Market Systems (CCMS), which is an analogy to the existing international trading blocks. An optimal emission target for a specific carbon system functions as a measure to assign membership in such a trading block. It reflects the carbon system's specific dynamics and the related uncertainties. In this paper, we argue that clusters of similar GHG emission patterns expressed by similar targets will find themselves more willing to establish common rules among themselves than in one global market, since the winner-loser gap can drastically be reduced within a CCMS and the established market rules will better fit the dynamics of the respective carbon systems. Furthermore, products to be traded in a CCMS will be more readily identified, more comparable, and thus markets of CCMS will be more transparent and predictable. We conclude that in a post-Kyoto world CCMS might be instrumental in increasing the participation in, the comprehensiveness and finally the effectiveness of, international actions to combat global climate change. However, we will have to live with some efficiency losses.

About the Authors

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Introduction

The Kyoto Protocol addresses one of the most challenging and difficult global environmental problems of today. The exact implications of climate change still remain impossible to quantify, but we know enough to recognize that any rational response must include significant efforts to limit all sources of emissions of all GHGs by all nations. Thus, it appears to be paramount that all carbon systems of all nations contribute in helping to effectively limit possible damages from a changed global climate.

However, the political reality is on the verge of being the materialization of a social dilemma on a common resource management problem. Climate change is about the management of a common resource, where the properties of the resource are still not fully defined, and actors are very (dis)similar with respect to the utility from and the contribution to the resource. In addition, actors are unequal in their negotiation power. These realities defining this particular social dilemma are mirrored in the outcome of the current Kyoto process, where only a number of industrialized countries were able to agree to a very specific modus of emission stabilization mainly from fossil fuel sources. In other words, carbon markets lack:

(1) comprehensiveness in terms of allowing all carbon systems to be included in the Kyoto Protocol, and

(2) full geographic coverage meaning that there is only a limited number of countries that committed themselves to positively contribute to the common resource.

There is little hope that the current version of the Kyoto Protocol is flexible enough to allow all sources of GHGs and all countries to participate in a single global market of emission reduction certificates using 1990 as the base year. So, for example, the accession of new entrants (such as China and India joining the Kyoto mechanism as a full member) to the Kyoto market will only become reality if major concessions are granted. We, thus, must acknowledge that we face an institutional deadlock with respect to temporal and structural compatibility for future Protocols. It has to be understood that a lack of comprehensiveness leads to less efficient and less effective solutions to the problem of dramatically increasing GHG concentrations in the earth's atmosphere.

One exit strategy from the current deadlock situation, as discussed in this paper, is to try to enlarge the geographic and structural coverage by trying to form what we call "Common Carbon Market Systems" (CCMS). Approximately equal partners in a CCMS will find themselves more willing to trade. Equality among partners in CCMS is defined by the physical and economic behavior of the underlying carbon systems trying to reach the agreed targets. Similar to the European monetary system, a single currency can only be successfully and sustainably established among approximately equal partners. If the partners participating in the same market are too different the socioeconomic system will show tendencies of disintegration.

Large dissimilarities in the underlying carbon systems combined with market power are prone to create biased market rules that will not find acceptance by all participating actors thereby leading to disruptive tendencies in the formation of a common market. Even within the already rather restrictive Kyoto Protocol there are discussions on ratification. Grubb *et al.* (1999) draw the conclusion that "*...the Kyoto Protocol could yet be destroyed: from within, by excessive national greed leading to uncontrollable inflation: from without, if those who do not want any agreement, acting together with those for whom Kyoto is not good enough, can block ratification in key countries. Yet this is unlikely. Governments have already made major political investments to establish this nascent regime. It offers a solid basis, and there are no credible alternatives on offer*."

The longer the Kyoto process lasts the more the Parties realize how complex the topic is. There are too many and too large questions to be solved by just one market with one set of global rules. This one market is supposed to handle a number of different currencies, geographically and structurally differing 'production systems' with products of varying quality. It is hardly believable that any rational investor in such a market will be sanguine to participate in such an unpredictable market.[1] And, in real life now at the end of 2000, the total amount of verifiable Kyoto actions is next to negligible with the exception of Soviet hot air that has yet to be verified in the period around 2010.

Despite the fact that market segmentation into CCMS necessarily leads to efficiency losses in the short-run, the effectiveness of the global carbon policy is most likely to improve. The establishment of CCMS will also allow a smoother transition to a less carbon intensive production and consumption system due to the fact that countries will be able work closer to their idiosyncratic long-run minimum cost curve and a CCMS will be more predictable for market participants. Overnight changes in the viability of production systems have already shown detrimental effects on economic output in transition countries.

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[1] In this footnote we will briefly illustrate with simple facts that the uncertainties produced by the set up of the market make operations for investors almost unpredictable. Righley (2000) presented the first abatement cost curves for all GHGs on very aggregate scales. Grubb (2000) showed that there is a wide range of CO_2 abatement cost curves generated by the different models currently available. Furthermore, GHGs are ambivalent joint products which add more uncertainty to the estimated cost curves. In addition, Trexler (2000) showed that only 10% of all JI and CDM projects he analyzed would pass a 'quality' text of verifiablility and additionality. If we assume that COP6 will finally generate the final rules of the market game and that the facts stated above mirror the current state of knowledge and information that will be used by Kyoto entrepreneurs to calculate project feasibilty then the risk premiums must be in the order of magnitude of at least 100–300% of the total turnover.

Efficiency of separate CCMS can be increased by allowing for inter-CCMS trade. Similar to most international product markets there is free exchange within a common market and regulations for trade between market blocks involving market regulation so that the joint interests (pressures) of the different blocks are protected, but benefits from inter-CCMS trade are still exploited.

Another issue of CCMS is more psychological in nature, but probably of larger importance than economic efficiency consideration. CCMS carry the potential to establish a brand for emission reduction of GHGs and thus creates incentives for firms to be involved in such an activity since it would increase the visibility of their actions. The current political tensions on high fuel prices, and the ignorance of firms on the micro-level to contribute to mitigate global warming (see, e.g., Vaze, 2000) show how large the resistance is to climate relevant policy actions. However, if the actors and their targets are clearly defined in a CCMS the success or failure on these lines can also be better marketed (e.g., CCMS on global [not only restricted to territories of Annex I countries] methane emissions from oil and gas drilling over-fulfilled its target by 25%).

Principles Guiding (post) Kyoto

According to Houghton (1999) three widely accepted principles will govern international agreements in trying to solve the problem of global climatic change. The first is the 'Precautionary Principle', embedded in the United Nations Framework Convention on Climate Change (UNFCCC). This convention states that the existence of uncertainty should not preclude taking appropriate actions. The second principle is the 'Polluter Pays Principle', which implies the imposition of measures, such as carbon taxes or carbon trading arrangements. The third is the principle of intergenerational and international equity. Applying the second and third principles would lead to a system allowing the allocation of carbon emission rights to nations on an equal per capita basis while also allowing for emission trading.

The action agreed in Kyoto in 1997 is a first step. Kyoto is not fully in line with the second and third principles, but seems to be the only politically feasible convention that allowed for real actions; although the stability of such agreements has yet to be proved.[2]

It should be understood that the Kyoto Protocol is at best a second best solution to the global warming problem. The necessary post-Kyoto action, however, will be more demanding and require more comprehensive approaches to the problem. Nonetheless, it is widely acknowledged that making the Kyoto Protocol operational will contribute to solving the problem of global warming and maintaining political momentum to devise better mechanism designs in the future.

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[2] The Norwegian government, which prided itself on a series of Kyoto friendly policy initiatives, fell in March 2000 in an attempt to implement Kyoto after losing a vote of confidence in parliament over its attempts to push strong greenhouse gas emission reductions (www.stratfor.com, 2 April 2000). Road blockages in the UK, France and Belgium are due to high diesel and gas prices.

The 2nd Precautionary Principle and the Role of Verification under the Kyoto Protocol

Experience and theory show that markets fail when they lack measures to verify quantities and qualities of the products traded (Obersteiner *et al*., 2000). It is unlikely that the Kyoto market will be an exemption to this rule, especially in the light of the large uncertainties of national GHG accounts. In addition, there is a danger that in some countries Kyoto provides additional incentives to push more of the carbon economy into the unobserved sector. It is, thus, indispensable to implement an appropriate verification mechanism for the mutual recognition of emission reductions. Clearly, the current verification provisions are by far not sufficient to guarantee an efficient market.

IIASA research has investigated in great detail issues of uncertainty in carbon accounting and has dealt with the implications of verification. Based on this research we can conclude that: *'All Parties are unable to verify their own Kyoto targets, but compliance with the target can still be made verifiable'*.

The first part of the statement refers to the empirical fact that the Parties' emission reduction targets are still within the total level uncertainty bands. The analytical concept to verify nations' Kyoto target with respect to the level uncertainty was developed in Jonas *et al*. (1999). It follows that policy makers will have to adopt, what we call *The 2nd Precautionary Principle.* This principle should assert that the responsibility connected to the non-verifiability of the Kyoto targets *per se* rests with the policy makers. Policy makers, thus, have to take on the risk of 'We do not know what we were doing'. This type of risk sharing, based on *The 2nd Precautionary Principle*, is a necessary precondition to make the Kyoto Protocol operational.

The second part of the statement refers to the verifiability of compliance with the target. Here the uncertainty concept of interest refers to the trend uncertainty. Uncertainties of the trend are smaller than level uncertainties due to the fact that dependencies between 1990 and 2010 measurements are taken into account (e.g., conversion factors are almost always fully correlated between the two years).[3] The most straightforward way to make sure that a country complies is by undershooting, i.e., with some probability that the reported emission is not allowed to be greater than the target (see, Obersteiner *et al*., 2000 and this paper). IIASA calculations of the Kyoto market for verifiable CO_2 emission reductions of fossil fuels indicate that, depending on the probability limit and the definition of uncertainty, total emission reduction costs will at least double if uncertainties can not be reduced significantly (see, Godal, 2000).

It can be concluded that verifiable GHG accounts and a credible mechanism of verifiable compliance are an absolute must for the functioning of the Kyoto market (Obersteiner *et al*., 2000). Likewise verification will help to avoid perverse incentives like subsidizing black market operations and improved knowledge and data will make carbon management systems more effective. However, verification will come at an economic cost. In this paper we take a particular verification mechanism into account.

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[3] Rypdal and Zhang (2000) estimate a level uncertainty of ±20%, while the trend uncertainty of the projected trend from 1990 to 2010 is ±4 percentage points.

The Flexible Instruments

The Kyoto Protocol (UNFCCC, 1998) to the UN Framework Convention on Climate Change (UNFCCC, 1992) contains the first legally binding commitments to reduce greenhouse gas (GHG) emissions of six greenhouse gases or groups of gases. According to the Protocol, Annex I Parties must reduce jointly their emissions of all GHGs by at least 5% below 1990 levels within the commitment period 2008–2012. The Protocol is mainly concerned with reducing the emissions from fossil fuels. Article 3.3 of the Protocol states that biological sources and sinks should be used for meeting commitments during the stipulated period, but limits these sources and sinks to afforestation, reforestation and deforestation since 1990. Further, Article 3.4 provides the possibility of using additional land-use and forestry activities to meet reduction commitments. These Articles, however, give rise to serious scientific and political concerns as large and maybe crucial parts of the carbon system are still omitted and that actions concerning these carbon systems will be hard to verify if treated partially so that in the end there is a great danger that lots of money will be spent on something we will never know whether it had a positive contribution to the goal of reducing GHG emissions and even less so with respect to meeting the goal of sustainable development. Negative spillover effects are largely ignored under the current provisions. In this paper we argue that, in principle, the widest set of possible actions to reduce carbon should be allowed, which precludes that all accounting has always to be tied to a FCA system. It can be expected that there are large potential savings from an increased coverage of actions reducing net carbon fluxes. It is crucial to understand that the ultimate goal function of any action should be the maximum reduction of verifiable net greenhouse gas emissions.

Another significant source of potential savings arises from emission trading.[4] Savings from trading increase with the coverage of the trading scheme and with the size of the market. Trading schemes and other flexibilities increase the likelihood of compliance.

The Kyoto Protocol contains four instruments of international flexibility:

1. 'joint implementation' (transborder project investments among industrialized countries that credit savings to the investing Parties; Article 6);

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[4] In this report we will not discuss inefficiencies that arise from the use of second best solutions within a country. Most climate actions considered by Annex I countries are of subsidy character to foster the fast diffusion of best available technology (BAT) and policy actions to reduce carbon emissions also heavily involve regulatory measures (see various National Communications on http://www.unfccc.org /resource/natcom/nctable.html#a1). Such policy measures have a number of drawbacks ranging from dead-weight losses to adverse indirect effects on the carbon and economic systems (see, OECD, 1999). However, subsidy packages, in contrast to higher costs for natural resource use, give the (virtual) impression that policy makers are actively trying to solve the climate problem. In contrast, the first best solution sets, such as the increased charges for the use of natural resources, involve considerable political cost are less popular as we currently experience with the many strikes in European states due to high diesel and gas prices. Mechanisms that hedge the risk of R&D project failures or of carbon taxes could, however, easily be established. Such market mechanisms, such as options and future contracts, could minimize the political risk. Future work will be needed to assess possible double dividends arising from the first best solution in contrast to the likely negative double dividends that could arise from uncoordinated and undercritical subsidy schemes.

2. the ‘clean development mechanism’ (that allows international project investments in developing countries that also contribute to their sustainable development, to generate emission credits that may be used by the investing countries; Article 12);
3. emission trading (Article 17), with all the rules, modalities, guidelines and so forth still to be negotiated; and
4. ‘bubbling’ (allowing redistribution of emission commitments at the time of ratification, principally for the EU; Article 4).

Although these four instruments are rather different, at least from an institutional point of view, they share common features with regard to the concept of market segmentation and verification presented in this paper.

Our task in this paper is to develop a model that builds the theoretical basis for the establishment of CCMS so that the effectiveness of the global carbon market is improved by:

- increased predictability and transparency of the market;
- increased market participation;
- more comprehensive carbon markets with respect to the overall action portfolio; and
- improved political viability due to smoother transition.

In addition, a verification clause should make sure that actions are verifiable and thus provide sufficient knowledge for effective managment and provide sufficient trust in the market that guarantees a functioning market. Proper verification schemes are only possible in comprehensive carbon accounting systems. Thus, CCMS if they turn out to be partial carbon systems should always be accounted for in FCA systems as shown in Obersteiner *et al.* (2000).

The Model

The model presented here is similar in its structure to the model presented in Obersteiner *et al.* (2000). However, the goal is rather different. In Obersteiner *et al.* (2000) we derived a model that allows us to compute the optimal choice of emission reduction and uncertainty reduction for a fixed Kyoto target. Whereas in this paper we are more interested in a hypothetical Kyoto target that the owner of a representative carbon system (e.g., a country’s Annex B emissions[5]) would still be able to support under a given external price schedule. The external price, which mirrors the costs of a benchmark carbon system, can empirically be determined by solving a Kyoto market model as described in, e.g., Grubb *et al.* (1999) for a particular set of countries that should form the benchmark carbon market or some heuristics can be used to determine the price. This concept of a country specific ‘maximum’ Kyoto target is then used to establish clusters of countries of similar targets reflecting the similarity of their underlying carbon systems. Such clusters would be prone to form common markets.

[5] For narrative ease, hereafter we use country and carbon system interexchangeably.

Setting up the Problem

In order to derive the basic structure of the problem, consider a usual Kyoto world where a country has to choose a path of emission reduction to meet a promised Kyoto target. Reaching the target means that the country must choose a certain rate of emission reduction, $\frac{dF}{dt}$, for each time period *t* (see Figure 1). Emission reduction means that a country incurs a cost c_F to finance projects that reduce carbon emissions or induce increased carbon sequestration. If the measures taken are not sufficient or if the cost of emission reduction in the country is too large, countries are allowed to reach the Kyoto target by using a flexible instrument. On the other hand, countries that shoot over the Kyoto target are allowed to sell their surplus on the carbon market or bank for use in subsequent periods.

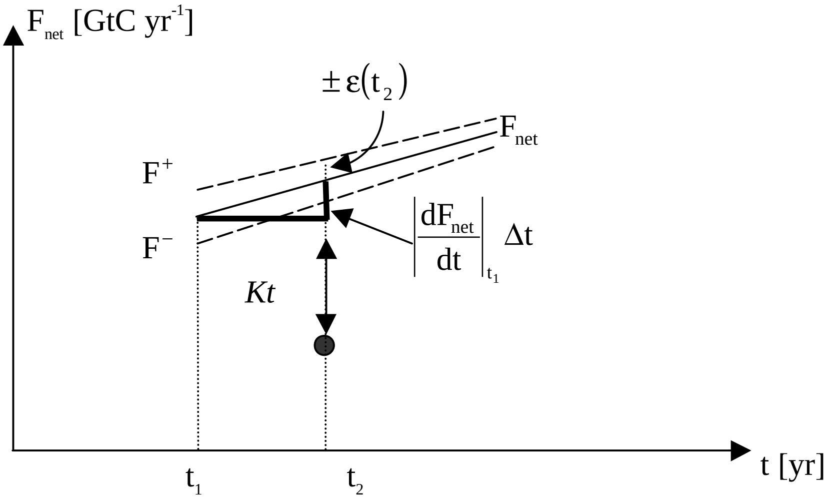

Figure 1: Simplified linear graphical representation of the problem for increasing net carbon emissions ($F_t < F_{t+1}$) and a decrease in their uncertainty ($\varepsilon_t > \varepsilon_{t+1}$) (Source: Adapted from Jonas *et al*., 1999).

Obersteiner *et al*. (2000) introduced an economic concept of verifiable carbon emission reduction. In this concept, countries are penalized for exhibiting uncertainties, which they are allowed to reduce over time by reducing uncertainty. A country starts with an initial uncertainty $\varepsilon = \frac{1}{2}\varepsilon_{t_1} = \frac{1}{2}\left(F_{t_1}^{+} - F_{t_1}^{-}\right)$ in 1990. Uncertainties can be changed at the rate of $\frac{d\varepsilon}{dt}\Delta t = \varepsilon_t - \varepsilon_{t+1}$ through a number of measures. If uncertainties cannot be reduced, the remaining uncertainty will be penalized by reducing the recognized amount of emission reduction, i.e., uncertainty comes at a cost.

Now, we need to derive a model that computes a Kyoto target that, under optimal conditions, would be supported by a given country and a given external market clearing price. The model is set-up as a profit maximization problem computed over one period. Given an external price schedule, profits are maximized by optimally choosing carbon emission reductions $(\Delta F = -\operatorname{sgn}\left(\frac{dF}{dt}\Delta t\right)\left|\frac{dF}{dt}\Delta t\right|)$, change of uncertainties $(\Delta\varepsilon = -\operatorname{sgn}\left(\frac{d\varepsilon}{dt}\Delta t\right)\left|\frac{d\varepsilon}{dt}\Delta t\right|)$, and the Kyoto target (*Kt*). Revenues, within a Kyoto framework, are calculated by the (discounted) value of total emission reductions. Since emission reductions must be verified, we also correct for uncertainties (which is the uncertainty in 1990 (ε) minus the change of uncertainty over a 20-year period in the Kyoto context). Using a zero profit condition we move the emission target so that cost and revenues are balanced, i.e., the shadow value of verifiable emission reduction λ equals the equilibrium price of the benchmark carbon market. The price *p* is assumed to be exogenous to the model and can be interpreted as the solution of a benchmark carbon market. Two types of costs arise if the country decides to take its own steps to actively reduce carbon emissions:

(1) Total cost of emission reduction, which is equal to the total amount of carbon reduced over the commitment period multiplied by the specific average cost c_F. For simplicity here the specific average cost is a function of ΔF and should exhibit the usual properties needed for microeconomic analysis (e.g., Varian, 1992). On a country level this cost function not only includes technological variables but also factors such as population and economic growth; and

(2) Total cost of uncertainty reduction is equal to the total amount of carbon reduced over the commitment period multiplied by the specific average cost c_ε. Similar to c_F, c_ε is a function of $\Delta\varepsilon$ and is assumed to exhibit the required properties in microeconomic analysis.

Formulating the Optimization Problem

The task now is to maximize the following goal function with respect to three choice variables $Kt, \Delta F, \Delta\varepsilon$:

$$\max_{\Delta F, \Delta\varepsilon, \lambda} \pi = \{(\Delta F - (\varepsilon - \Delta\varepsilon)\}p - c_F(\Delta F) - c_\varepsilon(\Delta\varepsilon)$$

$$s.t$$

$$Kt \le (\Delta F - \varepsilon + \Delta\varepsilon)$$

This maximization problem can be used to deduct the optimal solution for an individual country or even an individual project as well as for the ensemble of countries that participate in the carbon market. In a wider interpretation the profit function should also include differences in the expected damages and not just revenues from trading. Such environmental benefits are omitted from this analysis due to keeping the model as simple as possible. The optimization problem needs to be constrained due to the fact that countries are demanded to fulfill the committed emission reduction target (*Kt*) in a verifiable manner. We define verifiability in such a way that we require carbon emission reductions to be larger or equal to the legally binding commitment plus some defined uncertainty. In other words, it is required that the emission target must be over-fulfilled by some uncertainty level or from a different perspective countries are required to undershoot their targets to the extent of their uncertainty. A probabilistic interpretation of the constraint is given in Figure 2. In a probabilistic interpretation it is required that there is sufficient probability mass below the target (point at time t_2). It is required that the reported emission reduction rate (smiley face) must increase to the extent that the density function is shifted downward (from the dot to the smiley), so that the probability of meeting the emission reduction target is larger than a required probability, i.e., $P(Kt \leq \{\Delta F - \varepsilon + \Delta\varepsilon\}) \geq k$.

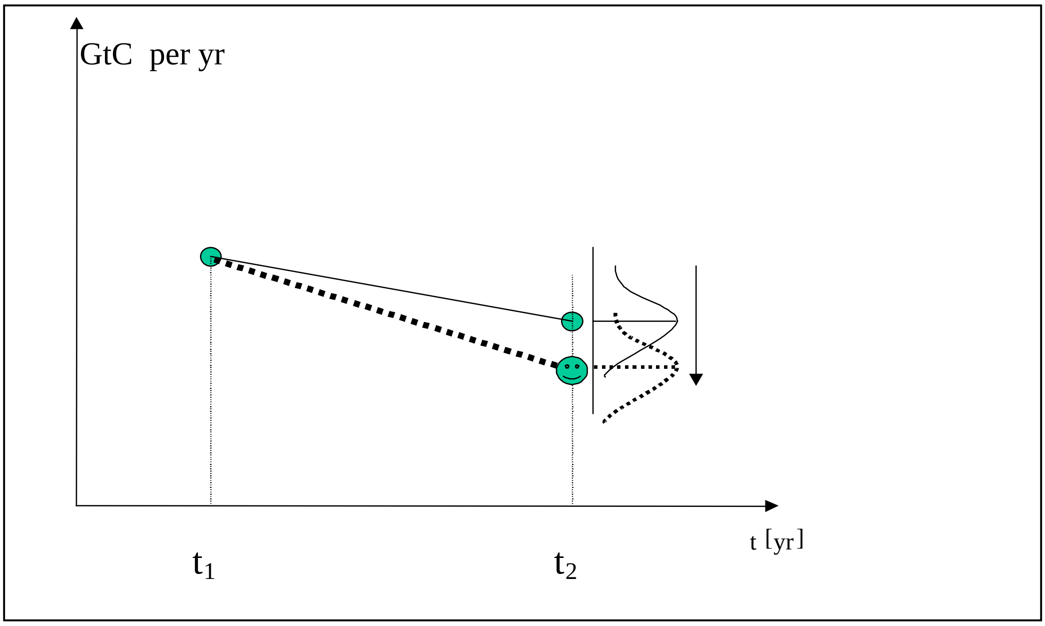

Figure 2: Linear trend verification concept. The trend is verifiable if there is sufficient probability mass below the target point (dot, trend symbolized by the thin solid line). The verifiable trend is symbolized by the thick dotted line and results from shifting the density function downward so that is sufficient probability below the target and the new target (expected trend) becomes the smiley face.

Setting up the Lagrangian,

$$\max_{Kt,\Delta F,\Delta\varepsilon,\lambda} \pi = \{(\Delta F - (\varepsilon - \Delta\varepsilon)\}p - c_F(\Delta F) - c_\varepsilon(\Delta\varepsilon) - \lambda\{Kt - (\Delta F - \varepsilon + \Delta\varepsilon)\} \quad (1)$$

In order to find the maximum we need to calculate the first order conditions (FOC):[6]

$$\frac{\partial \pi}{\partial (Kt)} = -\lambda = 0 \quad (2)$$

[6] Notational simplification: We define $\frac{\partial c_F}{\partial \Delta F} = c'_F$ and $\frac{\partial c_\varepsilon}{\partial \Delta\varepsilon} = c'_\varepsilon$.

$$\frac{\partial \pi}{\partial(\Delta F)} = p - \{c_F'(\Delta F) + c_F\} + \lambda = 0 \tag{3}$$

$$\frac{\partial \pi}{\partial(\Delta \varepsilon)} = p - \{c_\varepsilon'(\Delta \varepsilon) + c_\varepsilon\} + \lambda = 0 \tag{4}$$

$$\frac{\partial \pi}{\partial(\lambda)} = -\mathrm{Kt} + \{\Delta \mathrm{F} - \varepsilon + \Delta \varepsilon\} = 0 \tag{5}$$

From equations (2) and (3) follows an expression for ΔF and from equations (2) and (4) an expression for $\Delta\varepsilon$ as a function of the external price and the specific average costs and their marginal costs. Directly using these two expressions we can rewrite equation (5), which gives us:

$$Kt^* = \frac{p - c_F}{c_F'} - \varepsilon + \frac{p - c_\varepsilon}{c_\varepsilon'} \tag{6}$$

Figure 3[7] shows the plot of the solution to the maximum Kyoto target problem of equation (6). We can see that Kt^*, the optimal country specific emission target, increases exponentially with decreasing distance to the minimum of the average cost curve. To the left, the maximum of Kt^*, the emission reduction is under-critical and economies of scale or other positive feedbacks cannot be fully exploited. Below an emission reduction of 30 carbon units per commitment period the country would lose compared to the other market participants. To the right, the marginal cost is increasing, thereby suggesting that any further step to reduce carbon emissions brings with it an increase in the average cost of emission reduction. Up to 170 carbon units per commitment period, it would still be profitable to trade carbon in this particular market.

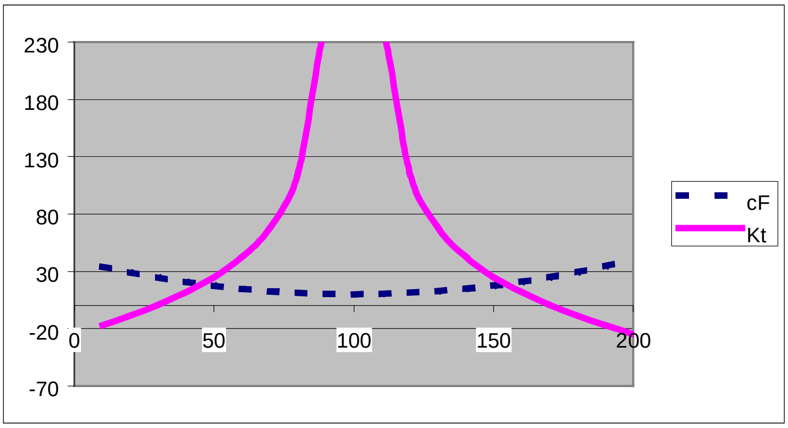

Figure 3: Optimal emission reduction target (*Kt*) and cost of emission reduction (c_F) as a function of emission reduction ΔF.

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[7] Here, we assume a simple quadratic cost function: $c_F = a(\Delta F - k)^2$ with *a= 0.003* and *k=10*, assuming no uncertainty ($\varepsilon = 0$), and *p=25 mU per carbon unit.*

Deriving the Segmentation Concept

Equation (6) represents a distance measure of a particular country up to which it could potentially be profitably engaged in a carbon market described by the benchmark carbon market. There is also a direct interpretation of equation (6). The larger the profit margin on a unit basis and the smaller the marginal average cost, the larger the distance to the optimal Kyoto target. Kt^* is the theoretical amount of verifiable carbon reduction, which a country could profitably produce given an exogenous price benchmark. It, thus, reflects the relative advantage of carbon reduction of a country's carbon system compared to the sum of all the other parties producing the benchmark market equilibrium.

Depending upon the market structure, on the one hand its rules and on the other its dynamics and cost structure, a country can either gain or lose or, worse yet, not be willing to join in the market. In this way, the country specific Kt^* becomes a measure of competitive advantage. Kt^* allows establishing a metric, where carbon systems can be plotted and distances are measured. Such a metric can be used to:

1. Make inference on the behavior of a carbon market actor in the negotiations on the rules to be established, and
2. Compute market segmentation of approximately equal actors based on a maximum Euclidean distance concept.

The first point made is illustrated in Figure 4. Figure 4 plots player **A**'s Kt^* under different markets. **A** can be thought to be the city of New York under different market rules. Under market rules which exclude biospheric actions to a large degree, but give credits for FF emission reduction, $\mathbf{A_{FF}}$ will have an advantage since net emission reduction can be implemented at comparatively low cost and Kt^* is large. In other words, New York would be able to profitably reduce carbon emissions up to Kt^* given the market condition of $\mathbf{A_{FF}}$. However, under market rules that favor mainly biological measures of reforestation and soil carbon conservation, the Kt^* will be negative for both the biological action and the FF action. The latter is negative due to fact that FF actions are not competitive with BIO actions and combined with a necessary cross-subsidization would make the remaining FF actions also non-competitive. Under market rules that allow for a large variety of emission reduction measures $\mathbf{A_{FF+BIO}}$ loses its competitive advantage compared to the FF dominated market, but gains relative to the market governed by rules favoring BIO actions.

Based on this illustrative example, we can now make inference on the outcome of negotiations defining the rules of a possible carbon market. For New York, it would be best to vote for market rules reflecting the competitive advantage under $\mathbf{A_{FF}}$. If New York has sufficient voting power then such rules would be established with at least two consequences that:

- biospheric actions, despite the fact that globally they could be more cost competitive, would be disqualified from the market, and
- only market participants which are favored by $\mathbf{A_{FF}}$ rules would stay in the market.

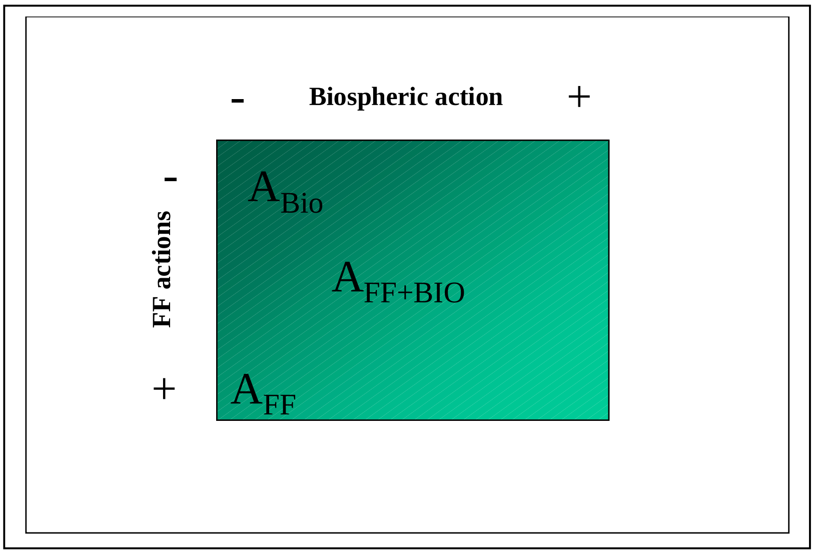

Figure 4: Kt^* under different market rules for country **A.** Kt^* is the measure on both axis.

These conclusions lead us to the second point made above and discusses the issue of forming CCMS. We have learned that market constellations could be such that entering countries would immediately want to exit the market due to the fact that their expected losses are too large or that the rest of the countries that already joined the market would suffer from price inflation due to the new entrant's large volumes of low cost emission reductions sold at that market. What market segmentation can do in such situations is to try to narrow the gap between losers and winners. In this respect, market segmentation does not necessarily lead to a Pareto improvement in the short run,[8] but the implementability of emission markets can be improved leading to more emission reductions. A clustering based on the distance measure Kt^* would help to establish improved rules and make the process of negotiation more transparent and efficient. If countries clump in (multi-dimensional) Euclidean space,[9] i.e., Euclidean distances between countries are sufficiently small, it seems to be sensible to establish a common market for such countries with a set of rules suited to the peculiarities of this group of countries. Such markets can be established based on factors such as the type of emission reduction measures as illustrated above for FF versus BIO, but also with respect to the term structure of such measures,[10] and stochastic nature and uncertainty of the respective carbon (sub-)systems.

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[8] Pareto improvement in the long run could arise in a situation of large externalities of Kyoto measures due to the superiority of new innovations creating double dividends. Pareto improvement could also arise if market segmentation in fact increases total emission reduction and the expected damage of this additional reduction is higher than the discounted costs.

[9] Country **A** and **B** are clumped if, with respect to the factors i, the following holds: $\sqrt{\left(\sum_i \left(\frac{\partial F}{\partial F_A}\right)^2 (Kt_i^A)^2 - \sum_i \left(\frac{\partial F}{\partial F_B}\right)^2 (Kt_i^B)^2\right) - 2\left|\left(\frac{\partial F}{\partial F_A}\right)(Kt_i^A)\right|\left|\left(\frac{\partial F}{\partial F_B}\right)(Kt_i^B)\right| \cos\left(\left(\frac{\partial F}{\partial F_A}\right)(Kt_i^A), \left(\frac{\partial F}{\partial F_B}\right)(Kt_i^B)\right)} \leq d^*$, where d^* is the benchmark in Euclidean space.

[10] Note that so far, all variables have been treated within one fixed time period. So, for example, emission reductions can be interpreted as $\Delta F = \sum_i \sum_j \sum_t \Delta F_{ijt} p_{ijt}$, where i stands for the type of action, j for the country (project), t for time. p is a probability measure of the success of emission reduction actions.

Discussion

Carbon systems[11] are *inter alia* different with respect to their comprehensiveness of the carbon subsystems they cover, their stochastic dynamic behavior, the underlying technologies and socioeconomic systems. If production systems are very different, then the features of the products and the production processes of such a product will be different. It follows that the products will have to be traded on different markets in order to minimize risk for market participants. If the true shape of the cost curves of competing products is very uncertain then entry to the market will be inhibited. Thus, market segmentation will prove to be beneficial for at least four reasons:

1. Increase predictability of the market.
2. Decreased disparity among market participants will lead to higher participation.
3. Market effectiveness will improve because participants can produce carbon reductions closer to their idiosyncratic optimum.
4. Carbon markets will be more comprehensive with respect to carbon subsystems that are admissible for trading.

All four arguments suggest that market segmentation will lead to more carbon reductions through an increasing number of participants, more projects, longer integration over time, and improved efficiency reflecting the differences of the carbon system.

In this paper we derived a model that allows the prediction of market segmentation based on the analysis of the governing factors of the different carbon systems. We suggest that if the system inherent differences, which are created by the restriction of rules governing the market, are too large, losing parties will want to exit the market. In the proposed model, differences are measured in Euclidean distances in a metric established by the use of an optimal emission reduction target concept that was deduced from a profit maximization problem. This methodology can be used to identify clusters of countries (projects), which are similar in their systems behavior and cost structure. Based on this analysis such countries are then identified to form a common carbon market. The optimal rules governing such a market can directly be deducted from the analysis reflecting the peculiarities of the underlying carbon systems. With this tool kit in hand one can not only give advice on the optimal strategy in a certain setting of the market game, but also give answers on how to change the rules of the game to increase market efficiency.

In the absence of economic cost information, a first cut analysis of the physical parameters of the carbon system can be used to establish country clusters along various segmenting factors *i*. Segmenting factors could turn out to be *inter alia* a damage factor, accumulated or current contributions to GHG emissions or its reduction, system boundaries such a the composition of GHG, geographic boundaries or boundaries like technosphere and biosphere, and simple cost differences and uncertainty differences. Building on the verification time concept first developed in Jonas *et al*. (1999), we can

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[11] In this text carbon systems should be interpreted as systems that emit or sequester GHG not only carbon.

establish the following distance function concept for a particular country (project) with respect to a respective benchmark Kyoto target $\hat{K}t$:

$$d = \prod_i \operatorname{sgn}\left\{\left(\frac{\partial F}{\partial F_i}\right)\left(\hat{K}t_i - \frac{\partial F_i}{\partial t}\Delta t + \varepsilon_i - \frac{\partial \varepsilon_i}{\partial t}\Delta t\right)\right\}\sqrt{\sum_i \left(\frac{\partial F}{\partial F_i}\right)^2 \left(\hat{K}t_i - \frac{\partial F_i}{\partial t}\Delta t + \varepsilon_i - \frac{\partial \varepsilon_i}{\partial t}\Delta t\right)^2} \quad (8)$$[12]

Equation (8) does not describe the maximum distance to a benchmark market, but the computed distance is described by the difference of the factual state of carbon net flux at *t+1* approximated at *t* using a first order Taylor approximation and the benchmark Kyoto target $\hat{K}t$.

Such clustering would have the advantage that uncertainties that arise from the approximation of the respective cost curves can be dismissed from the analysis. Cost curves are crucially dependent on technological innovations, which can cause dramatic shifts in the parameters of the cost functions. Another factor that is implicitly contained in the cost function is the inertia of technological and socioeconomic systems. Physical approaches are more capable of directly describing and capturing such phenomena, but non-linearity could also lead to interesting surprises (Gusti and Jeda, 2000). On the other hand, costs and innovation are the major drivers of real markets, which leads us to the conclusion that future research will have to be conducted using both approaches.

Conclusion

In this report we derive a concept, that allows us to compute maximum emission reduction targets. This concept allows us to plot countries' (projects') relative competitive advantage with respect to carbon emission reductions relative to a benchmark market of interest. Establishing this metric enables us to identify clusters of countries with a similar structure, interest and dynamics of carbon systems. The basic underlying question is: "Is it reasonable to assume that high potential damage countries with low per capita emissions will trade under the same rules in the same market with low damage high per capita emission countries?" In cases where countries show a high degree of similarity measured by Eucledian distances, we suggest that CCMS should be formed according to these clusters. It can be expected that market segmentation will lead to increased total participation in carbon markets. In addition, market segmentation will help in making the carbon market more effective. Under the current Kyoto rules many large players clearly reject to join the Kyoto market due to the apparent large differences in the underlying carbon system. In this respect, the Kyoto Protocol failed to establish a market segment for those countries that are unwilling to participate or are willingly excluded. With the help of the model presented in this paper one can not only identify potential CCMS, but also the set of optimal rules governing such a market

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[12] Similar to the Euclidean distance function in footnote 5 we need to introduce a correction factor CF to get normal distances between market participants. The correction factor is the product of the absolute values and the joint cosinus function. The distance in equation (8) is measured from the origin. We are, however, interested in the distance between market participants.

segment can be directly derived from the model structure. The rules reflect the common features of the underlying carbon systems forming the market.

We also conclude that despite market segmentation an overarching accounting system should be established. Uncertainties in GHG accounting are made up of essentially two components. Random errors and biases, where biased reporting can be used for intentional cheating. It is reasonable to assume that the probability of biases decreases with the comprehensiveness of the system analyzed, because we can make consistency checks. It is, thus, indispensable to always monitor the entire GHG system (Full GHG Accounting [FGA]) irrespective of what kind of actions are credited for in the Kyoto mechanism. A FGA should always be the compulsory monitoring system, whereas actions that are the means to get to the target and are subject to the Kyoto market rules have to be accounted for as (a) consistent subsystem(s) (Partial GHG Account [PGA]) within a FGA. Verification should make sure that the acknowledged credit influenced the atmospheric GHG balance in the intended (claimed) fashion. FGA provides the necessary accounting framework and carries the possibility of top-down verification under certain conditions.

A strong and independent international agency that is responsible for the assessment of verifiable emission reductions should be established. Either individual countries take measures themselves to lower uncertainties under the supervision of the international agency or they have to live with the verification penalty for the uncertainties that were assessed. Monitoring cost will probably decrease with increasing scale when countries join forces to decrease uncertainties. Some sovereign states will probably refuse inspections on their territory despite severe penalties.

Future research will be conducted on the empirical establishment of country clusters using the physical and the economic approaches of Eucledian distance computation.

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