Policy Instruments and the Limitation of Global Greenhouse Gas Emissions: The Case for Carbon Taxes

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I. Introduction

At this juncture in time, an international consensus on a global climate change treaty seems to be slipping out of our collective grasp. However, it is possible that proceeding on a different basis than the current focus of the Kyoto Protocol can provide a stronger foundation for agreement.

We attempt to demonstrate in this paper, that a system of differentiated carbon dioxide taxes, implemented within an international agreement that allows some type of trading, has the potential to bridge some of the differences that create barriers to an international accord. At the same time, the tax system has desirable properties such as economic efficiency, and a continuous incentive for both individual firms and countries to lower emissions.

The paper proceeds as follows. Section II looks at barriers to international agreement, while Section III discusses alternative policies for controlling emissions, focusing on the properties of carbon taxes and a marketable carbon permit system. Section IV looks at the incentives that carbon taxes provide for technological innovation, while Section V looks at how carbon taxes provide a never-ending incentive to reduce emissions levels. Section VI examines the important issue of how pollution taxes and trading among nations can be crafted into an international limitations agreement, Section VII places the issue of sequestration in the context of a carbon tax system, Section VIII discusses the issues of contraction and convergence and Section IX contains conclusions.

II. Barriers to International Agreement

With the collapse of the Hague round of global climate change negotiations in November of 2000, the world's environmental representatives are faced with rethinking the international agreement to reduce carbon emissions. The Kyoto Protocol, signed by 160 nations in 1997, remains to be ratified by many participants due to a few key concerns that have been left unresolved, and U.S. President George Bush has recently withdrawn U.S. participation from the Kyoto Protocol. Among other provisions, the Kyoto accord details a system of tradable permits for carbon that can be bought and sold among developed nations in an effort to reach efficiency criterion while reducing emissions to 1990 levels. In this accord, no limitations are placed on developing countries.

One of the major limitations to reaching consensus is regarding the scientific certainty with which climate change and climate change impact estimates are calculated. Although a global consensus has occurred among the world's leading scientists about the change in mean global temperature associated with a doubling of atmospheric concentrations of carbon dioxide, there is considerable uncertainty about the regional changes, which regions are winners (if any) and which regions are losers. More importantly, there is considerable debate about the ecological, social and economic costs of these regional impacts and uncertainty regarding the cost of reducing greenhouse gas emissions. [1]

The uncertainty regarding the cost of reducing greenhouse gas emissions is an interesting issue, because there are basically two ways to calculate costs. First, costs can

[1] See the web pages of the Inter-Governmental Panel on Climate Change (http://www.ipcc.ch/) and the U.S.E.P.A (http://www.epa.gov/ebtpages/iglobalclimatechange.html) for additional discussions of these issues.

be calculated in a "business-as-usual" fashion, with assumptions that new technologies will take considerable time to develop, and other types of adaptation will be slow in coming. This will imply considerable opportunity cost of limiting emissions. The second method would be to assume that technology will change quickly, and many opportunities will exist for rapid adaptation. Those who oppose the limitation of greenhouse gas emissions cite high cost estimates, but are they correct in this assumption?

One way of examining the assumption is to look at historical experience. The body of experience with environmental regulation has been with direct controls, which have proved very costly.[2] However, more recent experience with economic incentives has shown that initial cost estimates can be too high by an order of magnitude, because it is difficult to predict the adaptation strategies that will emerge in the context of economic incentives. For example, the U.S. Environmental Protection Agency originally predicted the price of a sulfur dioxide permit to be $1500 per ton, but revised this downward to about $500 in 1990 as the Amendments were being acted upon. In actuality, prices started out around $250-300 per ton in 1992, falling to $110-140 in 1995 and bottoming-out around $70 per ton in 1996, slightly less than five percent of the original cost estimate. (Bohi and Burtraw). While this is not an indication that the cost of reducing greenhouse gas emissions will be five percent of the current cost estimates, it is an indication that we need to be careful when making engineering cost estimates, because these do not incorporate the full potential of adaptation possibilities and technological innovation. Nonetheless, cost concerns are important, and a global climate change treaty will not be signed and ratified unless it addresses these concerns.

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[2] See Tietenberg, Kahn

A critical factor in the lack of agreement is the inherent conflict that persists between developed and developing nations. These conflicts include different opinions on who should be responsible for reducing emissions, what types of emission reductions should be allowed, and what types of sequestration activities should be given credit.

The question of who should be responsible for emissions reductions is a very interesting philosophical and ethical issue. The developing nations argue that the developed nations are largely responsible for the current stock of greenhouse gases in the atmosphere, and that the developed nations have grown their economies to their current levels as a result of the emissions of these gases. Developing nations should not be denied the same opportunity to grow, so the developed nations must bear this responsibility in its entirety. While this position is difficult to argue against on philosophical grounds, the developed nations make the practical argument that their own reductions will be meaningless unless developing nations, particularly large developing nations such as China, India, Brazil, and Mexico, have some limit placed on their emissions.

Another conflict exists among developed nations. Developed nations with large land masses (US, Canada, Australia) and significant opportunity for carbon sequestration would like to receive credit for these types of activities. It is conceivable that these nations could achieve almost all their required (under the now defunct Kyoto Protocol) reductions by changing agricultural and forestry practices. For example, a tremendous amount of carbon can be sequestered (and methane emissions diminished) by injecting liquefied cow manure under the top layers of soil, with better livestock management and through other agricultural practices. However, developed nations without these opportunities (many European and Pacific rim countries) are fearful that allowing these credits will increase their relative cost of production. Without the same type of land use opportunities, they would have to achieve their reductions primarily in the industrial and transportation sector. These costs would increase by more than in countries such as the United States, who have these opportunities. Therefore, the European and Pacific Rim countries would find themselves at a cost-disadvantage in the industrial/manufacturing sector. This, in fact, was one of the major reasons for the collapse of the Hague Round of negotiations in November of 2000, as major conflict concerning credit for agricultural sequestration caused some of the European nations to walk out of the negotiations.

Other sources of contention include exactly how baseline levels of emission should be measured, if countries should get credit for earlier reductions, what types of sequestering activities should be included in the system, and the way in which trading of emission credits could take place across countries, particularly between developed and developing countries. Economists argue that trading is very important because it offers the opportunity to reduce global costs in a win-win situation. However, there has been extreme difficulty in developing a trading plan that will satisfy both developed and developing countries.

III. Alternative Policies for Controlling Carbon Emissions

As with any type of emission problem, there are two basic types of policies to control the emissions, direct controls and economic incentives. Given the past experience with direct controls and the relatively high cost of compliance that they are associated with, we will focus on economic incentives and the choice between different types of economic incentives.[3]

[3] We do not completely rule out direct controls, as they may be effective in cases where monitoring is difficult or where there is imperfect information. In fact, energy efficiency standards and our labeling

The discussion of carbon dioxide limitations in the context of economic incentives has focused heavily on trading of allowances (also called credits or permits), or trading the right to emit pollutants. Under a system of this type, all counties would have limitations placed upon them, and they would be free to trade amongst themselves. Countries (and firms within those countries) that have high abatement costs would buy allowances from countries (or firms within those countries) with low abatement costs. The same level of pollution would be achieved, but at lower cost. Another often cited advantage of marketable pollution allowances is that it achieves the target level of pollution with much greater certainty than a tax.[4]

This greater certainty is illustrated in Figure 1. In this figure, let us assume that the actual marginal curve is MAC_2, but that policy makers think the actual marginal abatement cost curve is MAC_1. If the goal is to reduce emissions to E_3 from their unregulated level of E_1, policy makers could choose a tax equal to t. However, given that MAC_2 is the true marginal abatement cost function, this tax would only give an emissions level of E_2, much higher than the target level of E_3. That is why the economics profession has tended to focus on emission allowances, as if E_3 pollution allowances are created, society will wind up with a level of emissions equal to E_3 (subject to monitoring, enforcement and other implementation variables).

However, part of the reason that E_3 would be chosen as the target level was that policy makers thought the abatement costs were relatively low, as described by MAC_1. Note that if we create a pollution credit system designed to achieve E_3, costs will be relatively high, as the total abatement costs of achieving E_3 are equal to the area of

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requirements on appliance may be effective in limited applications, but if the whole economy was controlled this way, compliance costs would be very high.

[4] See Weitzman

triangle BE_1E_3. This is one of the reasons there is opposition in the U.S. to limiting greenhouse emissions, as the uncertainty associated with the costs of abatement could lead us to be surprised by high abatement costs. Note, however, that there is an absolute limit to abatement costs under

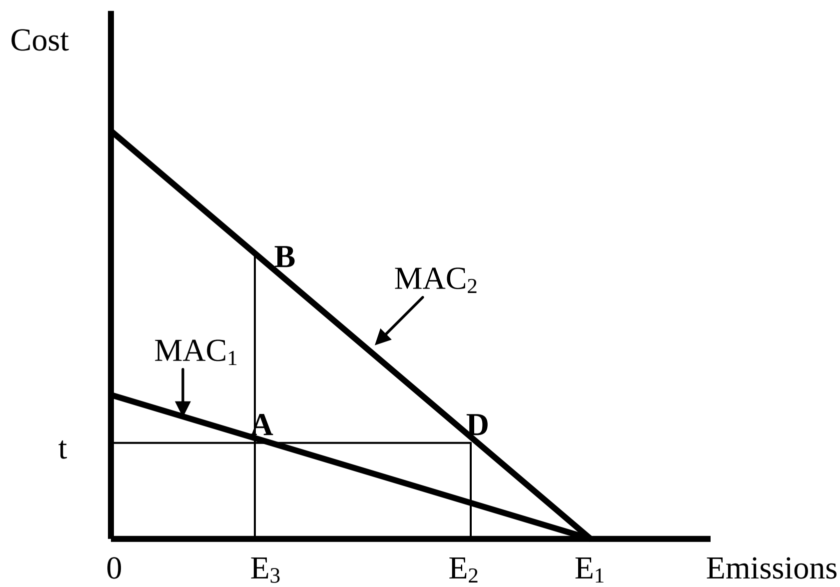

Figure 1. Responses to taxes and credit systems

the tax system. The maximum the costs could be is t^*E_1, which would be paying the tax on every unit of pollution, and not having abatement at all. Of course, some abatement would take place. In the case where MAC_2 is the actual abatement cost function, emissions would be reduced to E_2, and the total cost to polluters would be the area of rectangle $t0E_2D$ plus the area of triangle DE_1E_2. It is important to note that only the area of triangle DE_1E_2 represents a social cost. The area of rectangle $t0E_2D$ represents the taxes that are collected by the government, and represent a transfer rather than a social costs. These taxes could be used to reduce income taxes[5], or to pay for education, environmental improvements, research and development, or some other public good.

This idea that a tax can ameliorate the uncertainty associated with the cost of abatement is an often overlooked corollary to Weitzman's important article, as the focus of the economics profession has been on the ability of marketable pollution permits to reduce the uncertainty in terms of achieving the target level of pollution. However in the current political climate where there is such fear of excessive abatement costs and corresponding impacts on the macro-economy, an international agreement based on taxes as a system of compliance may be more feasible in a political sense, ***because taxes set a ceiling on the cost of compliance.***

The idea of a tax may seem counterintuitive in a political environment where voters are crying about the (perceived) high cost of energy. However, this potential objection can be easily dealt with by refunding all or a portion of the taxes to the citizenry. As long as the refund of the tax was carried out in a fashion that was unrelated to energy consumption or carbon emissions (such as a progressive tax refund or a lump sum distribution) the tax would still have the desired impact on carbon emissions.

The system could also be constructed to return all the tax revenue to firms. A good example of how to do this is the tax system for nitrogen oxides in Sweden.[6] Under

[5] See Kahn and Farmer for a discussion of the potential existence of a double dividend.
[6] See Blackman and Harrison for a complete discussion.

this system (which applies to electric power generators), the firms pay a tax per ton of nitrogen oxides emitted. All of the money that is collected from this is returned to the firms, based on their share of electric power generation. For example, if a firm generates 5% of the total electricity production, it receives a payment equal to 5% of the total revenue that is collected. Firms that are exactly average in pollution per kilowatt hour of electricity generated pay no net taxes. Firms that are better than average in terms of pollution per kilowatt hour receive a payment, and firms that are worse than average lose money under the system. This system generates additional incentives for pollution reduction by placing firms in competition with each other to improve their environmental efficiency.

Of course, any pollution instrument must have desirable properties in addition to political feasibility. The following sections detail these desirable properties.

IV. Taxes and Technological Innovation

Another seldom discussed advantage of taxes over pollution credits is that they give firms more incentive for technological innovation. This is illustrated in Figure 2, where E_1 is the level of emissions before the regulation, and E_3 is the level of emissions after regulation. First, assume that E_3 is achieved by pollution credits. Then, the benefit to the firms of developing better abatement technology (represented by a downward shift of the marginal abatement cost function from MAC_1 to MAC_2) is equal to the area of trapezoid CBE_1E_2, or the difference between the two marginal abatement cost functions for the amount of pollution they are abating (E_1-E_3). Note that if E_3 is achieved by a tax equal to t_3, firms have an even greater incentive to make the technological invocation. Not only do they receive the area of trapezoid CBE_1E_2, but they will also receive the area of triangle ABC. The reason for this is that for the area between E_3 and E_4, the cost of reducing emissions is greater than the tax (with the new technology) thus firms will respond by lowering their emissions and achieving greater saving.

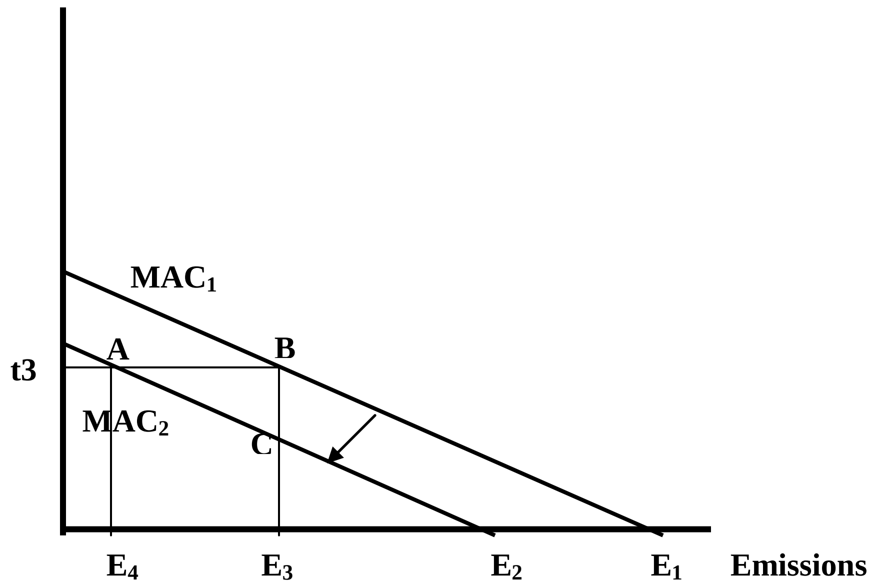

Figure 2. Abatement cost savings with technological innovation

V. Pollution Taxes and The Continuous Incentive to Reduce Emissions

The Kyoto Protocol focuses on a reduction of annual emissions to 1990 levels. However, fixing the annual rate of emissions does not stabilize atmospheric levels of greenhouse gases, as the gases remain in the atmosphere for long period of time.[7] Even if the Kyoto Protocol was implemented, global climate change would proceed, but at a slower level than without the Protocol. What is actually needed is a contraction over time of annual emissions of carbon dioxide and other greenhouse gases, well below the 1990 level, so that the rate of atmospheric accumulation can be slowed even more, and the

[7] For example, the atmospheric life of carbon dioxide is about 500 years.

steady-state level of atmospheric concentrations of greenhouse gases will be lower[8]. However, as a system, pollution credits do nothing to lower the level of pollution below the initial level of credits. To lower the level of pollution under a pollution credit system, the number of permits must be reduced. This could be done with a new set of negotiations conducted periodically (such as every five years), or it could be done with United Nations (or some set of nations) buying permits on the open market and retiring them. Either way requires international negotiation and agreement.

In contrast, with pollution taxes, when technological change occurs, firms have an incentive to lower their pollution, as seen in the movement from E_3 to E_4 in Figure 2. Also, as demonstrated in that discussion, firms have a greater incentive to develop and implement technological change. Thus, taxes generate a continual incentive to reduce the level of pollution, without the need to implement further legislation and/or international negotiation. Of course the tax system must be denominated in a fashion that makes it impervious to inflation and/or devaluation of the domestic currency. Otherwise, a tax level that is initially significant could soon become trivial.

VI. An International System, Pollution Trading, and Pollution Taxes

One of best ways to reduce the cost of meeting global limitation goals is to have some sort of trading of emission rights between developed and developing countries. Developing countries generally use older less efficient technologies, and can reduce emissions as relatively low cost by switching to more modern technologies. Good examples of this can be found in all the inefficient coal and lignite burning facilities in Eastern and Central Europe.

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[8] The steady-state level of greenhouse gas concentrations will occur when the alternative (non-carbon emitting) energy sources displace fossil fuels.

Such a trading system would require a limitation on both the emissions of developed countries and the emissions of developing countries. In many ways, this would be the most efficient system because it would allow for the maximum trading and therefore the maximum cost savings. However, this system is simply politically infeasible, as the developing countries are uniformly opposed to the imposition of limits on their current levels of emissions. They also are somewhat afraid that the gains from trade will be unduly captured by the developed nations, as they use their potential market power to force developing nations to compete against each other to participate in trades, and lowering the market price of a traded pollution credit.

An alternative that has been expressed and is actually contained in the Kyoto Protocol is the idea of Joint Implementation (JI) and Jointly Implemented Activities (JIA). Under these systems, developed countries have a cap on their emissions, but there are no restrictions on the emissions of developing countries. However, developed countries could gain credit against their cap by implementing a project in a developing country that caused a reduction in emissions that otherwise would not have occurred. For example, a French power producer could modernize a power plant in India, and receive credit for the emission reductions. The Indian power company might charge the French company for this opportunity, or might regard the modernization of the power plant as sufficient compensation for participating in this Joint Implementation Activity.

Despite what appears to be a win-win situation, developing countries tend to oppose JI and JIA. There are two probable reasons for this. First, they may fear that JI is the proverbial “Camel’s nose under the tent” and that if they become partially involved in the system in this way, they will soon by required to meet specific limitation agreements.

Second, and probably more importantly, they are afraid of the implications of JI for bilateral foreign aid. They are afraid that a country might say that the aid that was given for the power plant modernization and/or similar JI project constitutes the specific developed countries foreign aid to the developing nation. This would then hurt education, public health, environment and other development goals of the developing nation.

The Clean Development Mechanism (CDM), also mentioned in the Kyoto Protocol, is another type of quasi-trading system. However, it avoids the bilateral structure of Joint Implementation. Under this system, developed countries that do not meet their emission caps would be required to pay money into a Clean Development Fund. This money would then be dispersed by an international authority (such as the Global Environmental Facility or the United Nations Environmental Program) to developing countries to undertake projects that result in a reduction of emissions that otherwise would not have occurred.

The CDM tends to be preferred by developing counties over JI because it is not bilaterally structured. Since the penalty paid by the developed country goes into a general fund, it is less likely that developed countries will attempt to argue that their (involuntary) contribution to the Clean Development Fund constitutes development aid to a specific country.

Carbon Trading Systems and Carbon Taxes

Carbon trading systems and taxes are generally regarded as substitutes for each other, and it would be redundant and inefficient to have both working at once. However, if we move from a complete trading system to a quasi-trading system such as the Clean Development Mechanism, taxes complement the quasi-trading system very well. This will be illustrated with a discussion of a tax system working in conjunction with a Clean Development Mechanism.

As mentioned in Section VI, the Clean Development Mechanism develops a fund for implementing emissions reductions in developing nations. Developed countries that do not meet their emission limitations pay a penalty into the fund, and this is then distributed to developing countries on a project by project basis. The important questions are:

- Where does the money come from?
- What are the efficiency and equity implications of this source of funding?

We will begin the analysis by looking at a national level trading system from two perspectives. First, we will assume that the level of permits is set to generate compliance with the country's stipulated limitation. Second, we will assume that the country decides that it is too expensive to comply, and establishes a permit system which gives excess emissions and requires the payment of a penalty.

At first glance, it might seem optimal if a country could completely comply with its emission standards. But if we accept the proposition that cheaper opportunities to reduce carbon exist in developing countries, the cost of compliance is higher than need be. Of course, if cross-country (between developing and developed countries) trading existed, or even joint implementation, some of these cost savings could be achieved. However, if these two options are politically infeasible, and we default to the Clean Development Mechanism, there is no opportunity to take advantage of these cost savings if the developed country complies with its emissions cap.

The alternative would be for the developed country to set a level of permits that was excessive in that it exceeds the emissions limitation associated with the international agreement. The developed country would only do this if the penalty that they must pay per ton of carbon is less than the marginal abatement cost (which would be known since the market price of a carbon permit will be equal to marginal abatement cost). However, if the developed country makes this decision, there is an important question of how to collect the money to pay the penalty into the Clean Development Fund. One of the problems is that when marketable permits are bought and sold, the money flows between polluters and not between polluters and the government. Obviously, a country could pay the penalty with general revenues, but this raises an interesting equity issue in terms of the taxpayers in general having the responsibility to make this payment.

Another way to collect the money would be to have a surcharge on the price of the permit. However, if the surcharge is only collected on the sale of permits, this will discourage trades. If the surcharge is a tax on the use or possession of the permit, the surcharge becomes equivalent to a carbon tax.

A pure tax system is more compatible with the Clean Development Mechanism, as a portion of the tax revenue that is collected can be used to pay non-compliance penalities into the Clean Development Fund. Note that the lower the per ton carbon tax in the developed country, the greater the non-compliance and the greater the penalty to be paid into the Clean Development Fund. Conversely, the higher tax, the lesser the non-compliance and the less money that would need to be paid into the Clean Development Fund.

Carbon Taxes as a Mechanism for Reducing Developing Country Emissions

So far, the paper has not discussed direct emission reductions by developing countries, only indirect reductions through Joint Implementation or the Clean Development Mechanism. However, an emission tax system could limit the growth of emissions in developing country emissions, but still allow them flexibility by not requiring them to agree to a specific emission limitation. Thus, an international agreement that stipulates developing country participation through the domestic imposition of carbon taxes has a much greater chance of being acceptable to developing countries, and would also be attractive to developed countries since it would prevent the uncontrolled growth of greenhouse gas emissions in developing countries.

An extremely interesting question is why developing countries would agree to a carbon tax when they will not agree to carbon emission limitations. The answer to the question is the tax system becomes much more acceptable if one hundred percent of the tax revenue collected in a particular developing country is allowed to stay within that particular developing country. The tax revenue could be returned to the public and/or firms in one of the revenue neutral methods discussed earlier, it could be used to displace income taxes, it could be used to fund an internal (domestic) clean development mechanism or used for whatever development purpose desired by that particular country. The pattern of use of this revenue would be likely to be vary significantly with the development level of the country.

The other factor that could make this tax system more acceptable to developing nations is that the developing country tax level would be significantly lower than the developed country tax level. Also, there might be some differentiation within developing countries. For example, low income countries might face a lower tax than middle income countries, and the desperately poor countries (who have an insignificant contribution to greenhouse gas emissions) might face no tax, but be eligible to participate in the Clean Development Mechanism.

Other Tax Structure Issues

There are several important issues associated with the tax structure. First, as mentioned earlier, the tax must be inflation and devaluation resistance in order to maintain incentives to reduce emissions. Thus, the tax should be denominated in an inflation indexed weighted average of the traditionally strong currencies, such as the US dollar, the Euro and perhaps the Japanese yen.

Second, as the level of development of a particular developed country increases (or as its emissions per capita increase) the carbon tax should increase. This could be done by a tax growth function, which makes the tax payment proportional to the per capita income of the country, the per capita emissions of the developing country, or both. For example equation (1) expresses the tax of the developed country as relative to per capita income, where the denominator of the first term on the right hand side of the equation is the average per capita income of developed countries, the numerator is the per capita income of the particular developing country, and t_r. is the reference tax, denominated in an inflation and devaluation proof fashion, as discussed above.

$$t_i = \left(\frac{\frac{GDP_i}{Pop_i}}{\sum_{j}^{1\,to\,n} \left(\frac{GDP_j}{Pop_j} \right)} \right) (t_r) \qquad equation \quad (1)$$

Note that in this formulation of a carbon tax for developing countries, changes in global distributions of incomes are automatically factored into relative taxes. As the global inequality of the distribution of income declines, the developing country tax will approach the developed country tax. If, on the other hand, structural change or other factors favor developed countries, the relative tax payment of developing countries will decline.

It may also be desirable to build an automatic adjustment into the system that slows growth in emissions that may be caused by exogenous factors, such as population growth and so on. This is one of the great fears of global warming, that some sort of structural change in a populous country such as China or India could sink the carbon emission reduction efforts of the rest of the world. As a safeguard against such a situation, an adjustment function could be structured to increase the tax rate a particular country faces in proportion to the ratio between its per capita emissions and the per capita emissions of developing countries in general.

VII. Credit for Carbon Sequestration

The issue of giving credit for carbon that is sequestered in natural or engineered ecosystems is one of the most difficult issues in developing global climate change policies. Many questions have yet to be resolved, including the types of land uses that will be included in the system, how carbon sequestration can be measured and monitored, and what system will be used to compensate the land owners for carbon sequestration activities on their land.

The primary issues involved with the determination of what land use activities should be incorporated in the system include:

- Natural ecosystems
    - Should all natural ecosystems be included, or only those that would in jeopardy of destruction without sequestration credit?
    - Should credit be given for ecosystem sequestration in officially preserved areas?
    - How should baselines be measured, should countries receive negative credit for previous deforestation, etc.?

- Engineered ecosystems (agriculture and plantation forestry)
    - How does one give credit for engineered ecosystems and not give incentive to convert natural ecosystems to engineered ecosystem?
    - Should special credit be given for engineered systems that are established on previously degraded land?
    - How should baselines be determined, should credit only be given for sequestration above current (or 1990 levels)?

We will leave the resolution of these issues and the examination of monitoring and measurement issues to future research, and focus on systems for compensating landowners for sequestration activities. The usual focus on such credit is through a direct trading system, Joint Implementation, or the Clean Development Mechanism. However, it can also be done through a tax system, by providing a direct subsidy for sequestration activities.

One difficulty in establishing the system, is that there is no real benefit to sequestration today, if the carbon is released tomorrow. Therefore, the system must provide a continuous incentive to maintain the type of land use (such as rain forest cover) that is providing the source of sequestration. Caviglia-Harris and Kahn (2001) discuss the concept of a carbon annuity system for accomplishing this. Under such a system, the asset value of the sequestered carbon[9] could be converted into a perpetual annuity, that could be paid to the landowner on an annual or periodic basis, provided the sequestration activities continue. A portion of the tax revenues that are collected from emitters of greenhouse gases could be used to fund the carbon annuity system. Caviliga-Harris and Kahn discuss carbon annuity implementation issues in the context of giving small farmers in Amazonia an incentive to maintain forest cover.

VIII. Contraction and Convergence

Contraction and convergence are two characteristics that the Global Commons Network (http://www.gci.org.uk/contconv/cc.html, 2001), among others, argues must be generated by an international climate change agreement. Contraction refers to a continual reduction in annual emissions (from the 1990 reference level) so that the atmospheric accumulation of greenhouse gases is significantly lower in the distant future than it would be with simply meeting the 1990 reference levels. Convergence refers to the characteristic that in the distant future, per capita greenhouse gas emissions are equal across countries. Contraction is a characteristic related to efficiency, while convergence is a characteristic related to equity.

The efficiency implications of contraction are that damages from the accumulation of greenhouse gases in the distant future are likely to be quite large. At the

[9] The value of a ton of sequester carbon can be determined by the value of the prevented damages associated with lessened global climate change. A discussion of the literature that measures these damages is contained in Bruce, et. al. (1996).

same time, the costs of reducing greenhouse gases should decline as we move through time due to technological innovation, particularly the development of alternative energy sources such as biomass based fuels and fuel cells. The question is, how do we get this contraction?

Contraction could take place in the context of a pure trading system (provided that the nations would agree to this). However, note that in order for contraction to take place in a trading system, the number of permits must be periodically reduced. This would require that a new international agreement on limitations take place at regular intervals, or have an initial agreement on exactly how to distribute the reduction in emissions in each year over the next 60 to 100 years.

In contrast, contraction will automatically take place in the context of a carbon tax system, due to the "never-ending incentive to reduce emissions" that is discussed in Section V of this paper. In addition, the nations could agree to a schedule of percentage increases in the real magnitude of the tax over time. For example, even a relatively modest annual increase of 3 percent a year would result in an effective doubling of the tax every 23 years. In combination with the normal incentives associated with carbon taxes, this would provide a very effective contraction path. Additionally, it would provide a mechanism to eventually lead to a contraction in developing country emissions. However, it is important to note that under a tax system, some contraction will take place even without an increase in the real tax rate, as long as the tax rate is impervious to inflation and devaluation.

Convergence refers to a time path of emissions reductions by the various countries that results in an equal level of emissions in each country, where the equality is measured as equal levels of emissions per capita, not equal aggregate emissions levels. Although the Global Commons Network is a strong proponent of this concept of convergence, it must be noted that this is an equity-based argument, not an efficiency-based argument. In fact, if a standard is imposed to equate the emissions per capita across countries, this is likely to increase global costs of reducing emissions. The reason for this is cost-minimization would require the marginal abatement costs in all countries to be equal. This would only coincidently occur if emissions per capita were equal across countries, and in fact, is unlikely to occur given the different technologies, climates, transportations systems, economic institutions and cultures that exist in different countries.

We recognize, however, that an equity goal (even at the expense of efficiency) might make an international agreement more likely. However, the absolute convergence of emissions per capita is not necessarily equitable unless there is simultaneous conversion of income per capita. An income-adjusted convergence might be regarded as more equitable. Convergence of this sort could be stimulated by a tax system, where the tax could have two adjustment components. The first adjustment component would increase a country's tax if it were above average in emissions per capita, and reduce it if it were below average in emissions per capita. The second adjustment factor would reduce a country's tax if it was below average in income per capita, and increase it if it were above income per capita. Countries that made more progress in economic development would therefore move towards convergence more quickly, and countries that were having more difficulty would move towards the global convergence level less quickly.

IX. Conclusions

It is difficult to construct conclusions for global climate change policies, when there is so much uncertainty in the science of global climate change (in terms of the distribution and nature of regional impacts), in the economics of global climate change (in terms of both the economic damages associated with climate change and the costs of reducing greenhouse gas emissions), and in terms of the dynamics of domestic and international political processes. Nonetheless, there is a significant need to think broadly about global climate change policy and to structure hypotheses concerning potential structures of an emissions limitation system.

We advance the hypothesis that a system of greenhouse gas reductions based on carbon taxes might have the potential to move us towards global agreement more quickly. Among the desirable characteristics associated with a carbon tax system are:

- Economic efficiency
- Increased incentive for technological innovation
- A continuous incentive for emissions reductions
- An ability to put a ceiling on a country's abatement costs
- An immediate impact on developing country emissions that will grow stronger over time
- Compatibility with the Clean Development Mechanism
- Compatibility with credit for carbon sequestration
- Compatibility with convergence and contraction

Although the system we have proposed is not complete, and there is a need to address many implementation issues, we believe that the paper makes a convincing case that we should consider the potential of carbon tax systems to move us further towards an international agreement.

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