Post-2012 International Climate Change Policy (Draft 06/26/06)

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ABSTRACT

This paper discusses several aspects of international climate change policy. It begins by describing background information leading up to the Kyoto Protocol as well as information related to the period after 2012 (which marks the end of the first "commitment period" of the Protocol). It then proposes and describes three separate, but related problems: the "Scientific Problem", the "Emissions and Economy Problem", and the "Climate Change Policy Problem. The paper then proposes and explains the derivation of the Kaya equation and the carbon intensity measure based on it. After a short sketch of some of the post-2012 policy literature, an illustrative example of a global warming policy is presented. Conditions for the feasibility of a Climate Change agreement are developed. Some additional possible relationships between a carbon emissions trading system, such as the effect of emission trading on technological innovation and on funding of an Adaptation Fund, are suggested. Next a numeric illustration of a Global Agreement is presented. Finally, some additional issues are described and further research suggested. Appendices further analyze and discuss a rationale for different ways to allocate emission allowances and presents a two-agent graph of a carbon emissions trading.

1. Institutional Background Information:

The United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992 at the Rio de Janeiro meeting of the United Nations Conference on Environment and Development (UNCED). The UNFCC treaty went into force in 1994 and currently has 166 signers including the United States. Article 2 of UNFCC states:

> …The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the

atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". (UNFCCC Article 2)

The Framework Convention on Climate Change further suggests that

"Such a level should be achieved within a time frame sufficient
- to allow ecosystems to adapt naturally to climate change,
- to ensure that food production is not threatened and
- to enable economic development to proceed in a sustainable manner(*ibid.*).

The question "What constitutes "dangerous interference with the climate system"? or more simply "What constitutes dangerous climate change?" is a key question that has been the focus of much discussion. An increase of global average temperature of 2 degrees centigrade over pre-industrial levels has been a reference point in such discussions. Currently there has been a 0.6 degree centigrade increase in global average temperature over pre-industrial levels.

The Kyoto Protocol, though adopted in 1997, did not go into force until February 16, 2005. As of September 2005, 157 countries are signers. The most notable non-signer is the United States. For a group of countries, called the Annex B countries (almost identical to Annex I industrialized counties)[1], the treaty specifies emission targets for each Annex B county's average carbon emission levels for the period 2008 – 2012, the "first commitment period". For non-Annex I countries emission targets were not specified.[2]

Six nations (Australia, the People's Republic of China, India, Japan, South Korea, and the United States) on July 28, 2005 signed the Asia Pacific Partnership on Clean Development and Climate. This agreement did not specify emission reduction targets for countries.

The Conference of the Parties (COP11) and the Meeting of the Parties (MOP1) were held in Montreal Nov. 28 – Dec. 9, 2005). These were the first, full formal sessions considering international climate treaty policy beyond 2012, the end of the first Kyoto commitment period[3]. The meetings resulted in the "Montreal Plan of Action". One component of this plan established a process for negotiating further and deeper reductions in emissions for Annex I countries that are signers of the Kyoto Protocol. Also all countries, including the US and Australia, two Annex I non-signers of the Protocol, will begin a dialogue on "any and all ways to cut emissions". This involves meeting which will take place before the next annual COP/MOP in November 2006. No timetable was established for completion of this process.

[1] The list of Annex B countries in the original Kyoto Protocol was identical to the list of Annex I countries in the UNFCCC except, Annex B countries did not include Belarus and Turkey. In this paper the term "Annex I" countries will be used instead of Annex B. Not all Annex B countries signed the Kyoto Protocol, most notably the United States and Australia.

[2]In addition provisions were made for countries to achieve their commitment levels, in part, with the use of the Clean Development Mechanism (CDM) and Joint Implementation (JI) Programs which provide ways to account for projects between countries that are shown to result in lower emission levels compared to a base line estimate of what would be the case without the project.

[3] The Kyoto Protocol furthers the UNFCCC Treaty. The first commitment period of the Protocol is 2008-2012. It would be incorrect to refer to agreement for the period after 2012, in so far as it is a continuation of approaches, as a "Post-Kyoto" Agreement or Policy, but rather a post 2012 Agreement or Policy.

2. Some Observations of theoretical questions involved

It may be useful to consider Climate Change policy as three separate, but related problems.

The first problem could be called the "Scientific Problem": given a time path of anthropogenic emissions of greenhouse gases (GHGs) what is the time path and interactions of the components of the climate system: oceans, atmosphere, land surface and cryosphere (snow, ice and permafrost)?

The second could be called the "Emissions and Economy" problem: how do GHG emissions relate to the level of GDP and how do the climatic impacts of GHGs translate into economic impacts?

The third problem could be called the "Climate Change Policy" problem: how do countries and other agents interact (or not interact) to shape (or not shape) a coordinated response to Climate Change?

We will examine each of these questions further.

A. The Scientific Problem:

The basic facts underlying the Scientific problem are not in dispute:

- Particular anthropogenic gases, greenhouse gases, GHGs, (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride) absorb heat radiation. The Greenhouse effect is not disputed (IPCC, 1990)

- Atmospheric concentrations of these GHGs are increasing, for example, atmospheric concentrations of CO2 are 30% higher than at the start of the industrial age (IPCC, 1990) and are at the higher level in over 650,000 years as determined by analysis of air bubbles trapped in deep ice cores taken from Antarctica (American Association for the Advancement of Science 2005). This is sometimes referred to as the basis for the "enhanced greenhouse effect" arising from anthropogenic additions of GHGs

- To stabilize atmospheric concentrations of CO2 would require a 60 – 80% reduction CO2 emissions (IPCC, 1990)

- Even after atmospheric concentrations of CO2 stabilizes, global average temperatures would continue to increase before they stabilize (the thermal lag in the climate system) (New Zealand National Climate Center, 2006).

- The consensus estimate of the IPCCC was a 2 – 4 degree increase in global average temperatures by the end of the century depending in part of CO2 emissions.

Complicating this situation is the possibility of "abrupt climate" change, where in a period of decades significant changes could occur, e.g. a slowing of the Atlantic thermohaline circulation, which could result in significant reductions of temperature in Europe. Atlantic thermohaline circulation is driven by the difference in salinity of at different depths of the ocean. The salinity of the upper Atlantic is decreasing because of increasing glacial melt into the Atlantic. Overall, thermohaline circulation and the likelihood or timing of change occurring are not well understood.

Because of the uncertainty associated with understanding the climate system, the situation involves unknown probabilities (Meteorological Service of Canada, 2006). Consequently the question "Is it too late" to act on climate change is not the appropriate question. The analogy has been made that humans are "loading the dice" in ways that increase the chances of undesirable outcomes. The more humans increase GHG emissions, the more likely undesirable outcomes become, and it also becomes more likely that the worst of these outcomes could occur.

Though some suggest that the "tipping point" has already been passed, i.e. that some processes like melting of the Greenland ice cap, may already be irreversible (McCarthy 2006), there is still uncertainty regarding whether such a tipping point has been passed or not (Department of Environment, 2005). Consequently reducing GHG emissions that contribute to the Greenhouse effect and climate change would still tend to reduce the risks of undesirable climate change and would tend to reduce the risks of the worst cases occurring.

B. The Economy and GHG Emissions Problem:

i. The case of CO2 from fossil fuel use

The Kaya equation (Kaya, 1990, 1997) provides a very useful decomposition of the relationships involved in carbon emissions.

First, the Kaya equation, is derived from the Kaya Identity:

$$\text{POP}\ \frac{\text{GDP}}{\text{POP}}\ \frac{\text{Energy}}{\text{GDP}}\ \frac{\text{Carbon}}{\text{Energy}} \equiv \text{Carbon} \qquad (1)$$

where:

POP is population
GDP is GDP
Energy is use of energy
Carbon is carbon emissions (primarily from fossil fuel use).

Clearly, the above is an identity, true by definition, since all the terms on the (left hand side of the equation (LHS) cancel except for carbon leaving carbon equal to carbon.

Here we find it useful to compress carbon intensity of energy, and energy intensity of GDP, to [4]a single carbon intensity of GDP variable.

$$POP \; \frac{GDP}{POP} \; \frac{Carbon}{GDP} \equiv Carbon \qquad (2)$$

Taking the natural logarithms of both sides yields:

$$\ln POP + \ln(GDP/POP) + \ln(carbon/GDP) = \ln carbon \qquad (3)$$

If the above is done for period t and again for period t+1, and the equation for period t is subtracted from the equation of period t + 1, we obtain expression that is the definition of the growth rates for each of the components, namely:

Growth rate of POP + Growth rate of per captia GDP + Growth rate of carbon intensity = the growth rate of carbon emissions

Using Γ for growth rate:

$$\Gamma\, POP + \Gamma\,(GDP/POP) + \Gamma(carbon/GDP) = \Gamma\, carbon \qquad (4)$$

This can be used to relate trends in the above variables. Since 1990 global population has increased approximately 1.5% per year, per capita GDP 2.5%, and carbon intensity has declined, -3% and carbon emissions increased at approximately 1% per year. This is consistent with the Kaya equation, namely:

$$1.5\% + 2.5\% - 3.0\% = 1\% \qquad (5)$$

Subtracting ln(POP) from both sides of equation (3), results in an equation for the growth rate of per capita emissions:

$$\Gamma\,(GDP/POP) + \Gamma(Carbon/GDP) = \Gamma\, Carbon/POP \qquad (6)$$

For the 1990 – 2003 period, these values are approximately,

$$2.5\% - 3.0\% = -0.5\% \qquad (7)$$

In other words for this period per capita emissions have declined globally at a rate of ½ a percent per year.

For carbon emissions to peak globally, Γ Carbon must equal 0. Referring back to equation 4, Γ Carbon must equaling zero implies that

$$\Gamma POP + \Gamma\,(GDP/POP) + \Gamma(Carbon/GDP) = 0 \qquad (8)$$

or

$$\Gamma\,(GDP/POP) + \Gamma(Carbon/GDP) = -\Gamma POP\,) \qquad (9)$$

[4] Some argue a Kuznets-type curve regarding GDP and CO2 emissions (Pan 2003). i.e. as low income economies grow, their carbon intensities tend to rise. Eventually with further growth carbon intensities tend to fall.

Consequently, if Γ (GDP/POP) is positive, i.e. if per capita GDP is growing, and for carbon emissions to peak, carbon intensity of GDP must be the same magnitude as per capita GDP growth plus the growth rate of population, but negative.

$$\Gamma(\text{Carbon/GDP}) = -(\Gamma(\text{GDP/POP}) + \Gamma\text{POP}) \qquad (10)$$

If carbon emissions are to decline globally, the carbon intensity must decline at a greater rate than population and per capita GDP increase. To achieve this, the two components of carbon intensity, carbon intensity of energy and energy intensity of GDP must be such to result in the needed decline in carbon intensity.

ii. The relationship of GHG emissions and economic impacts of climate change

Because the Scientific Problem is beset with uncertainty, estimating the economic impacts of climate change is basically uncertain. It is difficult, perhaps, impossible, to ascertain how much a particular climatic circumstance is attributable to change in the climate system; for example how much of the damage from Hurricane Katrina is attributable to climate change? Climate models do suggest that tropical storms will tend to be more severe with climate change. Consequently the difference between a the results of a climate model based on one set of GHG emissions over time, could be compared with that model based on another set of GHG emissions over time and the difference in economic impacts between these two scenarios could be estimated.

Climate impacts would vary over regions and would affect different groups and interests within regions differently. Determining the total global economic impacts would be difficult, if not impossible and is likely to involve subjective assumptions that could be questioned. Comparing net global net benefits, i.e. economic impacts minus climatic damage, for different time path of emissions could provide some useful insights. For example, annual GHG emissions that are likely to lead to result in a 2 degree increase in global average temperatures over pre-industrial global average temperature (Jaeger, 2005) appear to some, including the European Union, to result in climatic damages that exceeds the economic benefits of these higher GHG annual emissions and appear consistent with the UNFCCC objective of

> ...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (UNFCCC Article 2)

iii. Climate Change Policy Problem

Rather than there being a common response to a common global problem, the global response will be the determined by the interaction of agents (ranging from some form of cooperation to completely independent action). Some of this interaction is reminiscent of the Prisoner's Dilemma: each entity acting independently could lead to global GHG emissions that, taking into account climatic damage for that entity, are less desirable for that entity than, if each entity reduced its GHG emissions. But if one entity reduces its GHG emissions and other do not, then that entity has lower net benefits than if it acted uncooperatively in its own self interest.

Also at the level of countries, there are significant differences regarding what is felt to be fair and just. A view supported by developing countries is that the current situation is the result of GHG emissions largely from industrial countries. Consequently industrial countries have correspondingly large responsibility to reduce emissions. Further, a related view is that developing countries have a right to develop, and so they need to be allowed GHG emissions, particularly CO2 emissions, sufficient to develop and grow.

There are differing views on the extent that GHG emissions, particularly CO2 can be reduced through energy efficiency and technological innovations. Other differences involve the efficacy of international agreements, including the efficacy or desirability of specifying emission reduction targets for countries and differences regarding the extent that emissions can be achieved voluntarily.

At the COP11/MOP1, the Montreal climate change meetings, dissatisfaction was expressed regarding the small number and small quantity of emissions covered by approved CDM projects. Also concern that funds for "adaptation" (funds to address immediate needs arising from climate impacts, especially in developing countries) were inadequate.

The above discussed issues and concepts will be addressed in a further analysis of Global Climate Change Policy. After the following review of the literature

3. Sketch of Some Post 2012 Policy Literature:

There have been many meetings, discussions, and publications concerning the post 2012 period.

The IMF published "*International climate regime beyond 2012: Are allowance allocation rules robust to uncertainty"* (Lecocq and Crassous, 2003). Discussed were different criteria for assigning allowances, e.g. "Grandfathering where "allowances are distributed pro rata [based on] past emission levels", per capita allocation, "ability-to-pay", "multi-criteria", and "Historical Responsibilities," which indexes allowance allocation to the relative responsibility of each country for atmospheric carbon concentrations and a "bottom-up" approach which divides each country into three sectors, heavy industry, power generation and domestic with "[a]batement targets for the former two derive from assumptions about growth, generation and technical substitution. Allowances for the third sector are based on a per capita emissions allocation."

Meetings were held in 2003 and 2004, involving among others, Kristian Tangen (Norway), Taishi Sugiyana (Japan), Axel Michaelowa (Germany) and Jiahua Pan (China) and Henrik Hassleknippe (Norway). These five co-authored a Briefing Paper "Scenarios for the global Climate Regime (www.fni.no/post2012/briefing_paper.pdf). Four scenarios were developed titled "Graduation and Deepening"; "Market Convergence; Orchestration of Treaties"; and Human Development with Low Emissions; and "Human Development with Low Emissions" (see the Briefing Paper for discussion of these scenarios). These same authors published another Briefing paper "Where to next? Future steps of the global climate regime (December

2004, www.fni.no/doc&pdf/where-to-**next**.pdf). This paper had sections entitled "Re-engaging the US"; "Acceptable and predicable targets"; and "Breaking the Stalemate". The paper suggested that "Equitable target setting may secure global participation". Relevant to the preceding is a paper by Pan "Understanding Development Potentials and Demands for Greenhouse Gas Emissions" (2003, www.ccchina.gov.cn/english/source/ga/ga2003082101.htm).

In 2004 the Pew Center published *International Climate Efforts Beyond 2012: A Survey of Approaches* (Bodansky) which systematically characterized 44 different "Beyond 2012" proposals. Robert Stavins of Harvard published "Forging a More Effective Global Climate Treaty," in the December 2004 issue of *Environment*. Stavins observed that a second commitment period should be designed to attract both the United States and developing countries; that top-down approaches are complemented by bottom-up measures and that technology transfer from industrialized to developing nations is an essential ingredient in this process.

Previously Aldy, Barrett and Stavins (2003) published "Thirteen Plus One: A Comparison of Global Climate Policy Architectures" that evaluated possible policy "architectures" and concluded that "Kyoto is "too little, too fast"; developing countries (DCs) should play a more substantial role and receive incentives to participate; implementation should focus on market-based approaches, especially those with price mechanisms; and participation and compliance incentives are inadequately addressed by most proposals."

Many presentations relating to post-2012 climate policy were made at the Montreal meetings. These will be surveyed in future versions of this paper[5].

4. Analysis of the Global Warming Policy Problem – An Illustrative Example

For purposes of illustration consider the case of two agents, the Annex I (I) or industrialized country agent, and the Non-Annex I (Non-I), developing or non-industrial country, agent.

A. Without A Global Climate Agreement Case

Consider first the case where there is no international agreement on a Global Climate Change Policy. Each agent's annual emissions for a particular year are, among other things, an increasing functions of its own GDP and its own carbon intensity. World emissions are the sum of the emissions of the two agents. Although this applies to all GHGs, for purposes of illustration, we are considering this to be the case of CO2 emissions from fossil fuel use. The above can be expressed as:

$$E^{I}{}_{w/o} = E^{I}{}_{w/o}\,(GDP^{I}, C^{I}/GDP^{I}) \qquad (11)$$

$$E^{Non\text{-}I}{}_{w/o} = E^{Non\text{-}I}{}_{w/o}\,(GDP^{Non\text{-}I}, C^{Non\text{-}}{}_{w/o}GDP^{\,Non\text{-}I} \qquad (12)$$

[5] One of these presentation was by Robert Lempert on the book *Shaping the Next 100 Years* and the article "Shaping the Future" (Popper 2005), who will be a presenter in a session, the author is organizing for the Western Economic Association International Conference in San Diego in July, 2006.

$$E^{I}_{w/o} + E^{non\text{-}I}_{w/o} = E^{W}_{w/o} \qquad (13)$$

Each agent has a subjective estimate, or "view" of the range of emissions it is likely to experience. These are shown in the figure below, where the line segment AB is the I's view of its likely annual emissions of the range of its own emissions. Line segment CB is the Non-I's view of its likely annual emissions of the range of its own emissions. The lowest world emission level is the sum of points A and C and the highest emission levels are the sum of point B and D.

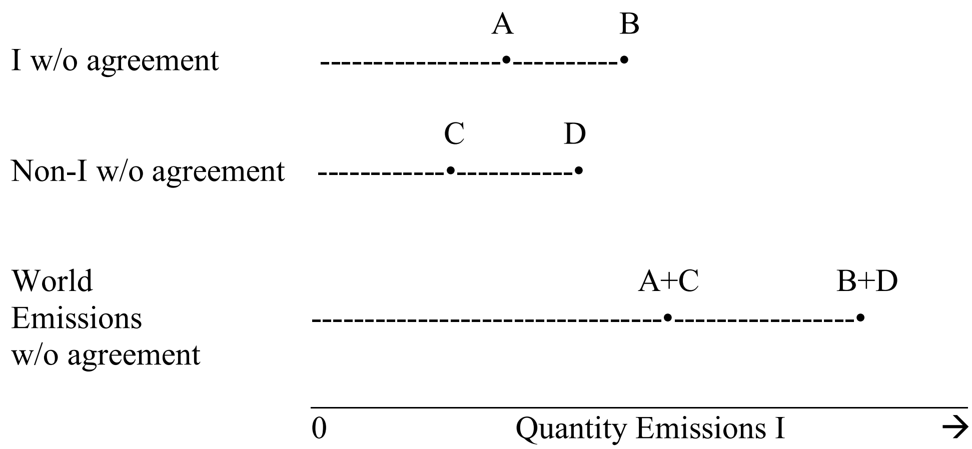

Figure 1: Agents' Views and World Emissions Range without a Global Climate Agreement
(note: a numeric illustration of the above will be presented in a later section)

B. With a Global Climate Agreement Case

Suppose welfare[6] (W), for agent I (W^I) is an increasing function of I's GDP (GDP^I), and a decreasing function of the Climatic Damage experienced by I (D^I). Welfare (W), for agent Non-I ($W^{Non\text{-}I}$). is an increasing function of Non-I's ($GDP^{Non\text{-}I}$), GDP and a decreasing function of the Climatic Damage (D), experienced by Non-I (D^I).[7]

Consider a global agreement where the world emissions level (E^{W}_{A}) is the sum of I and Non-I's emissions with this agreement:

$$E^{W}_{A} = E^{I}_{A} + E^{Non\text{-}I}_{A} \qquad (15)$$

[6] By welfare we mean the utility function for representative of the agent negotiating the agreement. This could include political consideration regarding changes in the electability of the administration negotiating the agreement

[7] For our purposes here consider agent's welfare a being for the particular year in question. We are already treating the five years of the second commitment period. A five year time horizon may approximate the time horizon for a politically motivated agent. A more complex model could consider the present value of GDP in future years and the present value of climatic damage in future years.

And where the world emission is greater than the lower bounds of the range of world emission levels without an agreement ($E^{W|a+c}$) and lower than the upper bound ($E^{W|b+d}_{w/o}$) (16)

$$E^{W|a+c} < E^{W}_{A} < E^{W|b+d}_{w/o} . \qquad (17)$$

A global agreement would be feasible, if welfare for I with E^{I}_{A} , is greater than I's welfare with $E^{I}_{w/o}$ and welfare for Non-I with $E^{Non\text{-}I}_{A}$ is greater than Non-I's welfare with $E^{Non\text{-}I}_{w/o}$.

$$W^{I}(E^{I}_{A}) > W^{I}(E^{I}_{w/o}, D^{I}(E^{W}_{w/o})) \text{ and} \qquad (18)$$

$$W^{Non\text{-}I}_{w/o}(E^{Non\text{-}I}_{A}) > W^{Non\text{-}I}(E^{Non\text{-}I}_{A}, D^{Non\text{-}I}(E^{W}_{w/o})) \qquad (19)$$

If such a world emission level exists, then designate it as $\acute{E}^{W}_{A}$.

The feasibility conditions and the levels of world and I and Non-I emissions can be further specified.

Suppose Agent I not only has a view of its own likely emissions, but also has an estimation of the range of emissions that are feasible for Non-I. This could be based on a different estimation the impact of technological improvements on Non-I's emissions. Suppose that this range of emissions given technological improvements is represented by the line segment EF. Suppose also that Non-I's view is that Agent I has a responsibility, given its history of emissions, for reducing its annual emissions greatly. Suppose that the very least Non-I expects Agent I to reduce is given by point G_{min} and could be a greater reduction indicated by the arrow show below. Suppose also that what Non-I expects I to reduce is less than point A, the amount that I thinks is the lowest emissions it is likely to achieve without an agreement. Finally consider a particular point H which is a particular emission level between E and F, and point G which is a particular emission reduction/level for Agent I. Suppose the world emission level corresponds to points G + D,

```
                       I Emissions                    Non-I Emissions
                                  A        B             E      F
I's View       ----------------------•----------•     ------•---------•
                       G  Gmin                                C    H    D← h →
Non-I's View   -------←---•---•                       -----------•---•-----•--------•
               ______________________________         ___________________________
               0      Quantity Emissions I  →         0   Quantity Emissions Non-I →


World                  G                   G+D
Emissions      -------------•----------------------•
Range
               ___________________________________________________________________
               0                       Quantity Emissions I                      →
```

Figure 2: Agents' Views and World Emissions Range with a Global Climate Agreement

$$\acute{E}^{W}_{A} = G + D \quad (20)$$

Where Agent I is allocated G emission allowances and Non-I is allocated D emission allowances. H is the level of emissions Non-I achieves through energy efficiency and technological innovation.

Such world emission level could be feasible in the sense of being possibly acceptable if:

$$G + (D - H) > A \text{ and} \quad (21)$$

$$D – (D - H) > E \quad (22)$$

This would correspond to Agent I buying (D – H) emission allowances from Non-I.

If the above conditions were not met, it is easy to show[8] that there exists a quantity of emissions allowances, h, such that

$$\acute{E}^{W}_{A} = G + D + h \quad (23)$$

and

$$G + (D + h - H) > A \text{ and} \quad (24)$$

$$D – (D + h - H) > E \quad (25)$$

With the purchase of (D-H) or (D + h – H) allowances, Agent I would be above the lower range of what it expects would be its emissions without an agreement and Non-I would be above the low range of what in I's view would be Non-I's emissions.

5. Some Other Considerations Affecting Global Cap and Allocation

The following are other relationships relevant to the Agreement Case compared to the Without Agreement Case.

If Agent I buys allowances from Non-I, then Agent I has an additional cost equal to the price of an allowance, P_A, multiplied the number of allowance (D – H) or (D+ h- H), whichever of these two cases might apply. This cost would have to be taken into consideration in evaluating the Welfare of Agent I (W^I). On the other had the amount spent of emission allowances would be a benefit to Non-I and corresponding affect the Welfare of Non-I ($W^{Non\text{-}I}$).

As the price of allowances rises, the incentive to improve efficiency and develop carbon intensity reducing technologies increases. Consequently the lower range of what could be expected for both Agent I and Non-I's emissions would tend to be lower.

[8] h need only exceed A - G_{min} + (D- H) or E - D – (D- H) (which ever is greater).

If funding of an Adaptation fund were tied to the sale of emission allowances, in so far as an agent's Welfare was improved by being able to draw from such an Adaptation Fund, that Agent' Welfare function would improve as the price and number of allowances purchased and sold would increase, thereby partially offsetting the cost of purchases of allowances or further benefiting the seller of allowances.

6. One example of an Emission Allocation Formula

For purposes of illustration consider the following:

The allocation to Agent I could be based on the Kyoto Protocol reduction target for Annex I countries, i.e. a 5% reduction from 1990 emission levels. Since this reduction is over a 20 year period, as noted previously, it implies an average annual rate of somewhat less .025 growth a year. The 2010 target is further reduced by 0.025 per year[9] for the 5 years from 2010 – 2015 to determine the 2015 allocation. This is represented as $E^{I|1990}(1 + r)^5$.

For Non-I, allowances can be estimated by calculating the annual growth rate of emissions between 1990 and 2003, $r^{Non\text{-}I}$, raising it to the 12th power for each of the 12 years between 2003 and 2015 and multiply this by 2003 emissions or: $E^{I|2003}(1 + r^{Non\text{-}I})^{12}$.

The sum of Agent I and Non-I calculated as indicated above would be the world emissions.

Allocations could simply be at these levels. This could be called basing emission allowance allocations on "historical" considerations exclusively. This acknowledges that historically the disproportionately higher emissions have come from industrialized economies, and also recognizes developing countries need to develop and grow given their current situation. Also basing developing countries emissions on current levels is similar to the approach"grandfathering" approach used in cap and trade systems which allocates emission allowances based on recent emission levels.

An alternative method of allocations that addresses some other considerations regarding allocation involves the following:

If emission allowances were allocated based, at least in part, on carbon intensity: lower carbon intensities would be rewarded and encouraged, and higher carbon intensities, penalized and discouraged. This would be an added incentive for efficiency improvements and technological innovation that reduced carbon intensity. Making allocations proportional to a country or agent's GDP as a percentage of world GDP would achieve this:

$$\frac{GDP^i}{GDP^w} A^w \quad i = \text{Annex I, Non-Annex I per capita emissions allowances} \quad (26)$$

[9] Raising 1.05 to the 1/20th or .05 power equals .00222.

Also if emission allowances were allocated based, at least in part, on a per capita basis, this could be argued as fairer than basing allocations on historical or carbon intensity considerations only (this is discussed further in Appendix A):

$$\frac{POP_t^{\,i}}{POP^w} A^w \quad i = \text{Annex I, Non-Annex I per capita emissions Allowance} \qquad (27)$$

Combining the historical with the carbon intensity and per capita approaches, emission allowances could be a weighted average of these three approaches. where the weight are a, b, c add up to 1 (a + b + c = 1).

The Carbon Intensity component of the emission allowance allocation could be based on the actual GDP of the agent for the year of the allocation divided by the actual world GDP and could be estimated by taking the most current year and multiplying this by the estimated GDP growth rate for the period leading to the allocation year.

The Per Capita emission component of the emission allowance allocation for year t, is the world emission total for that year divided by the designated world population for that year, this being determined as the world population in a base year increased by an agreed upon annual population growth rate for each year from the base year to year t. To remove the incentive for increasing population to seek to secure a larger number of emission allowances through increasing its population, a country's population could be its population in a base year or years divided by world population for that period. This could be further refined by increasing population by its growth rate for the number of years between the base year and 2015, recognizing that historically the population growth rate of developing countries has been higher than for industrial countries.

An individual country i's allowance (A), is a weighted average of the above allowance components, where the weights are given by a, b, and c where a, b and c > 0 < 1 and a + b + c = 1:

$$A^I = a\, E_{2010}{}^I (1 + r)^5 + b \frac{GDP_{2015}{}^I}{GDP_{2015}{}^w} A_{2015}{}^w + c \frac{POP_{base}{}^I}{POP_{base}{}^W} A_{2015}{}^w \qquad (28)$$

$$A^{Non\text{-}I} = a\, E_{base}{}^{Non\text{-}I} (1 + r)^{2015\text{ - }base} + b \frac{GDP_{2015}{}^I}{GDP_{2015}{}^w} A_{2015}{}^w + c \frac{POP_{base}{}^{Non\text{-}I}}{POP_{base}{}^W} A_{2015}{}^w \qquad (29)$$

7. A numeric illustrative example

The following roughly approximates the emission for Annex I and Non-Annex I countries through 2003 and projected allocations based on maintaing the Kyoto Protocl emission reduction targets annual rate through to 2015 and for Non-annex I countries basing allowances on their average annual growth rate between 1990 and 2003.

	1990	2003[10]	% Chg 1990 - 2003	2010	2015 Allocation
Annex I (spreadsheet illustrative example)	4248	4004	-1%	3935	3984´
Non Annex I " " "	1448	2200	52.%		2994
World Total ' " "	5894	6004	1.9%		6978
World Total Actual (EIA))	5837	5909	1.2%		

Table 1: Summary of Illustrative Example
in billions of metric tonnes C

Some of the discrepancies between the World Total based on Annex I and Non-Annex I emissions arise due to some accounting difficulties dealing with countries that comprise the former Soviet Union, countries that have divided such as Czechoslovakia and the Congo and countries that were counted in 1990 and are not included in 2003 total such as Iraq.

The following table very roughly approximates the GDP (Purchasing Power Parity) and population for the Annex I and Non-Annex I countries.

	GDP in trillions $	%	Pop in billions metric tonnes C	% of
Annex I	31 T	56.4	1.2 B	19%
Non Annex I	24 T	43,6	5.1 B	81%
World	55 T		6.3 B	

Table 2: GDP and Population

For purposes of illustration the above numbers are further rounded off to:

	Emission Allowance in billions of metric tonnes
Annex I	4000
Non-Annex I	3000
World	7000

Table 3: Emission Allowance Example

[10] The end of the Soviet Union and the breakup of the Soviet Bloc saw a significant decline in emissions from the countries involved. This is major part of the decline in Annex I emissions between1990 and 2003. Additional declines would have to be realized to reach the emission reduction targets assigned in Annex B of the Kyoto Protocol. Annex B included a 7% reduction for the United States. The United States is not signatory or participant in the Protocol

	% World GDP	% World Population
Annex I	55%	20%
Non-Annex I	45%	80%

Table 4: GDP and Population %

Using the following weights a = .90; b = .05 and c = .05, the allocations are:

	Emission Allocation in billions of metric tonnes C
Annex I	3863
Non-Annex I	3137
World	7000

Table 5: Allocation with weighted averages

8. Some Other Issues

A. Inclusion of the United States and China

The United States in not a participant in the Kyoto Protocol. In the first commitment period, developing countries have no limitation on their emissions. Having the US participate in an international effort to reduce emissions and also having developed countries emissions limited are essential for capping global emissions. Capping global emissions is necessary before emissions are reduced the 60 – 80% needed to stabilize atmospheric concentrations of CO_2 so as to reduce the risks of dangerous impacts from climate change. Establishing a cap and trade system would create a mechanism for achieving, first, a capping and then reductions of emissions.

The US's 2003 carbon emissions, though, are 16 % above its 1990 level. For the US to achieve a 7.5% decrease from 1990 levels would require nearly a 24% decrease from current levels. This, though, could be achieved through purchase of allowances or some combination of actual reductions and purchases of allowances. The purchase price would decline if additional allowances were provided to Non-Annex I countries. Provision of technology to Non-Annex I countries such as China and India by the United States would benefit the United States economy and US companies. At the UNFCCC meetings in Kyoto in 1997 the United States delegation agreed with other countries on emission reduction targets, in large part, through the last minute intervention of US Vice President Gore, in the form of inclusion of carbon sequestration in forests, an area in which the United States has significant advantages. Though difficult, there may be enough flexibility and advantages for eventual US inclusion in an effective international climate change agreement.

B. Measurement and Carbon Trading System operation

The US Department of Energy's Energy Information Agency has data on annual carbon emissions for over 200 countries, practically every country in the world, from 1980 to 2003. This is updated continually. Determination of Carbon emissions is based on fossil fuel use which is measured through point of production, export and import, and through use by sectors, such as power generation, or use for transportation. The UNFCCC requires and provides countries with guidance on monitoring their emissions. Based on data, such as currently exists, emission allowances could be issued and tracked. For a given period a country would need to possess emission allowances at least equal to its carbon emissions. Purchase and sale of allowances would be recorded though a central clearinghouse. If funding of an Adaptation Fund were based on sale and purchase carbon allowance these amounts would be calculated also through this clearinghouse.

C. Enforcement

If a global cap and trade system were in place for the second commitment period 2012 – 2017, this could take the form of countries being required to possess allowances equal to their emissions for this five year period. A country not possessing allowances equal to its emissions could be considered as having an unfair trade subsidy of its domestically produced exports. Some form of sanction or countervailing duty could be allowed to penalize such a shortfall of allowances. In addition a country could buy allowances from the third commitment period and apply them to that country's second period emissions.

D. Corruption and/or irresponsible government

It is possible that the government of a country could sell allowances that the country would need to cover its own emissions. Aside from possible enforcement, as mentioned above, this is largely an internal matter to be dealt with by whatever form of governance process exists in a country. As with other domestic issues like large government deficits, a country possessing sufficient emission allowances to cover its own emissions could be a consideration in multilateral lending to a country.

E. Flexibility with a Emission Cap and Trade System

A global emissions Cap and Trade System provides more flexibility than the current reduction target and CDM-JI approaches. In addition, current period allowances could be purchased and "banked" for use in future periods when they may be more valuable. If entities feel the global cap is too high, it could be permitted for allowances to be purchased and "mothballed", and thereby effectively cancelled, which would be equivalent to reducing the global emissions cap.

9. Suggestions For Further Research

Several elements of a research agenda would be useful to pursue:

- The illustrative numeric model could be refined to better reflect actual Annex I and Non-annex I data.
- Work begun on calculating allowances on individual countries could proceed and result in specific allowances for each country.
- Calculating the range and magnitude of emissions reductions through different combinations of efficiency and technology would be useful to better assess the feasibility of a global climate change agreement.
- The policy framework suggested could be analyzed using the approach described in "Shaping the Future" (Popper, 2005): a "rigorous, systematic methods for dealing with deep uncertainty…by using the computer to help frame strategies that work well over a very wide range of plausible futures." (ibid. p. 67).

Overall it is important to engage with the UNFCCC working group and others who, over the next few years, will be fashioning post-2012 climate change policy. It is the hope that an agreement could be crafted and ratified so that it can be implemented in a timely manner and in such a form that eventual participation of the United States is not precluded and emissions are capped and then reduced and the risks of dangerous climate change likewise reduced.

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Appendix A: Analysis and Rationale for Allocating Allowances[11]

Why allocate allowances as a combination of three different bases? ?

First, the historical component takes into account the status quo, or status quo ante, the situation prior to the establishment of the cap and trade system. "Grandfathering" is standard for cap and trade systems, ranging from the US's use of a cap and trade system for SO2 to allocation of transferable fishing allowances. For the Non-Annex I countries, the proposed historical component acknowledges the level of carbon emissions these countries use in the base year, increased by the world trend growth rate of emissions. For the Annex I countries, the historical component acknowledges the Kyoto emission reduction targets and changes emission allocations based on the annual emission reduction implied in the Kyoto emission reduction targets.. Use of the carbon emission levels implied by Annex I countries' Kyoto targets can be justified as taking into account these countries being more responsible historically for past fossil fuel carbon's emissions contributing to current increased atmospheric concentrations of CO2. Also using these implied emission levels, rewards Annex I countries in proportion to the extent they have moved toward these emission reduction targets.

The second and third component together can be viewed as possibly encouraging certain features desirable in the future: reduction in countries carbon intensities per dollar of GDP and less disparity in per capita emissions. Increasing the weights for the carbon intensity and per capita components increases the importance of these components.

As described previously the second component, the carbon intensity of GDP component is simply the ratio of a country's GDP to world GDP multiplied by the world carbon emission allowance (which is the sum of all countries allowances). Suppose a country's carbon intensity of GDP is the world average,

$$\frac{c_t^i}{GDP_t^i} = \frac{c_t^w}{GDP_t^w} \tag{30}$$

then, multiplying both sides by GDP_t^i / c_t^w implies

$$\frac{c_t^i}{c_t^w} = \frac{GDP_t^i}{GDP_t^w} \tag{31}$$

Consequently, if an allowance was the ratio of a country's GDP to world GDP multiplied by the total world allowance, then if a country's carbon intensity is the s same as the world average carbon intensity, then that country would be allocated the number of allowances equal to its carbon emissions.

[11] This appendix was prepared as a section of an earlier paper. Some of the notation differs, for example Agents are referred to as Developed and Less Developed, instead of Annex I and Non-Annex I.

Countries with carbon intensities lower than the world average carbon intensity would have allowances greater than their carbon emissions and would be able to sell allowances. Countries with carbon intensities higher than the world average carbon intensity would need to buy allowances. Lowering carbon intensities would be desirable for a country either to increase that country's number of allowances that could be sold, or to reduce the number that need to be purchased. In addition basing allocation on the ratio of a country's GDP to world GDP can be considered fair in that it allocates more allowances to those who produce more, but the number of such allowances allocated is proportionally lower, the higher the carbon intensity of the country's economy.

If a country had a carbon intensity of GDP lower than the world average, suppose it was 90% of the world carbon intensity, then

$$\frac{c_t^i}{GDP_t^i} = .9\ \frac{c_t^w}{GDP_t^w} \tag{32}$$

then, multiplying both sides by GDP_t^i / c_t^w implies

$$\frac{c_t^i}{.9\ c_t^w} = \frac{GDP_t^i}{GDP_t^w} \tag{33}$$

Or

$$\frac{1.1\ c_t^i}{c_t^w} = \frac{GDP_t^i}{GDP_t^w} \tag{34}$$

In other words a country with a carbon intensity lower than the world average would have 10% more allowances allocated under this method, than it had used to produce its GDP. Since further increases in that country's GDP would entail smaller than its average carbon emissions per GDP, i.e. since its marginal emissions per GDP is declining, that country's carbon intensities, to increase its GDP 10% would require less than the 10% allowances it was allocated in excess of its current GDP level. Consequently such a country could apportion these additional allowances to both economic expansion and for sale.

Conversely, for a country with a higher than average carbon intensity, that country would be allocated fewer allowances than it currently uses to produce its current GDP. It would need to reduce the carbon intensity of its current level of GDP, pursue a lower carbon GDP growth path, and purchase allowances.

Allocating allowances only on the basis of carbon intensities could be seen as unfair in that it rewards larger and richer economies whose carbon intensities are generally lower than those of developing countries. In addition, if a Kuznet's type inverted U carbon emissions curve exists for countries as they range from lower to higher per capita GDP (Pan, 2003) i.e. as very poor countries increase their per capita DP, their carbon intensity may increase before it declines. If so, developing countries would be doubly at a disadvantage, especially if their marginal carbon intensities were high relative to the world average and the developed countries.

This possible bias against developing countries can, in part, be offset by use of the third component, per capita GDP. If a country is poor, the ratio of its population and world population, exceeds the ratio of that country's GDP and world GDP. Suppose a country's per capita GDP was 50% of the average world per capita GDP, then

$$\frac{GDP_t^i}{POP^i} = .5 \frac{GDP_t^w}{POP^w} \qquad (35)$$

then, multiplying both sides by GDP_t^i / c_t^w implies

$$\frac{GDP_t^i}{.5\ GDP_t^w} = \frac{POP^i}{POP^w} \qquad (36)$$

or

$$\frac{2\ GDP_t^i}{.\ GDP_t^w} = \frac{POP^i}{POP^w} \qquad (37)$$

In other words, a poor country with only half the world average per capita income, would receive twice the number of allowances it would receive, if allowances were based on the ratio of its GDP to world GDP. Additional allowances beyond what are needed for its current level of GDP could be used first economic expansion and any remaining surplus allowances could be sold.

Using a base year for a country's population and increasing this by the world's trend growth rate would remove the incentive for a country to increase its population in order to be allocated more allowances.

In addition, allocating allowances on the basis of population can be further understood through a simple stylized thought experiment. Consider a one period world, in which use of one type of input, fossil fuel, produces energy which results in benefits. Use of this type of fossil fuel also produces carbon emissions which collectively results in externalized damages globally and for each country in the same period. Consider two countries with different populations and different technologies for producing energy (and benefits) from the use of fossil fuel. Prior to this period, a cap and trade system for carbon emissions has been agreed upon as the method to achieve the optimal level of net benefits globally and for each country. Applying the Coase Theorem to this situation, given a world cap on emissions it is would not matter how the "property rights" of the carbon emission allowances are assigned, through negotiation or purchases the optimal division of allowances would occur. If all the allowances were assigned to country one, country two would buy allowances from country one, until the marginal benefit of purchase of any additional allowance equaled the marginal benefit to country two from use of the last emission allowance purchased. Though, according to the Coase Theorem, the division of allowances would be the same, at the end of the transactions the country allocated the allowances would be made wealthier and the other country poorer.

One could apply a Rawlsian veil of ignorance approach to designing the allowance system for the above world, i.e. those designing the allowance system would not know to what country they would be "born". If a person had the same probability of being born as any particular person, the chance of being born in either country would be proportional to that country's population, then the fair way to allocate allowances would be on the basis of population.

Next consider a two period model, where in the first period countries do not know that use of fossil fuels results in externalized damage. Also in the first period countries develop different technologies and accumulate different amounts of wealth proportional to their use of fossil fuel. Then prior to the second period, the countries learn that the combined carbon emissions from fossil fuel from the first period and from the second period result in externalized damages. For period 2 a carbon cap and trade system is decided to be implemented. For simplicity assume also there are two different (non-overlapping) generations in each country and the populations for both countries for both period is known. One way to allocate allowances would be to determine what sum of emissions for both periods is desired and divide by the total number of people for both periods. Each country then would have a total number of allowances. Emissions for a country in Period 1 would be subtracted from that country's total allowance and that would be the allowances available to that country in Period 2. Each country would then buy or sell allowances until the marginal benefit of buying or selling allowances were equal. This two period model supports considering countries' prior emissions when allocating allowances; this is, in part, captured by basing Annex I countries' allowances on these countries base year emission target reduction levels.

Overall increasing the weights for the carbon intensity and per capita components, shifts the allocation away from a "grand-fathered-in", somewhat arbitrary basis, toward allocation based on efficiency, as embodied in efficiency of the carbon intensity allocation compenent and fairness in a Rawlsian-sense of the per-capital allocation component.

Appendix B Graphical Illustration Carbon Emission Trading Market[12]

Consider two countries and two periods, the present, period 0, and the future, period 1. Suppose one country is a "developed country", DC and another "less developed country" (LDC). Suppose DC has a smaller population than the LDC.

There is a single fossil fuel source for carbon emissions and a single world fossil fuel price (such as a world price for a barrel of oil, but here applicable to all fossil fuel). Also assume that there is a fixed amount of emissions per unit of fossil fuel used.

In a pre-cap and trade world, each country emits carbon until the marginal benefits from using fossil fuel equaled the price of the fossil fuel. Consider a country's utility function as measured by its GDP (or more precisely by its per capita GDP).

This is depicted in Graph 1 with the LDC use of fossil fuel in a year on the x axis (measured to the right from the origin on the left at point U_0 and price of the fossil fuel and its marginal benefit on the y axis reach 0 at the point above U_0. equal to the price of the fossil fuel[13].

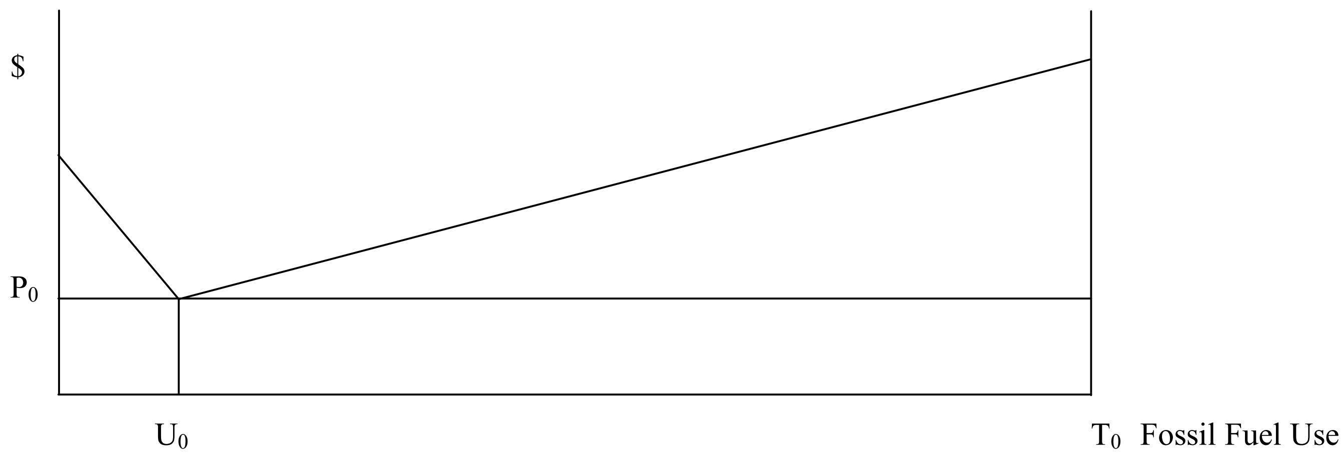

Figure 1

[12] This appendix was prepared as a section of an earlier paper. Some of the notation differs, for example Agents are referred to as Developed and Less Developed, instead of Annex I and Non-Annex I.

[13] The current price of fossil fuel, particularly petroleum, exceeds its production cost. This would be consistent with Hotelling's Rule and the future prices of the resource being even higher than future production cost such that marginal present discounted value of future profits equals the current marginal profit. In part, the current excess of price over costs perhaps results from a refining capacity constraint

Mark the total fossil fuel used on the x axis at point T_0 . The use by DC would be represented by the distance between the total use point and the point indicating the LDC's use.

Draw a vertical line from the total use point. Use this show the marginal benefit of fossil fuel use by DC (as well as the price of the fossil fuel).

The marginal benefits, in this two country model, touch at the price of fossil fuel above the point corresponding to fossil fuel use by LDC and DC.

Suppose without a cap that fossil fuel use for both countries increases in period 1 and consequently, global use increases, i.e. the 3-sided box, expands (to the right), but both countries (new) marginal benefits still meet at the fossil fuel above the point indicating their new fossil fuel usage as shown in graph 2 below (see attachment). [note: not addressed in this model is the relationship between carbon emissions, fossil fuel use, and GDP. For simplicity, here we treat these relationships as fixed. However, the cap and trade system would create incentives for a country reducing the amount of carbon emissions per unit of fossil fuel used as well as increase the GDP benefits from fossil fuel use. In other words the system creates incentives to lower both the energy intensity of GDP and the carbon intensity of energy, which would shift the curves involved in this simple graphical illustration].

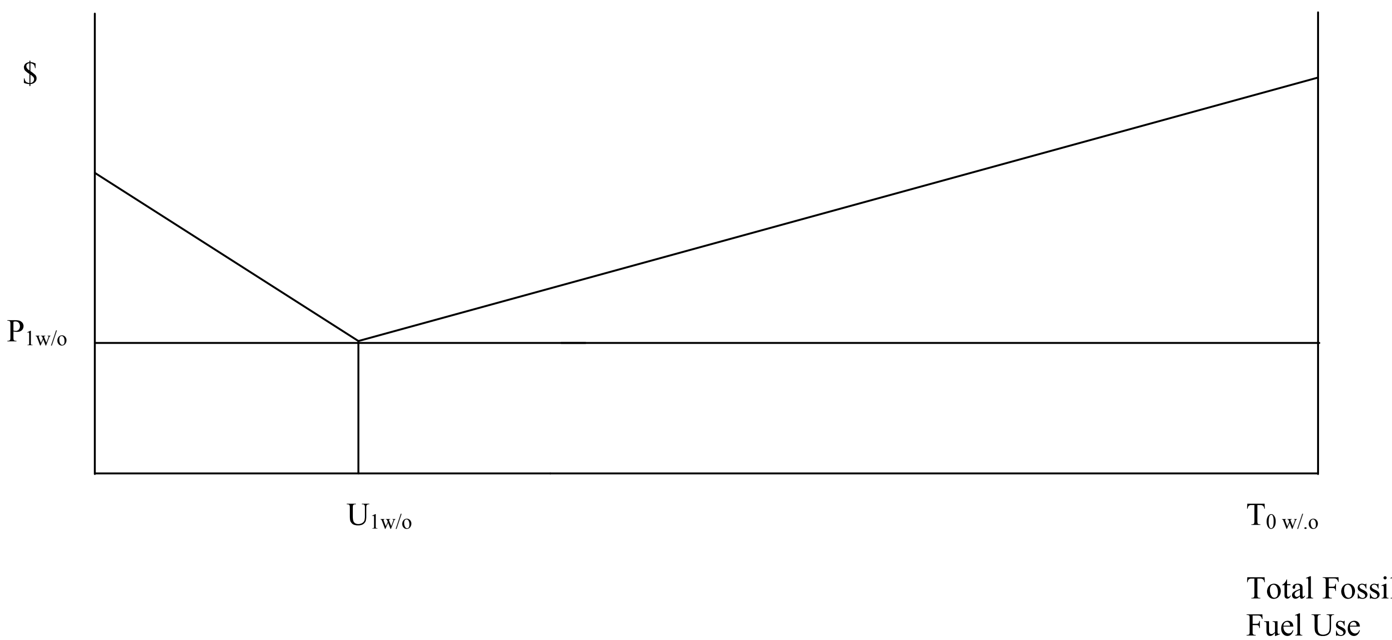

Figure 2

Now suppose the 3-sided box is compressed to the size of the box in year 0 (this would be a year 1 with a cap) as shown in Graph 3 below (see attachment).

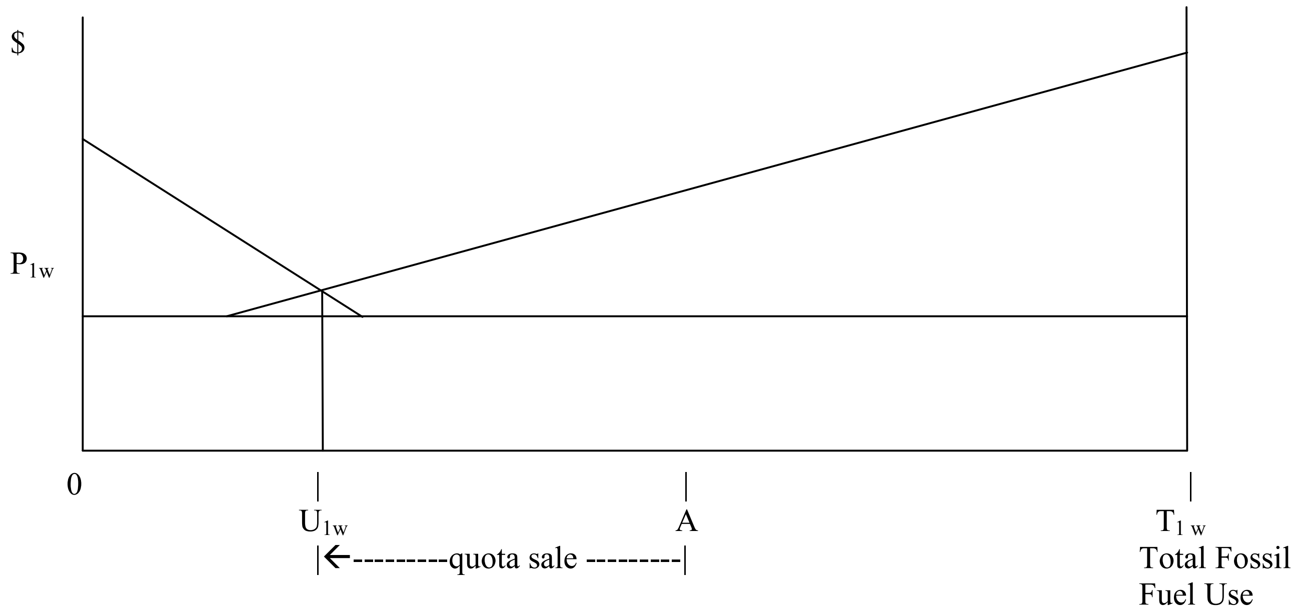

Figure 3

If LDC were allocated quotas indicated at pt. A measured from left to right, then DC could sell quotas to DC at price P_{1w} for of amount indicated by the arrow, marked quota sale to from point a to point U_{1w} (measured from point A to the left to $U_{1w.}$). Beyond the point $U_{1w.}$, the marginal benefit to DC from more quotas, would be less than the amount for which LDC would be willing to sell quotas.