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DEVELOPING COUNTRIES AND THE CONTROL OF CLIMATE CHANGE

A Theoretical Perspective and Policy Implications

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Developing Countries and the Control of Global Climate Change:

A Theoretical Perspective and Policy Implications

I. Table of Contents

II. Introduction[1]

In the international negotiations over the control of climate change, the developing countries have so far played a limited role. In the Kyoto Agreement on limiting greenhouse gas (GHG) emissions, only a subset of the world's economies, the so-called Annex I countries, have agreed to treaty-based limits on GHG emissions. Annex I countries, are essentially the highly developed economies plus Russia, Ukraine, and parts of Eastern Europe. Developing countries enter the treaty obliquely, mainly through the Clean Development Mechanism, which aims to foster projects linking the developed and developing countries in emissions control.

The United States is calling for more active role for the developing world, including binding commitments of GHGs by several of the large developing countries. In general, the developing world has resisted such entreaties, arguing that their highest priority is to grow, and that growth requires increased emissions of GHGs. They stress that per capita GHGs in the advanced economies are several times those of the poorer countries, so that limiting the emissions of the poorer countries would be unfair. The USG counters with the argument that efficient reduction of global GHGs necessarily requires efforts of all countries that contribute to the GHGs. Since GHG concentrations in the Earth's atmosphere depend on the actions of the entire world, the entire world must be part of an efficient control strategy.

At present, this dialogue -- or debate -- has not progressed very far. There are several reasons. First, there is a major distinction between efficiency (where in the world should the control be undertaken in order to minimize the global costs of control) and equity (who should ultimately bear the costs of GHG control and the damages from anthropogenic climate change). The distinction of efficiency and equity has not be clarified. In our view, the developing countries are correct that current proposals to have them join the global treaty are simply not equitable. Since the developed countries have caused, and will continue to cause, a disproportionate amount of the increase in GHGs, while the developing countries are likely to bear a disproportionate amount of the damage from climate change, an equitable approach to the problem requires that the developed countries bear the lion's share of the control efforts. Indeed, equity may well require compensation from the rich to the poor countries for climate-change damages caused by the rich-country emissions.

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At the same time, we agree with the position that global efficiency requires that the developing world should play a larger role in reducing GHG emissions. There are several reasons for this. First, efficiency dictates that the marginal costs of GHG-control should be equalized across countries and over time. Thus, if an extra ton of carbon can be sequestered more cheaply in China than in the United States, it makes sense that China should undertake the carbon control. (Since this control will, in general, involve costs for China, fairness may dictate that the costs should be compensated one way or another by the richer countries). Second, plausible forecasts for future GHG emissions show that the developing world will become the main contributor to emissions in the foreseeable future, though per capita emissions will still be much higher in the developed countries. As a practical matter, therefore, there is little chance of effective climate control unless the developing countries participate in a global (or at least more inclusive) treaty.

This paper aims to clarify the terms under which the developing world might be brought into a global climate change agreement. Section II discusses some of the basic economic theory of climate-change control, stressing the distinction of efficiency and equity, and identifying the conditions for efficient and equitable GHG control. We examine the implications of the basic fact that the likely damages from climate change lie disproportionately within the developing (especially tropical) countries, while the source of anthropogenic climate change are disproportionately found within the developed countries. Section III discusses the major policy implications of our finding. We stress the following: (1) the need for a global framework, including both the developed and developing countries; (2) the advantages of GHG taxation over quantitative limits on GHG emissions in an efficient control program; (3) the need for appropriate compensation of the poor countries by the rich countries as part of an equitable process.

III. Efficiency and Equity in Climate Change Control

The problem of GHG damages, and the need for government intervention

At a basic theoretical level, the problem of anthropogenic climate change is clear and well-studied. In a competitive market economy, private producers choose the level of energy inputs to equate the marginal value product of energy with the marginal cost of the energy input. On a social basis, however, the marginal private cost of the energy input -- equal to the unit market price of the energy -- does not equal the marginal social cost of the energy input. The social cost equals not only the private price of energy, but also social damages that result from use of the energy which are not part of the market price. In the case of coal mining, for example, social damages might include unregulated (or untaxed) environmental despoilation caused by open-pit mining. In the case of fossil fuels generally, the social costs include the economic damages that result from greenhouse gas emissions into the atmosphere. The goal of policy is to equate the social benefits from energy use (and land use) with the social costs (including both the direct costs and the social damages).

According to prevailing scientific theories, increased concentrations of carbon and other GHGs in the atmosphere induce global warming and other changes in ecology and climate (e.g. in patterns of precipitation, the frequency and severity of tropical storms, the level of the oceans, the functioning of complex ecosystems). In turn, anthopogenic GHG emissions (mainly carbon, but also other gases) into the atmosphere, caused variously by fossil fuel burning or by deforestation (which releases the carbon in the forest biomass into the atmosphere) have a direct and persistent effect on the concentration of carbon and other GHGs in the atmosphere.

Let E be GHG emissions, T be the stock of carbon in the atmosphere, D(T) the social damages resulting from the stock of carbon in the atmosphere, and Q the GDP. Since energy is an input in GDP, we can write:

(1) $Q = F(E) - pE, \quad F' > 0, F'' < 0.$

Here F is a production function with the standard assumption of diminishing marginal productivity of E. Here p denotes the market price of energy. Since E causes a change in T, we can generally write a dynamic equation for T of the form:

(2) $dT/dt = \beta E - \delta T.$

The meaning of equation 2 is that atmospheric carbon changes for two reasons. First, T rises with βE, where β is a constant, determined by the empirical properties of the energy source. Second, part of an increase in T is absorbed out of the atmosphere by other natural carbon sinks, especially the ocean, at a rate of δ. We should think of T not as the absolute amount of carbon in the atmosphere, but as the anthropogenic contribution, that is the part of atmospheric carbon due to man-made processes. The natural level of atmospheric carbon (or pre-industrial level, as it is sometimes called) is estimated at 590 billion tons of carbon (GtC). Thus, we should think of T as the carbon in the atmosphere minus 590 billion tons.

(3) $D = D(T) \quad D' > 0, D'' > 0.$

Damages rise with atmospheric carbon (as described later). It is typical to presume that the marginal damages are increasing in T, that is the extra social cost of another increment in T is higher the higher is the level of T at which the increment occurs. Thus, while a low T might have only modest effects, twice that level might cause much more than twice the damage.

The basic efficiency condition

The private market solution to the level of emissions is found by solving the following problem:

(4) $\text{Max} \int_0^\infty \exp(-rt)\,[F(E) - pE]\,dt.$

The social optimum is found by solving:

(5) Max $\int_0^\infty \exp(-rt)\,[F(E) - pE - D(T)]\,dt$ subject to (2).

The private market solution is immediate: simply equate the marginal product of energy with the market cost of energy.

(6) $dF/dE = p$.

The social optimum is found according to the following first-order conditions:

(7) (a) $dF/dE = p + \gamma\beta$

(b) $d\gamma/dt = \gamma(r+\delta) - dD/dT$.

Here γ is the social cost of an incremental unit of anthropogenic carbon (or other GHGs), so that $\gamma\beta$ is the social cost of an incremental unit of energy input. dD/ dT is the social cost of an incremental unit of carbon in the atmosphere.

The social optimum uses less energy than the private optimum. In the social optimum, the marginal product of energy, dF/ dE, is equated to the *full social cost of energy*, which is the private cost p plus the social charge $\gamma\beta$. This is obviously higher than the private cost. One standard remedy is to levy a corrective tax on emissions (akin to, but obviously not exactly the same as, the famous BTU tax) in the amount $\gamma\beta$. The key step, then, would be to find γ (β is essentially a technical, not economic, parameter). We can solve (7)(b) to yield:

(8) $\gamma = \int_t^\infty \exp[-(r+\delta)(t+j)]\,dD/dT\,dj$.

In a word, the social cost of an incremental emission at time t is the discounted value of future marginal social damages, where the discount rate is equal to the interest rate r plus the rate of carbon dissipation δ. If the carbon dissipates rapidly (δ is large), then the discount rate is high: today's emission does not cause heavy damages in the future, since the emissions do not linger in the atmosphere. Similarly, if r is large, then the future damages are also highly discounted.

To understand (8), consider the following. An extra unit of emission causes, at an instant of time, an extra unit of damage dD/ dT. Since the emission lingers in the atmosphere, and only gradually dissipates (as it is absorbed by natural sinks such as the ocean), the marginal damages also linger. Starting at t, the social costs of the incremental emission at instant t+j will be given by $\exp[-(r+\delta)j]dD(T(t + j))/ dT$. Note that the damages are evaluated according to the carbon that will be in the environment at time $T(t_0+j)$. Thus, marginal damages may be low today if T(t) is small, but the today's emission could cause high damages in the future if the path of T is increasing. Note that in the special case of a steady-state equilibrium level of T, marginal damages dD/ dT are constant, and (8) can be written as:

(8') $\gamma = (dD/dT)/(r+\delta)$.

Notice two important points about the optimum. First, the optimum emission is clearly less than the private emission level. Second, the gap between the private and the optimum emissions increases over time. This is because the marginal damages of emission rise over time, as the atmospheric stock of carbon rises. The point is the *optimum abatement is backloaded*, in recognition of the fact that the marginal costs of emissions are rising over time.

Continuous versus catastrophic damages

The algebra of the last section is based on the continuity of two key relationships: between GHGs and temperature; and between temperature and societal damages. It is assumed, especially in simulation models, that global temperature (and other key climate parameters) increases smoothly, and with a roughly constant slope (or elasticity, depending on specification) with respect to atmospheric carbon. Similarly, it is generally assumed that the damages increase continuously, and with relative constant elasticity, with respect to temperature. Both these assumptions are open to scientific question and the policy implications of discontinuous climate change, and discontinuous damage functions, may be significant.

On the scientific front, climate may be a discontinuous function or a highly non-linear function of carbon. After a threshold of carbon, and hence global warming, is reached, various kinds of non-linear feedback processes in the environment could lead to sharp jumps (discontinuities, or strong non-linearities) in climatic processes. For example, a rise in temperature above a threshold might lead a melting of polar ice caps, triggering a massive increase in sea level; or a breakdown in the ocean currents that leads to dramatic *cooling* in Europe as a result of the collapse in the Gulf Stream; or a warming of the tundra sufficient to release a massive amount of methane impounded in frozen soils. In all of these cases, a small change in temperature -- above a threshold -- leads to a massive change in climate. Such events are regarded as low-probability events in the vicinity of a 2X CO_2 atmospheric concentration, but with a steeply rising probability at higher carbon concentrations (e.g. 3X CO_2). Pizer (1997)

Damages might similarly be discontinuous in temperature. Certain crops may be little affected by modest temperature changes, but hit thresholds at which crop productivity collapses. The frequency or severity of tropical storms may respond discontinuously to temperature changes, and so forth. Ecological systems may collapse when temperatures cross key threshold levels (for example by destroying a key niche in a complex food web).

The implications for policy may be important. The small risks of catastrophic outcomes may be as important, or more important, than the damages resulting from moderate temperature increases. Gradual changes in temperature may pose only small economic losses (especially if such changes are properly anticipated). The big risks of climate change may come mainly from the small chances of very large events. Policy would then be directed, for example, at evaluating the various risks of catastrophe;

identifying the possible thresholds at which such catastrophes might occur; and preventing the thresholds from being crossed rather than mitigating CO2 emissions per se. Price mechanisms such as Pigouvian corrective taxes (Pigou 1952) would make sense at low levels of GHG concentrations (where catastrophic risks are small), while quantity constraints might begin to make sense at high levels of GHG concentrations, where catastrophic risks have a higher probability (see discussion in the following section).

Prices versus quantities

The social optimum can be secured in two ways. The first, and most straightforward, is the Pigouvian, or corrective, tax on energy use, in the amount $\gamma\beta$. The second is a quantity limit. The government would mandate the level of total emissions, and might distribute tradable emissions permits in the total amount of the efficient emissions level. (In the illustrative case, the permissible level would decline over time). Assuming efficient secondary markets in permits, the market price of a permit would equal the corrective tax. Either the "price approach" (via taxation) or the "quantity approach" via tradable emissions permits would have the same efficiency properties.

Following Weitzman (1974), it is has been recognized that one or the other approach might be preferable in a situation of uncertainty (see Pizer 1997 for the best recent analysis). The choice, in general, depends on the relative uncertainties regarding the damage function and the abatement cost function, and on the relative slopes of the two. If the damage function is steeply kinked at the optimum level (a sharp threshold, above which catastrophe occurs), then quantity constraints (e.g., tradable permits) generally make more sense than price controls. If the damage function is nearly linear, on the other hand, then price mechanisms (e.g., a corrective tax on emissions) are generally more efficient. Most simulation studies (e.g., Pizer 1997) have found that at moderate temperature increases (e.g., 2X CO_2), the risks of catastrophe are small enough, and the damage function is linear enough, to argue for price mechanisms rather than quantity mechanisms as the optimum intervention.

Public versus private investments

In the analysis up to this point, markets are distorted because they do not price the damage from GHG emissions. A corrective tax on emissions is sufficient to restore the optimum resource allocation. In practice, of course, markets fail for many other reasons as well, so that a corrective tax may not be all that is needed to address the climate change problem. One major problem, for example, is that some of the steps needed to reduce GHGs involve investment in public goods. Almost by definition, private markets by themselves will under-supply the optimum level of public goods.

There are several public goods involved in optimal energy management. A considerable amount of energy conservation is ultimately based on *basic science*, for example the synthesis of new materials that offer improved insulation, or the development of alternative non-GHG energy sources, such as fusion energy or more efficient solar cells. In general, such technological advances are only partially patentable.

The benefits of such inventions are only partially appropriable by the original inventors. Economic theory teaches that markets therefore under-supply the inventive efforts in such areas unless government subsidizes the inventive activity in one way or another, e.g. through grants from national science foundations, public prizes for important discoveries, or temporary subsidies in the introduction of new, innovative processes.

The presence of public goods in the limitation of GHG emissions is pervasive. In addition to research on materials and energy use, programs to control *population growth* (e.g., through community education) may be crucial to limiting the GHG emissions resulting from deforestation, but such family planning programs are almost inevitably represent public rather than private goods. Similarly, the establishment of efficient land-use and concession laws for forestry management is a form of public goods. One of the most effective remedies to deforestation may be improved *tropical agricultural technology*, so that swidden (slash-and-burn) agriculture can be replaced by more stable, and less destructive, agricultural practices. Again, both theory and experience have shown that advances in agricultural technology require a significant investment of public funds.

These examples illustrate a fundamental proposition. Efficient GHG controls will surely require not only corrective taxation but also a portfolio of investments in key public goods. The public investments may turn out to have an overriding empirical significance in the long run.

The two-country case

If we move from one emitter to multiple emitters, we introduce several new issues, though the underlying structure of the problem remains unchanged. In the case of two emitters, we have the following problem:

(5') Max $\int_0^\infty \exp(-rt)\,[F_1(E_1) + F_2(E_2) - p(E_1 + E_2) - D_1(T) - D_2(T)]\,dt$, subject to:

$$dT/dt = \beta(E_1 + E_2) - \delta T.$$

The main points about (5') are, first, that the worldwide net output is maximized, and second, that the stock of carbon depends not on one country's emissions, but on the sum of emissions from the two countries. Technically, the carbon released by any one country mixes rapidly in the atmosphere, raising the carbon concentration facing all countries.

The conditions for efficient control are now the following:

(9) $dF_i/dE_i = p + \gamma\beta \qquad i = 1,2.$

And $\gamma = \int_0^\infty \exp[-(r+\delta)t]\Sigma_i\,(dD_i/dT)\,dt.$

In this case, each producer equates the marginal productivity of energy to the marginal social cost, in which the social cost is now equal to the discounted value of the *sum of* *marginal damages*, and where the summation is taken over the two countries. In other words, when considering the marginal damages caused by emissions of either country, the damages include both the damages to country 1 plus the damages to country 2.

How much should each country abate its emissions? By a constant proportion of the baseline? Or by a differing amount, depending on relative cost conditions in each country? The answer is clearly the latter. Suppose that two countries start out with equal size and equal energy use, but that in one country energy use is highly price inelastic, given the industrial structure and other characteristics of the economy, while in the second country, the energy use is highly elastic (i.e. energy is easily substitutable by other inputs). Concretely, suppose that the elasticity of energy demand is 0.1 in the first country, and 1.0 in the second. Suppose, further, that along the optimal path, the corrective tax $\gamma\beta$ is 100 percent of the private cost of energy (i.e. a doubling of the tax-inclusive price). On these assumptions, the first country should optimally abate just 10 percent of its energy use, while the second country should cut its energy use in half. Overall energy use declines by 30 percent, but it is not evenly divided between the two countries.

A standard which says that each country should introduce a tax of 100 percent on energy inputs would lead to the optimum solution. A standard which says that each country should reduce its energy use by 30 percent would be highly inefficient: the global outcome would be achieved, but at excess cost. Country 1 would be doing too much adjustment, and country 2 would be doing too little. A standard which says that each should reduce energy inputs by 30 percent but that they may trade their emissions rights would, once again, lead to the efficient outcome, assuming low transactions costs in the tradable permits market.

The implications of putty-clay technology

One major practical hurdle to emission control is that energy substitutability is much higher when choosing among industrial equipment at the time of an initial investment, than after the equipment is already in place (retrofitting is very costly). For example, there are many types of fossil-fuel power plants. By spending more on the initial physical capital it is generally possible to reduce the flow input of energy used to produce a kilowatt-hour once the plant is operating. However, after the type of plant is selected, and the plant is installed, there is little remaining flexibility in the capital-energy substitution. Retrofitting the equipment may be possible in some circumstances, but at extremely high marginal costs per unit saving of emissions. Economists term this situation one of "putty-clay" technology. Initially, the capital-energy ratio is malleable (putty); once in place, however, there may be no substitutability at all (clay).

There are two important implications of this general situation. First, the optimum adjustment path to a lower level of energy intensity will be backloaded. Since it is very costly to retrofit equipment, essentially all of the efficient energy saving must be achieved on new installations. Since these installations come gradually over time, the optimum adjustment is slow and rises over time. Second, and for the same reason, the proportionate adjustment will be larger in faster-growing economies, since such economies will tend to have a higher effective turnover of the capital stock.

Consider the following simple example. Suppose that there are two kinds of power plants. The first emits 1 unit of carbon per kWh, and the second emits only 0.75 units per kWh. Initially, economies 1 and 2 both use only the first type of power plant, which is the private sector optimum. Now suppose that with the introduction of an optimal corrective emissions tax, the optimum choice shifts to power plants of the second type. Economy 1 is a mature, advanced economy. The overall energy use is constant, though 5 percent of every power plant depreciates each year and must be replaced. All new installed capacity is of type 2. Economy 2 is a dynamic, fast-growing developing country.[2] While each power plant also depreciates at 5 percent per year, the economy's overall energy use also grows by 5 percent each year for the next 30 years, and all replacement investment plus incremental capacity are of type 2.

Now suppose that the optimum corrective tax is put in place in year 1. It is an easy exercise to check that the average energy intensity (emission per kWh) of the two economies is as follows:

Year	0	1	5	10	15	20	25	30	4
Economy 1	1	.95	.94	.90	.86	.84	.82	.80	.75
Economy 2	1	.98	.90	.84	.81	.78	.77	.76	.75

In the long run, both economies have a twenty-five percent reduction in carbon emissions per kWh of electricity. In the mature economy, it takes about 13 years to reach half of the total adjustment, and only 80 percent of the long-run adjustment is completed within 30 years (because 21 percent of the power plants still in use are of type 1). In the fast-growing developing country, it takes just 6 years to make half of the long-term adjustment, and by year 30, 96 percent of the long run adjustment has been made. Just 5 percent of installed capacity is of the original, high-emission type 1.

A short-hand way to describe this situation is to say that the long-run elasticity of substitution between capital and energy is (much) higher than the short run elasticity of substitution, and is higher in fast growing countries than in slow-growing countries. Equivalently, we can say that the elasticity of energy use with respect to price is higher in the long run than in the short run, and is higher in fast-growing countries than in slow growing countries. One immediate implication is that we might expect a larger optimal proportionate reduction of energy use -- relative to a baseline that assumes no corrective taxation -- in developing countries as opposed to developed countries, on a time horizon of say 5-20 years. In the long term, however, when the overall capital stock has fully turned over, the proportionate adjustments in the two types of economies will be much more similar.

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[2]We must hope that such economies still exist!

Structural change and optimum energy use

Most theoretical, and even many empirical, studies of GHG emissions are based on an assumption of a constant-returns-to-scale aggregate production function with the property that the derived demand for energy is unit-elastic in total output (see for example, Nordhaus 1998). For example, suppose that gross output is produced by valued added V and energy E, according to $Q = E^{\theta}V^{(1-\theta)}$. Then, equating the marginal product of energy with the price of energy it is well known that the derived demand for energy is $E = \theta Q\, p^{-1}$. Thus, energy use increases with unit elasticity in Q, and decreases with unit elasticity in p. From the point of view of simulations and projections, this kind of model leads to the view that as GDP grows over time, energy use -- and hence carbon emissions -- tend to increase in the same proportion.

Once we allow for structural change, however, this unit-elastic assumption seems much less plausible. It is well known from theory and experience that economic growth involves systematic structural change. At low levels of income, most economies are largely agricultural. As GDP increases, output and employment shifts from agriculture to industry. As output continues to rise in the course of the industrialization process, the share of employment and output in industry reaches a peak and begins to decline, as the economy shifts to services. At a broad level, the energy/emissions intensity of agriculture, industry, and services are likely to differ markedly. Thus, as GDP increases over time, the increases in GHG emissions are unlikely to vary in the same proportion, even if the relative price of energy remains unchanged.

In particular, it seems likely that the energy and emissions intensity of industry is higher than that of agriculture or services. Thus, on a trajectory of development from agriculture to industry to services, we might expect to see an inverted-U in the levels of emissions per unit of GDP. Initially, as industry's share of output is increasing, emissions per unit of GDP also rise. As industry begins to diminish as a share of GDP and services begin to rise, the energy or emissions intensity of the economy may begin to decline. We test this proposition in the following section and find evidence to support it. This alternative to the standard unit-elastic assumption has very important implications for long-term forecasts. It holds that energy emissions in relation to GDP might well diminish for most economies as they pass the peak of industrialization, leading to lower long-term estimates of GHG emissions.

The same phenomenon is likely to hold on the damage side of the ledger. Most of the non-catastrophic damages of climate change involve disruptions of agriculture and public health, as well as vulnerabilities to increased extreme weather patterns. The agricultural disruptions are likely to be larger as a percent of GDP in poor countries, since agriculture has a larger share of GDP in those countries. Similarly, poor countries will tend to lack the public health institutions and capacities to offset the public health damages of climate change. And surely people in poor countries are the most vulnerable to extreme weather patterns, as a result of populations living in hazardous conditions (e.g. in floodplains, or on the slopes of unstable mountainsides). Thus, we would also expect the damage function to show *less than unit elasticity* with respect to aggregate GDP. As development occurs, the damages from global climate change as a result of GHG emissions are likely to decline as a percent of underlying GDP.

With respect to the low-probability catastrophic damages, such as the massive rise of sea levels or a break in the thermohaline circulation of ocean currents, the damage functions are different. For such outcomes, damages depend heavily on the specific natural geography. Europe, for example, one of the richest parts of the globe, could be the hardest hit region from a combination of massive sea-level increases combined with a breakdown or reversal of the ocean currents that bring warm Gulf stream waters to the North Atlantic.

Emission reduction versus damage mitigation

So far we have assumed that the damage function, D = D(T), is fixed and immutable. In that case, efficient emissions control policies all focus on reducing T (and therefore E on a flow basis). In general it may be also possible to intervene to reduce the damages resulting from a given level of T. Thus, rather than making investments to limit emissions, investments are made to reduce the impact of climate change on the society.

Suppose that damages can be written as D = D(T)-M, where M is the amount of damage mitigation. We assume that mitigation costs are given by C = C(M), with C' > 0, C''>0. The new maximization problem is:

(5'') Max $\int_0^\infty \exp(-rt)\ \{F(E) - pE - [D(T) - M] - C(M)\}\ dt$ subject to (2)

At the optimum, dC/ dM = 1, which simply says that mitigation efforts should be carried out to the point where the marginal benefits of a unit of mitigation (scaled to equal 1 in the way we have stated the problem) are equal to the marginal costs of mitigation, dC/dM.

There are several obvious areas where mitigation expenditures will surely be efficient. If climate change will damage crop yields, part of the optimum response should be to invest in crop varieties that are adaptive to the anticipated climate change (e.g. drought resistant or temperature resistant). Similarly, if it is expected that global warming might increase the range of various infectious diseases, such as malaria, then expenditures on malaria control (ranging from mosquito vector control, to use of bednets, to increased research and development on malaria vaccines and drug therapies) will likely be a key part of an efficient response to GHG emission control.

Many of the key mitigation efforts, such as the responses in crop varietals and public health measures that we have just mentioned, have strong public goods aspects to them, especially since they require basic scientific research. Thus, mitigation efforts will not proceed at an optimal rate without a clear international strategy. Simply imposing a Pigouvian corrective tax on GHG emissions will not do the job. Corrective taxation (or emissions limits with tradable permits) will have to be complemented by an international research and development effort in many key areas.

Equity in emissions control

As mentioned in the introduction to this paper, efficiency is only one fundamental principle for managing global climate change. A second principle is equity. While Pigouvian corrective taxes may cause economic agents to internalize the external effects of their actions, they do not compensate the losers for the damages that are done. We propose that equity considerations require that victims of the behavior of others should be compensated. In a world in which every country's actions affect all other countries, such regimes are not easy to design.

One proposal that has been offered, particularly by developing country signatories to the protocol, is that emissions property rights be allocated to countries on a per capita basis. This need not effect the efficiency of the final emissions allocation if trading occurs with low transaction costs, but would result in a transfer of wealth to the developing world since that is where the majority of the world's population is found. However, we propose that this is only a partial solution to the equity dilemma because the damages from climate change will not be felt equally be all individuals. Most research suggests, and as we show in the companion empirical paper, tropical developing countries will be relatively severely impacted. A complete solution to the equity problem must consider contributions of countries to the stock of CO_2 and the differential damages experienced by each country.

We propose the following standards for compensation. Suppose that the total atmospheric carbon concentration is T. First, we allocate the total carbon emission into the contributions of each country i, by tracking the historical evolution of T according to the emissions of individual economies. Thus, $T = \Sigma_i T_i$. Let $\sigma_i = T_i /T$ be the share of global emissions due to country i. Next, we define worldwide damages caused by T, as well as indirect damages resulting from abatement and mitigation efforts. The damages in an individual country are thus the sum of two components: the damages due to T, given by $D_i(T)$, where $D' > 0$, $D'' > 0$, plus the loss of GDP resulting from mitigation efforts, which we designate as ΔY_i . Thus, total damages are $D_i (T) + \Delta Y_i$. Worldwide damages are therefore $WD = \Sigma_i [D_i (T) +\Delta Y_i]$. Let $\lambda_i = D_i /WD$ be the share of worldwide damages accounted for by country i.

Our proposal is based on the premise that victims of climate change should be fully compensated for the damages that they incur. This would follow from a philosophical position in which each person owns the "right" to an unchanged environment, and therefore must be compensated in full when the environment changes due to human causes. Thus, global compensation would be C = WD. Each country would receive a share of global transfers equal to λ_i WD. Each country would make a transfer equal to the share in which it *caused* the global damages, σ_i WD If in fact damages were suffered equally by every individual in all countries, λ_i would be equal to a country's share of the world population. In this case, if a country's share of emissions equaled its share of world population, its net transfer payment (NTP) would be zero. If countries experience differential impacts, λ_i may be greater or less than the country's population share. The NTP that each country makes would therefore equal the damages caused minus the damages received:

$$(10)\ NTP_i = \sigma_i WD - \lambda_i WD = (\sigma_i - \lambda_i) WD.$$

By construction, of course, $\Sigma_i NTP_i = 0$. That is, net positive transfers by some countries exactly balance the net negative transfers (i.e. the compensation for net damages). The net contributors to the global damage (i.e. those countries that cause more damage to the world than they incur) pay the net victims (i.e. those countries that incur more damages than they cause).

In the empirical paper that accompanies this one, we make illustrative calculations of σ_i, λ_i, and NTP_i for nine groups of countries that we call the "Nordhaus regions" since the groups have been created by Nordhaus (1998). One persistent point is that the temperate-zone economies cause more damage than they sustain. Thus, *the direction of global compensation should be from the temperate- to the tropical-zone economies*.

An important question is the relationship between the optimal corrective tax (or allocation of emissions permits) and the standards for compensation that we propose. Unfortunately, there is no tight link between corrective taxes for efficiency, and equitable transfers to make net compensation payments. There are two major reasons for the lack of a clear relationship. First, compensation should apply to bygones, because past emissions determine the current stock of CO_2, and thus, current levels of damages, while corrective taxes do not apply to bygones. Thus, if past actions of the developed world contributed to a high, and therefore damaging, level of carbon, the victims merit compensation even though it is too late to make corrections on past emissions.

Second, the optimum corrective tax is linked to the *marginal* damages from an incremental unit of emission, while compensation is linked to the *average* damages from a unit of emission. Thus, the corrective tax on an increment of emissions is given by: $\gamma dT = \int_0^\infty \exp[-(r+\delta)t]\Sigma_i [(dD_i/ dT)dT]\, dt$. On the other hand, the discounted value of compensation that will be owed as a result of incremental emissions is: $\int_0^\infty \exp[-(r+\delta)t](\Sigma_i D_i)(dT/ T)\, dt$. In general, the corrective tax payments will be higher than the compensation payments, since $dD_i/ dT > D_i /T$ where $D'' > 0$, and $D(0) = 0$. In one case, though, the corrective tax payments will exactly equal the compensation payments. This is when the damage function is linear in T, so that $D_i = a_i T$. In that case, average damages (D_i/ T) are equal to marginal damages (dD_i/ dT).

The conclusion is that if optimum corrective taxes are collected on carbon emissions, only a fraction of those taxes will be needed to pay compensation to victims of climate change, since the corrective tax collections will overstate the total damages from climate change. More generally, the efficiency attributes of climate change should be kept distinct from the equity attributes. On the one side there should be optimum corrective taxes or quantity limits to emissions. On the other side, there should be an effective system of net transfer payments to compensate losers from climate change.

IV. Some Policy Implications

Our theoretical discussion suggests several key policy conclusions. We stress at the outset that there are many crucial gaps in knowledge at every stage of the argument: in the level and prospects for GHG emissions; in the links of GHG emissions to GHG concentrations in the atmosphere; in the relationship between GHG concentrations to climate change, especially temperature and precipitation; in the economic and public health damages resulting from climate change; and in the types and probabilities of catastrophic outcomes.

1. An efficient global strategy for GHG emissions requires the participation of all countries, both rich and poor.

2. Efficient climate control involves the pricing of GHG (especially carbon) emissions. This can be accomplished either through corrective taxes or quotas on emissions. Theory suggests that barring catastrophic risks due to threshold effects on GHGs, price strategies (i.e. carbon taxation) are likely to be more effective than tradable permits. More work needs to be done on this choice of policy instruments.

3. An efficient global allocation of mitigation efforts requires that all producer/emitters of GHGs face a similar marginal corrective price of emissions, either through a corrective tax or through the purchase price of emissions permits.

4. Optimal mitigation efforts should be backloaded in two senses. First, the optimum corrective tax should rise over time, reflecting the fact that the discounted value of marginal damages will also rise over time. (This last point is due to the fact that marginal damages are an increasing function of GHG concentrations, which are of course on a rising path). Second, the proportionate response of emissions to any corrective tax is larger in the long run than in the short run, because of the effects of putty-clay technology described earlier.

5. The efficient reduction in GHG emissions as a proportion of the baseline projections will be larger in the fast-growing developing countries than in the slow-growing advanced economies, because of the effects of putty-clay technology. In short, since the developing countries are adding emissions capacity at a faster proportionate rate than are the advanced economies, the opportunities for energy saving are also proportionately greater. This greater saving will be the market outcome to a uniform corrective tax on emissions imposed on both the developed and developing countries.

6. Efficient mitigation and adjustment efforts will also require substantial investments in public goods, i.e. in areas of research and development, and infrastructure investment, that will not be provided by normal market forces. This applies to the basic research in climate change itself, where the level of knowledge remains insufficient to make long-term policy decisions, as well as to areas of mitigation and adjustment, such as the development of improved agricultural technology to forestall deforestation in tropical areas, or the reduction in cost of sustainable energy sources.

While the case for including the developing countries in the climate change agreements is sound, the methods for their appropriate inclusion are yet to be worked out. The developing countries should be included according to criteria both of efficiency and equity. While the developing countries should certainly participate in an efficient global mitigation efforts, most of the developing world should also receive compensation for the damages that they incur as a result of GHG emissions from the advanced economies. The most transparent form of participation would be through a global commitment to the taxation of GHG emissions, combined with a program of compensation for the global victims of climate change. In addition, it is important to mobilize a worldwide programs on public goods investments in this area, to improve the science of climate change; as well as the R&D in areas of emissions mitigation, sustainable land use and tropical agriculture; and other areas of scientific and technological inquiry.

V. References

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