Climate Change, Security, and Redistribution:

How Can Political Dilemmas Linked to the Global Environment Be Solved?

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Global environmental change—particularly climate change—raises important security concerns since it affects the world naturally, economically, and socially, while impinging heavily upon the relationships between developed and developing countries. These developments will have all kinds of difficult consequences, especially since they are linked to particular types of individual and social activities.[1] Such behavioral dimensions are, in part, responsible for the negative evolutions in terms of climate and resource trends. As we show below, similar types of actions can exacerbate major security issues both locally and regionally by encouraging predatory moves in terms of resource acquisitions. However, we will also argue that solutions are not only available in the form of transfers between countries and regions of the world, but are also essentially profitable for all if applied correctly. These transfers are efficient and can be applied through classical market or taxation mechanisms even at the international level. First, we will look at the climate problem in perspective, and then examine

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the theoretical notions underlying the population natural resource–conflict–security nexus at the root of the issue. In order to accomplish this, we will use an analytical construction that can account for these relationships. Finally, we will investigate solutions to these difficulties by demonstrating—with the help of the same analytical construct—that compensation between richer and poorer regions constitutes an efficient and worthy answer to the issues raised.

The Problem in Perspective

The late twentieth century and the beginning of the new millennium have been characterized by global environmental change. For the first time in history, it has become clear that human activities can affect the global evolution of natural processes and thus, the environment. Some geologists now identify the current period starting in 1945 as the "Anthropocene" because thousands of years from now, the human impact on the planet's geology will be observable in the rock formations. Climate change is a particularly salient manifestation of global change. It influences geophysical trends, which can detrimentally affect societies through a higher frequency of extreme meteorological events and also progressively modifies the natural settings in which societies are evolving.[2]

As Swedish scientist Svante Arrhenius established in 1896, climate change is essentially caused by variations in solar energy reaching the Earth during its orbit around the sun and by the amount of greenhouse gases in the atmosphere. These gases, like the glass of a greenhouse, retain some of the solar radiation hitting the planet within the atmosphere. Hence, an insufficient concentration of greenhouse gases leads to cooling, while an excessive concentration leads to warming. One of the main greenhouse gases is carbon dioxide, which is produced whenever fossil fuels are burned. Other gases are also important in regulating Earth's temperature, such as methane, a product of plant decomposition (especially in water) and raising cattle, and water vapor. Since the beginning of the industrial era, carbon dioxide concentrations in the atmosphere are estimated to have risen from about 280 to 368 parts per million and methane concentrations from about 700 to 750 parts per billion. Higher greenhouse gas concentrations have been accompanied by an increase of about 0.6 percent degrees Celsius over the twentieth century. Moreover, the 1990s was the warmest decade of the last millennium and the 2000s were even warmer.[3] The consequences of such developments are detrimental for reasons of safety and security. A sharp rise in temperature will likely increase climate instability and the frequency of extreme weather events such as storms, hurricanes, and tornadoes.[4] Summers should

become hotter, and winters should become warmer. The hot summer of 2003 in Europe, during which temperatures regularly exceeded 40 degrees Celsius in the middle and southern parts of the continent might be repeated many times in the future with even higher temperatures. These rising temperatures along with the melting of glaciers, the Arctic, and, eventually, the Antarctic ice sheets will also contribute to the expansion of ocean waters. This sea-level rise will threaten coastal zones and induce many of their inhabitants to leave. Some of these developments are so ominous that the Pentagon identifies climate change as a leading national security issue.[5]

The indirect effects on activities linked to the weather, such as agriculture and human health, could pose serious security concerns. Developing countries are at a particular risk because their agricultural production is not as flexible as that of industrial countries. Moreover, a larger portion of their populations depends on it. In addition, adverse weather conditions are expected to become more frequent in tropical and subtropical areas. The state of global health could also deteriorate as pathogenic microorganisms, previously confined to tropical areas, expand into other geographical zones. Similar expansion patterns are predicted for pests, affecting agriculture.[6]

In addition to potentially facing more natural disasters, the international community may also be confronted with a large-scale population movement mostly from South to North in proportions unmatched thus far. The United Nations stated a few years ago that there are 25 million climate migrants in the world, a number that it expected to double in the next few years.[7] However such catastrophic and immediate migratory responses have been strongly disputed.[8] However, even the scholars critical of the UN pronouncement recognize that climate change is an aggravating factor within the multiple reasons that account for mass migration. Finally, the likelihood of low-probability global catastrophes will increase. This could include a major reversal of present ocean currents such as the Gulf Stream, which would force abrupt climatic change on whole regions, or a sudden acceleration of the greenhouse effect due to a massive release of methane from permafrost (previously frozen ground).

Two conclusions emerge from this brief overview of climate change, its causes, and its likely consequences:

From a policy point of view, it appears necessary to mitigate climate change by taking measures to diminish emissions of greenhouse gases, such as by lowering consumption of fossil fuels, reducing methane through different agricultural techniques or, in some regions, abandoning agricultural production altogether. Relying on natural balancing mechanisms such as carbon dioxide fertilization

of plants favoring carbon sequestration is probably an illusion.[9]

Mitigation measures alone, however, are insufficient in dealing with the threats of global climate change. Current levels of greenhouse gas concentrations in the atmosphere have a strong long-term momentum. Even if forceful mitigation measures are adopted, some increase in concentrations is inevitable. Therefore, some form of climate change will occur even if emission reductions were to begin immediately. Hence, adaptation strategies will also be necessary.

One could immediately establish a link between environmental change trends and conflict, a step that the Canadian scholar Thomas Homer-Dixon did not hesitate to take.[10] There seems also to be *a priori* plausible relation between the difficulties associated with resource management under mitigation or adaptation policies and conflict, since these sometimes require great efforts on the part of populations already suffering hardships, especially in developing countries. Therefore, theories abound about interactions between the environment, resources, and conflict. They invoke various, often opposing relations: fighting occurs because too many people are competing for scarce or degrading resources or because some groups have unfettered access to natural resources, which allows them to finance rebellions.[11] Such opposing views suggest that if a direct causal relationship between environment and conflict exists at all, it is complex and involves many factors.[12] As detailed earlier, climate change is already underway. Its effects are predicted to negatively affect production potential and resource availability in many regions of the world where conflict and poverty already take their toll.[13] If environmental change, combined with existing patterns of conflict and population pressure, further degrades already fragile ecosystems, we can expect, according to Homer-Dixon, widening spirals of violence in the future. On the other hand, if conflict is driven by uncontrolled access to primary commodities, then environmental pressures on natural resources may also spur more confrontations to secure shrinking resource pools. Both theoretical frameworks suggest a more hostile future world dominated, especially in some developing areas, by militarized warlord competition. In one scenario, conflict arises from scarcity; in the other, it starts with an abundance of natural resources. These conflicting views make policy design problematic. A closer examination of the processes underlying each approach, however, reveals some common core factors that resolve the apparent contradictions and untangle the population, natural resource–institutions–conflict nexus.

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The analysis of population–resource conflict relations is not new. Thomas Malthus' rigorous early study proposed an interlocking economic–demographic system in which there is incompatibility between the arithmetic increase in production—even taking into account changing technology—and the exponential growth of population.[14] In Malthusian theory, passion fuels population increase, reinforced by institutional mechanisms, such as David Ricardo's "Iron Law of Wages." Equilibrium is ultimately achieved through mortality, a "positive check" on population growth. Conflict is implicit in this framework and is one of the ways mortality would be expressed. Abundance is never sustained in this system because it is rapidly dissipated through incentives to increase population in order to capture rising wages.[15]

Basic Question

The analytical framework presented here takes as its starting point the implications in Hardin's influential paper. In effect, Hardin identifies weak or absent regulatory frameworks as the source of environmental scarcities. In other words, resource depletion is not exclusively dependent on the degradation of the environment per se, but rather poor incentive structures that, in the long run, lead to an inferior social outcome. It is this outcome that is the origin of the overuse of environmental resources. Hardin believed that the absence of a private property system was at the root of the deterioration. However, shortly after the publication of Hardin's article, a vast empirical literature demonstrated that a balance between people and resources had been achieved in many parts of the world without recourse to private property structures.[16]

Moreover, Hardin had presented a "common sense" argument, limited to the very narrow context of cattle herding on a publicly accessible meadow. This open-access feature leads to overgrazing. A formalized version of Hardin's reasoning and a generalization of his approach were presented later by Dasgupta and Heal.[17] Chichilnisky further develops this model by showing that open-access property rights for environmental goods in developing nations explain the current international trade patterns and global environmental risks—climate change included. Developing nations in Latin America and Africa overspecialize in natural resource exports, not because these correspond to inherent competitive advantages, but because of the absence of well-defined property rights.[18] These trade structures thus contribute to the overuse of natural resources. These scholars' work shows that Hardin's presentation only accounts for a special case situation where individual incentives lead to socially inferior outcomes. They

also insist that many of these incentive structures do not permit the development of long-term retaliation strategies that help foster cooperation.

Thus, cooperating for the organization of regulations often presents great difficulties. In order to understand the problem Hardin raises, one must look at the general question of how regulatory structures such as property rights can be initiated. As suggested by Dasgupta and Heal's analysis, some regulatory structures might not bring about optimal results. Some might be so restrictive that they hinder innovation and development; others might be too lax and imprecise to protect natural resources. In both cases, and especially in the latter, conflicts are likely to develop. We will call such events the *political* tragedy of the commons. Therefore, it is critical to highlight theoretically the significant linkages between the overexploitation of natural resources, property rights protection, political stability, and population increase. An explanatory framework for the "multiple tragedies of the commons" appears necessary.[19]

Policy responses within this framework often amplify feedback relations as exemplified by the following sequence. Once regulatory schemes are weakened, they tend to further deteriorate. The government increasingly loses control over environmental goods since people observe protective rules less in order to seize control of resources. The same can be observed about the overuse of natural resources, which is often encouraged by government policies. The more resources are available, the more they will be taken as people rush to seize them before others can. If such behavior degenerates into warlord competition, state authority is diminished even further.

All economic activities do not stop under these conditions, but instead become subjected to the protective powers of private individuals, political entrepreneurs, and warlords—the only ones who can ensure that their clients' property rights and their own are respected and their contracts enforced. Instead of the rule of law, the arbitrary decisions of political entrepreneurs and warlords govern the economy.

Three consequences can be deduced from these considerations. First, with no collective authority and with stringent competition among warlords, each individual has an incentive to increase the number of individuals that he or she can control. As previously noted, this would allow him or her to personally acquire more resources.[20] The incentive structure is thus set for a demographic increase. Second, since power relations rather than the rule of law dominate, no long-term property protection can be maintained. Every natural resource appears to be of a fugitive nature: everyone tries to take as many resources as possible today because tomorrow these resources might belong to someone else.

This leads to the economic and consequently environmental tragedy of the commons. Third, within a society dominated by warlords, the incentive structure tilts severely toward fighting, either for some political entrepreneur or for oneself. One can assume here that agricultural or industrial production usually requires an investment, which, however small, necessitates a financial sacrifice in terms of forgone consumption. On the other hand, fighting for a warlord usually leads to an immediate profit from starting salary and then potentially from looting activities. Moreover, when a significant part of the population is engaged in fighting or warlord activities, it becomes increasingly difficult to produce agricultural or industrial goods, at least on an independent basis. Production becomes subject to looting and confiscation.[21] Ultimately, only activities under the protection of the warlord can still be continued. If society truly works this way, then two possible outcomes can result. If society manages to establish an authority structure that imposes the rule of law and protects property rights, productive activities become more desirable than fighting. If arbitrary appropriations are punished and if there is very little profitability in them, then most members of society will strive to acquire revenues by working in the regular sectors of agriculture and industry. Fighting as a means to achieve greater income and wealth thus disappears. In addition, the environment will be further preserved and respected since the rule of law and property rights, including those on natural resources, will be better enforced.

There is no direct link of causality between environmental scarcities and conflict.

If property rights and the rule of law are not protected and warlord competition prevails, fighting and permanent struggle between warlords will ensue. This particular outcome constitutes a "Fighting Warlords Trap," which will be difficult to escape. The reason for relative stability in fighting and appropriation is that even when the profitability of certain activities increases, warlords can extract output. In turn, these new revenues will be used to finance their combat enterprises. Thus, even if a centralized but weak state persists, it will not be able to collect the financial resources it needs. Only huge new profits and a systematic restriction of warlord behavior can pull a society out of a trap where environmental abuse contributes to its persistence. Such an evolution out of a warlord-dominated society, while difficult, is by no means impossible. For example, in the 1920s and part of the 1930s, warlords controlling the opium production and trade dominated China. After many upheavals and tremendous setbacks, China now boasts one of the fastest growing economies in the world.[22]

The conclusions from this analytical presentation are relatively straight-

forward. Contrary to the conception presented by Homer-Dixon and more in accordance with that of Gleditsch and Urdal, there is no direct link of causality between environmental scarcities and conflict. However, an absence of a regulatory state, which imposes the rule of law and protects property rights, will actually generate conflict. Conflict, in this sense, can be related to both naturally abundant and scarce environmental resources, but it always fosters overuse and degradation in the end. Empirical evidence shows that such processes took place on Easter Island. Though it had a friendly natural setting, the absence of a regulatory state promoted population growth, warlord rivalry, and fighting. It finally led to the exhaustion of the island's resources by the indigenous groups.[23]

The Analytical Construct

The considerations made so far can be synthesized in an analytical construction. Imagine that individual (or household) preference in a society depends on the total quantity—most often the sum of a collective good—consumed, purchased, or produced by all members of the society. This is the case for security or defense, but also for all kinds of regulatory schemes and their institutional structures. At the same time, individuals or households also consume private goods, which they may have produced or acquired, and are therefore exclusively their own. However, these individuals must forgo consumption by selling their goods or giving them up in the form of taxes for the collective good. It follows that an important aspect of this analytical construction is that, to a large extent, the purchase of the collective good depends on the activities of all members of the society. It is easy to show that under these conditions, unless some collective authority manages to establish itself and collect taxes, collective goods will be supplied at a non-optimal level.[24] However, such an optimal supply is widely deemed necessary. Otherwise, productive activities and economic transactions cannot reach their optimal levels either because of unprotected property rights or unenforced contracts.

We differ here with Dasgupta and Heal in the kind of preference function postulated. Standard assumptions about rational behavior often assume, in contradiction with empirical evidence, that most preference schemes, whether individual or collective, can be described as either risk-neutral or risk-averse. These premises are often established for mathematical convenience in order to simplify complex issues. Experimental psychologists and even observers of animal behavior have noticed, however, that risk preference often appears after risk aversion when a decision maker is faced with the prospect of losses.[25] In

other words, one is willing to take greater risks if and when losses become more probable. Risk aversion and risk-preferring behavior are regularly seen together. Various attempts have been made to explain their joint appearance.[26] In particular, Fishburn and Kochenberger show that the majority of individuals have an everywhere increasing utility function $u(x)$, where x is a measure of gains and losses that increases more than proportionally for small or negative x and then less than proportionally for relatively high values of x.[27] Such considerations can also be based on the classical Engel curves of consumption behavior.[28] Most individuals are thus risk-averse about gains and risk-preferring about losses. This notion can serve as a theoretical justification for Hirshleifer's contention that the poor have a comparative advantage in appropriation, obviously a more risky way to acquire wealth than accumulating capital in savings.[29] In general, this type of utility function leads to a different, but quite plausible, bargaining behavior compared to traditional functions.

A natural extension of these considerations is to represent an average decision maker's preference or utility function by an increasing S curve, which would adequately express the mix of risk-aversion over gains and risk-preference over losses.[30] An S-curved utility function is not only obtained as a result of psychological analysis. It may also result from productive processes, which exhibit first increasing and then decreasing returns to scale. If an individual agent is a producer and derives utility from the way he or she produces, then he or she will also have an S-shaped utility function. This case will be discussed later. As will be shown below, preference for this utility function over a standard one is not made uniquely for the sake of conformity with well-established empirical results. It allows for the linkage between preferences and several key variables such as resources and population, which would be difficult to establish without this assumption. Below, we will express the results we obtained only verbally. Formal mathematical demonstrations can also be found in the Appendix.

Now, we will further assume that, initially, individuals have one unit of the private good and none of the collective good. Agents are, however, able to convert the private good into the collective good at a given rate. This transformation rate can be just proportional, more than proportional, or less than proportional. A more than proportional transformation signals a greater capacity to transform private resources into collective ones. These considerations help define a budget constraint and the utility function. Maximization of this utility function, which is subject to the budget constraint, can lead to several types of equilibrium situations.[31]

If all agents in society maximize utility in the same way as an individual,

a particular kind of Nash equilibrium emerges based upon the expectation the agents have about the quantity of collective goods every other agent produces or purchases.[32] This condition is a *society market* or *anarchic equilibrium*. Such an anarchic equilibrium constitutes a mix of both a pure competitive equilibrium for private goods and a noncompetitive but decentralized equilibrium for collective goods.

Quite clearly, the anarchic equilibrium is not Pareto optimal. It reflects the "Tragedy of the Commons" outcome where the absence or minimal provision of the collective good—in this case regulation—leads to a socially undesirable outcome.[33]

Is the anarchic solution thus always suboptimal? Not necessarily. If an efficient market that includes all externalities can be established, we will obtain a Pareto optimal equilibrium —similar to a so-called Lindahl.[34] However, the creation of such a market implies, at least initially, the formation of an organization and a collective good to define, protect, and guarantee Pareto optimality for that market, such as in the form of property rights.[35] The organization of such a market involves potentially considerable costs. If one wants to create a market for the collective good, another collective good is necessary to organize it. Another market can be imagined that organizes markets for collective goods, but then this necessitates another collective good for its own organization. This leads to an infinite regress in terms of collective goods and markets. For instance, it is difficult to imagine the creation of an efficient market for defense. In most cases, such a market will turn into a mafia-style competition for the protection racket by the different armed groups involved. Property rights will be neither well defined nor protected since the use of force will make the temptation to extract rents from the people whom the market is supposed to defend hard to resist.[36]

Given the necessity of an initial organization for the provision of any collective good, mechanisms must be provided to allow societies to establish an initial good and thus move toward Pareto optimality.[37] This is the case with tax equilibria where societies agree to provide or are forced to maintain collective goods with regular mandatory contributions.[38]

Unlike markets that do not presuppose any form of organization to solve collective-good problems, the authority to tax assumes the existence of a social order to enforce the collection of mandatory contributions. However, as in the case of markets for externalities, the power to tax is far from obvious. It requires the possibility of punishing recalcitrant members. The imposition of taxes on a society is difficult without the consent of at least some of its members and usually requires the existence of a relatively important level of transactions in

some form of "numéraire" that can then be taxed.[39] If they wish to avoid seeking consent, political entrepreneurs can rely on their own private sources of revenue.[40] However, even in this case, the collective good could at least initially be supplied at a suboptimal level. One difficulty arises with a significant reduction in the number of taxable transactions, which is almost impossible to overcome without a reorganization of the social order. Usually, the organization of defense as one of the initial collective goods has the advantage of solving both the protection and the taxation problem. It gives the means to use external force and the power to enforce tax collection to an authority.

Taxation is thus a way to compensate for the absence of Pareto optimality in an anarchic equilibrium as long as the taxation is "Pigouvian," meaning it is explicitly meant to correct for the Paretoinferior outcome represented by the anarchic equilibrium.[41] We will thus also consider a subsidy that a social authority would give for the purchase or production of a unit of a collective good by an agent as well as a lump-sum tax that the authority imposes on private goods. In other words, it can be further shown—refer to the Appendix—that under Pigouvian taxation principles, total expenditures equal total revenues. The collective good budget is balanced and leads to Pareto optimality, which establishes taxation equilibrium. The optimal size, in terms of number of agents of a coalition necessary to establish Pareto optimal tax equilibrium, can also be computed.[42] If the transformation from a private to a collective good can be done cheaply, with increasing returns to scale, then the required coalition to establish it is much smaller than when it can only be done at great expense, with decreasing returns.

Clearly, this analysis establishes the importance of the number of people in creating collective good–providing coalitions. More people are necessarily required if the collective good is relatively expensive; fewer are needed if the collective good is cheap. However, there might be differential prices and thus costs within a society. One group might have cheaper access to collective goods than another, which can lead to its domination. Moreover, if two or several groups have cheaper access to a collective good, such as defense, armed conflict between them to control other resources might erupt. If such collective goods are still relatively expensive, then numbers matter and each group will engage in competitive recruitment efforts. Demographic processes, among others, play a major role in providing subpopulations from which recruitment efforts can be undertaken. We will now examine their evolution, their links with resources, their depletion, and their impact.

A population problem may occur in a particular delimited area when rates of population growth are high. For example, the growth rate of the sub-Saharan African region is between two and three percent per year, which should lead to a doubling of population in approximately 30 years.[43] Thus, this will place increased pressure upon the environment's carrying capacity since land and resources cannot be expanded at will.

Demographers and economists have shown that bargaining theory can be applied to reproductive decisions inside the household.[44] Indeed, men and women do not equally share the costs of bearing and rearing children: pregnancy entails foregone work-capacity and an increased probability of dying. Furthermore, caring for children is time-consuming and imposes material restraints on disposable income. In regions such as sub-Saharan Africa, one can expect men to engage in "reproductive free-riding," or begetting children without considering the costs of rearing them, since these expenses can be spread or shared among kith and kin.[45]

Dasgupta provides two answers to the possible divergence between seemingly rational decisions at the level of the household and their effect on society as a whole.[46] First, households get the wrong incentives because of inefficiencies in the relative pricing of various goods and services. Second, each household imposes negative externalities onto others. Because of lack of restrictions to entry, open access to the resource provides an incentive to have too many children since parents do not have to bear the full costs of rearing them. Another basis for externalities is simply the social environment—individual behavior can be dictated by norms and culture. Societies may have acquired customs and mores that favor high fertility rates. Such norms traditionally stem from historic conditions involving high mortality rates, low population densities, and high probabilities of war. However, they tend to survive as part of a community's identity even when the rationale for their existence has disappeared. In such circumstances, each household's utility is a function of its own actions and the average actions of all others. As long as all households seem to respect the norm, no one has an incentive to deviate from it. For example, sub-Saharan African fertility regimes seem to be defined to a large extent by customs like a young marriage age, polygamy, weak conjugal bonds, and strong kinship support systems for children of the community.[47] Moreover, such social arrangements favor males, who have a disproportional incentive to engender children since they only partially incur the costs of rearing them. The basic conclusion is that

a society can be stuck at a suboptimal equilibrium with households knowingly having too many children because no one has an incentive to depart from this accepted pattern of behavior. As underlined by Dasgupta, this is a typical coordination problem involving a multiplicity of Nash equilibria, which can only be addressed through the regulatory activity of the state.[48]

One puzzling feature of the sub-Saharan African demographic regime is that fertility rates have only just begun to react to declining mortality rates.[49] This can be explained by Dasgupta's first hypothesis. Children must be viewed as goods that provide various benefits to the household. Obviously, the first motivation for having children may be that they constitute an end. However, from the viewpoint of their parents, children may be considered as productive assets. Given the constraints on savings in rural areas, children represent a sort of insurance for parents in their old age. This viewpoint is even stronger in the context of the availability of pensions for the elderly in such regions. More importantly, children in rural areas are viewed as assets yielding additional income. When agricultural output is low, energy and water become prohibitively expensive due to the lack of basic infrastructure. Since the possibility of investing in capital remains nonexistent, people must engage in complementary activities such as collecting wood, monitoring cattle grazing, or fetching water. Children are therefore essential as workers for the survival of their family.

Clearly, a positive feedback sets in. To the extent that property rights are poorly defined, high fertility rates imply further stresses on the environment–resource base. Giving incentives to expand the family increases the depletion of resources.[50] Hence, resource scarcity and development are intrinsically related. Investments in infrastructure in order to reduce, for example, the price associated with basic commodities such as fuel or water would decrease the value of children as income-earning assets. Similarly, increased savings and investment opportunities would lessen the need for children as a sort of insurance. Nevertheless, development programs aiming to promote growth and modernization can also exacerbate resource degradation to a large extent in the absence of clearly defined property rights.

Indeed, it can be stressed again that no single dominating strategy is available to actors operating in an open-access type of situation.[51] Thus, the Prisoner's Dilemma is not an apt metaphor for such circumstances.[52] However, one can clearly see that, whereas no producer has a dominant strategy to continue extracting more resources, no one can oppose a credible threat to prevent others from doing so. Hence, the behavior of actors in an open-access type situation is closer to that of players in a "Chicken" game.[53] The corollary of the absence

of credible threats is the source of intense competition for the first move. The first mover enjoys a durable advantage over his opponent. This, in turn, yields a sub-game perfect Nash equilibrium where gains or losses are disproportionately distributed in favor of the first mover. Given the asymmetry at equilibrium, it is extremely difficult to reach another outcome. Thus, patterns of behavior exhibiting strong inequalities can easily be maintained over long periods of time. Moreover, entitlements to the products in managed common-property systems across the globe have mostly been based on private holdings.[54] Such institutional arrangements tend, therefore, to replicate inequalities in terms of wealth among participants at the level of resource use. Hence, even when access to a common-pool resource is restricted, it is likely to provide the privileged with greater benefits. To be sure, the asymmetry in resources and capabilities provides the latter with credible threats in devising collective agreements to control exploitation of the environmental base.

Moreover, not only asymmetric players—for example, elite versus non-elite—produce a stable unequal distribution of benefits accruing from the exploitation of a resource. Specific types of retaliatory strategies easily support agreements such as these.[55] When scarcities occur as the availability of arable land diminishes, the bargaining power of certain groups of the population is altered by changes in relative prices. Actors with few resources may put a premium on the short term. Indeed, in such instances, small parcels of land may be sold to powerful landowners to rapidly obtain liquidities. Furthermore, as competition intensifies, it becomes perfectly rational for individuals to overexploit the commons in order to avoid being the last one without available resources.[56] On the one hand, resource scarcities may lead to overuse by their users. On the other hand, it can lead to competition for appropriation amongst peasants and between peasants and landowners. Finally, the impact of the environment–resource base's depletion on customary rules and norms must be considered. As land becomes a commodity through market operations, it is no longer ruled by customary norms and restraints.[57] Actors are, therefore, more inclined toward overexploitation and short-term calculations. This mechanism both illustrates and answers the paradox of attributing the causes of violence either to a scarcity or an abundance of resources raised by the relationship between environment and conflict. In the short term, scarcities and abundance of resources are part of the same dynamic. Overabundance exists because incentives are always present for more resource appropriation, even when the price of the resources plummets because the opportunity cost of labor is cheap compared to what can be gained by selling it. However, it is precisely this overexploitation that eventually leads

to scarcities.

Formal Aspects: Population

If overuse of resources leads to population increase at first according to the scenario outlined above, then incentives must be present within the previously presented formal structure to produce that particular outcome. To show that this is the case, we will analyze two expressions derived from our formulation:

- The individual utility function of the representative agent within an anarchic equilibrium must increase with growth in the population variable.
- The gap between the anarchic equilibrium and the Pareto optimal situation where resources are not overused should increase as the number of agents in a society rises.

Both these conditions are fulfilled, which is shown formally in the Appendix. We can now reproduce the paradox described earlier. There is an individual incentive to increase the number of people in a household, even though this increase causes the overall social situation to deteriorate. This paradox again illustrates the fact that there are individual advantages in exploiting natural resources. In a social system that does not guarantee property rights and the rule of law, an increase in the number of workers in a household leads to an overuse of natural resources, harvested without constraint.[58] Conversely, the existence of property rights and the enforcement of the rule of law will limit and eventually completely curtail this behavior. Too many offspring in a family will excessively divide an estate and reduce the incentive to have more children. In this case, no special immediate gains can be obtained from harvesting an open resource since its access will be prohibited or strongly reduced.

Solutions

Is there any way out of incentive structures that favor resource overuse and, according to our previous analyses, eventually conflict? This issue is especially important in the context of climate change. Property rights protection and the rule of law must be established in all areas. Then, the proper incentive structures will follow. However, the matter is not that simple. On the one hand, enforcing rules requires a state organization with some strength. Such structures are often quite weak, especially in developing countries. Moreover, the problems caused

by climate change might weaken such structures even more. In addition, even in developed countries, evenly spread collective evils such as climate change are more difficult to fight with appropriate measures because their effects cannot be easily associated with particular groups within society. Their detrimental consequences appear only slowly through time. Here, as in other instances, cooperation within societies sustained by international cooperation should play a major role. We will show here that there is an inherent advantage in cooperating on climate change, especially through the process of some stipulated compensation mechanism between rich and poor and between developed, developing, and emerging countries.[59]

One might argue that such a scheme is already included in existing institutions such as the 1992 United Nations Framework Convention on Climate Change (UNFCCC) and the additional Kyoto Protocol of 1997 through the principle of Common but Differentiated Responsibility which is stated in Article 3 of the UNFCCC and reaffirmed in the Kyoto Protocol. However, the current situation is far from satisfactory. This interpretation of the Common but Differentiated Responsibility Principle was included in the UNFCCC and was reaffirmed in 1995 within the first Conference of the Parties (COP1) held in Berlin.[60]

Even if the Copenhagen, Cancun, and Durban conferences slightly modified this perspective by, especially in Cancun, including developing countries in an emission reduction scheme, such a system is far from legally binding like the Kyoto Protocol.[61] At most, it represents a willingness on the part of developing and emerging nations to consider the issue. It does not, however, solve the main question regarding the distribution of obligations to mitigate climate change.

Characteristics of the Climate Change Regime

As is the case for many other international responses to problems, the 1992 Rio Framework Convention on Climate Change (FCCC) takes the form of a "framework convention," or a document that specifies general principles and recommendations but has practically no legally binding mitigation requirements. Thus, the FCCC accomplishes no more than obligating countries to report on their greenhouse gas emissions and recommending that parties develop climate change policies that, for industrialized countries, would lead to a stabilization of emissions to their 1990 levels by 2000. Moreover, parties are encouraged to favor the dissemination of greenhouse gas emission-reducing technologies to developing countries.

The basic idea that industrialized countries should make the major initial effort toward reductions was confirmed, as mentioned above, in the first FCCC Berlin Conference in 1995. In Geneva in 1996, it was agreed that industrialized countries—Annex I countries in UNFCCC texts— should work toward "quantified limitation and reduction objectives within specified time-frames, such as 2005, 2010 and 2020, for their anthropogenic emissions by sources and removals by sinks of greenhouse gases."[62] This statement, adopted in the form of a "Ministerial Declaration," prepared the groundwork for the elaboration of the Kyoto Protocol in 1997. Undersecretary of State for Global Affairs Timothy Wirth, a member of the United States delegation that authored the protocol, strongly endorsed the idea of legally binding targets in exchange for the rejection of "harmonized" policies and measures on developed countries such as a uniform Corporate Average Fuel. His method implemented more flexible, market-based approaches, such as an emissions-trading scheme similar to that found in the United States Clean Air Act.[63] Quite clearly, this statement did not question the principle of the Berlin Mandate, which was then included in the Kyoto Protocol.

The Clean Development Mechanism was the only step in the Protocol involving developing and emerging countries. It encourages firms from developed states to share emission-lowering investments with developing areas, which should help mitigate climate change on a purely voluntary basis. In a decision taken by the 2011 Durban Conference, this mechanism should be operating at least until 2015, like the Protocol itself. Unfortunately, for the moment, the Mechanism was not able to reduce worldwide emissions or to significantly slow them down in emerging countries such as China. Nevertheless, because of its ties to other "flexible" mechanisms included in Kyoto such as emissions trading, the Mechanism contains the first attempts to establish a global reduction certificate market.[64] While including developing countries in the process is a promising first step, no compensations or mandatory targets remain for them.[65]

The Kyoto Protocol thus essentially reaffirmed the absence of obligations imposed upon developing countries; a position that was, until recently, condoned by most industrialized countries. The exception among industrialized countries was set by the United States, which argued against the lack of mandatory greenhouse gas reduction efforts for developing countries, an argument included in the famous Byrd–Hagel resolution to not ratify the Protocol.[66] By 2009, it became clear that one of the predictions contained in the Byrd–Hagel resolution—namely that greenhouse gas emissions by developing countries would be rapidly overtaking those of industrialized ones—was being confirmed. By

2011, carbon dioxide emissions per capita in China overtook those of France, even though, in terms of GDP per capita, China is a much poorer country.[67]

Unidirectional transfers from richer to poorer agents or states are efficient and advantageous to all. If this were the case, there would be at least a major additional incentive to cooperate at the international level in order to create a more effective long-term climate change regime. Cooperation would not be guaranteed, as shown by the political–economic literature on trade and domestic interests, but at least one could demonstrate that cooperative advantages exist.[68]

In fact, a convincing case can be made that such compensations are actually Pareto optimal. They make both richer and poorer parties better off under certain conditions. Assume that we are dealing with a uniformly spread collective evil like climate change, measured in terms of greenhouse gas emissions. The removal of the evil—a collective good—has the same properties as a uniform distribution. Lowering emissions in China has the same effect on the climate system as curtailing them in the United States. What might differ significantly, however, are the costs of reducing them. It would be much cheaper in an emerging or developing country than in an industrialized one. In part, this is because an emerging or developing country's infrastructure is not yet established. It can therefore be constructed or reconstructed quite easily with huge energy and emissions savings in mind.

This point is also valid in the case of adaptation strategies. However, there are also theoretical reasons for this occurrence, which are related to the relatively high marginal value of consumption for an emerging or developing country compared to a developed one.[69] Higher marginal utilities for the consumption of private goods lead to lower-priced collective goods.[70] A developing or emerging country might have a relatively inexpensive public good available, but might also desire more private goods, which are abundant in industrialized countries. If a developed country purchases public goods from a developing one, it provides an opportunity for the poorer country to acquire more private goods. In some sense, the emerging or developing country will, at the end of the process, be better off because it acquires more private goods. The industrialized country will also be better off because it has more cheaply acquired public goods.

This can be done, for instance, by providing a significant amount of emission rights to the developing country, which will then have to be purchased by the industrialized country. In this case, the developing country can then purchase more private goods.[71] The traditional tradeoff between equity and efficiency does not hold, since transfers from richer to poorer countries are associated with higher efficiency. As shown in the Appendix, there are limits to this proposition. It only

holds if the price of the public goods is neither too high nor too low. If public goods are too cheap in developing regions after allowing for exchange, they will not bring in enough private goods to compensate for them. If their post-exchange price is too high for developed areas, then their purchase will require too many private goods to make it worthwhile.[72] Therefore, emerging countries, which have not yet reached high levels of individual wealth, are probably the best candidates for such exchanges. States such as China, India, and Brazil are probably still suitable. Further increase in their individual wealth levels, however, might close this window of opportunity rather rapidly.

Implementation Problems

Even though it can be shown that compensation through greater attribution of property rights to the poorer party can be efficient, and thus constitute an incentive for cooperation, it is not clear that such a scheme can actually be implemented. The implementation problem, as Hurwicz describes it, is linked to the institutional setting that solving an externality problem such as climate change entails.[73] To reduce greenhouse gas emissions overall, allotting a large quantity of permits to developing and emerging countries has been suggested. Firms and households within industrialized states would then purchase these permits. In other words, what would be necessary is the establishment of a market for permits, which is in some sense a market for the externalities generated by greenhouse gas emissions. In order to function, such a market cannot be too thin. It would need to incorporate a sufficient number of agents. Moreover, several authors have pointed out that such a market has trouble working if non-convexities are present in the production of the externality, for instance in the form of positive feedback mechanisms such as increasing returns to scale.[74]

Finally, and perhaps most importantly, the rights or certificates associated with emissions must ultimately point to a real occurrence and not to some imaginary scheme. These cannot be inflated by referring several times to the same production processes. If a firm from an industrial country replaces a piece of equipment for reduction credits—for instance, a furnace replaced by a more efficient heater that emits fewer greenhouse gases—the older inefficient device cannot be reused somewhere else. In other words, the market has to be strongly monitored and cheaters have to be severely punished, as is the case in the United States Clean Air Act with respect to carbon dioxide emissions.

Setting up an effective monitoring regime is difficult, as the controversies over the control of the national and international financial systems demonstrate.

Hurwicz raises the problem of preventing cheating and purposeful misrepresentation of preferences surrounding public goods, especially if they are connected to the realization of the Lindahl equilibrium, for which externalities are exchanged without necessarily realizing unique price equilibrium.[75]

How can this be overcome? One can refer here to the importance at the domestic level of the rule of law and the separation of powers, which allow for mutual control, a solution Hurwicz also proposes. Clearly, such monitoring and mutual controls are costly to maintain and are supported within states by taxation schemes. Thus, at the international level, similar measures must be implemented.

Tax and Market Equilibria

As mentioned above, if an efficient market can be established that includes externalities, a Pareto optimal equilibrium will be obtained.[76] However, the creation of such a market implies, at least initially, the creation of an organization—a collective good—to define, protect, and guarantee Pareto optimality (such as in the form of property rights) for that market.[77] Moreover, market equilibrium for externalities does not exist when significant non-convexities are present in production processes, as in the case where increasing returns to scale characterize them.[78]

The organization of such a market involves potentially considerable costs. Given the fact that the creation of a market involves the necessity of a collective good, which could then lead to an infinite regress, only a Pigouvian taxation scheme can break it. Thus perhaps a generalized taxation scheme should be established that would both structure the public good and then correct for the externality instead of a market.

Provided that such a taxation-based collective good used to correct the externality is allocated to favor the poor and that the rich pay according to a progressive income schedule, it can be optimal.[79] However, two difficulties make such a notion hard to implement. First, if a tax is established in a rich country to buy a public good in another poorer country, its introduction will create distribution issues within the rich country and induce some lobbies to fight it. Second, it might be politically dangerous to argue for a tax whose proceeds will essentially finance purchases in another country. These two latter considerations suggest a market structure, but in the end either a tax or a market solution will accomplish the goal.

If a strong cooperation regime can be established between developed and

developing countries, it can be done in the case of climate change mitigation at the international level. On the one hand, incentives must exist for such collaborations to emerge since a system of compensation from first to third world is efficient. Moreover, if this regime is established, transactions should increase globally as emission rights are traded. These transactions can be taxed in order to further support the institutional framework that is necessary to sustain the monitoring and trading of rights.

It seems essential that this system of exchange should occur within a convex environment—one that does not distort cost, productions, or preference structures across firms or agents because of environmental factors.[80] The institutional framework has to be able to "convexify," or internalize the externality of carbon dioxide pollution through the trading structure with the help of an optimal taxation scheme. Our perspective shows that it is possible to define tax equilibria in a partially non-convex environment, as demonstrated in the Appendix.[81]

Conclusion

The establishment of redistributive schemes at the domestic and international levels is not only equitable but also desirable since they profit richer and poorer as well as developed, developing, and emerging countries. Their redistributive aspects would go a long way toward lowering conflict incentives at both the domestic and the international levels. In order to work, however, such compensation patterns have to take place between political systems that have reached internally efficient, Pareto optimal economic levels.

Furthermore, such schemes will only work if the prices of mitigation and accompanying adaptation measures are neither too high nor too low. This result places some spatial and temporal limitations on the implementation of a redistribution policy. On the one hand, only a limited window of opportunity is available with respect to emerging countries. Their fast pace of capital and infrastructure development might make mitigation and adaptation measures related to climate change so expensive that appropriate investments from developed countries become unattractive. In space, the result tells us that very poor developing countries might not gain enough in compensation from richer countries because the value of their mitigation investments is too low to be profitable. A wide range of compensation mechanisms across the globe can raise efficiency and prices of both collective mitigating and adapting goods. Indeed, a broad transfer of resources from developed to developing countries should raise the prices of collective goods not just in the targeted country, but also overall. This

renders compensation more attractive for poor areas. Moreover, from a political point of view, a rise in the price of collective goods results in the need for a larger coalition to implement them. Since many more segments of the population are included in the workings of the system, this results in a push toward more democracy and the rule of law.

Due to the extremely slow pace of international negotiations on climate change, the question arises whether the measures created will still be useful. In other words, it is debatable whether there will be a mitigation and adaptation regime in place to ensure that the compensation system will be effective. Clearly, the current process of climate negotiations within the UNFCCC is exceedingly cumbersome and brings about only slow progress, if any. In analogy to the international trade domain, alternatives exist for which the establishment of an international regime has been relatively successful and compliance with multilateral trade treaties has been assured through an institutionally strong dispute settlement mechanism. The principle of the multilateral trade regime is based upon an extension of bilateral treaties through generalization of a most-favored nation clause. Perhaps a similar mechanism could be envisaged for climate change where the building blocks of an international climate regime would be strong bilateral agreements that could later be extended to other nations through a multilateral treaty system. In any case, the entire system of climate change mitigation and adaptation has to be substantially reworked to make it more effective and facilitate efficient solutions to present climate change problems.

Appendix

Utility Functions and Tax Equilibria

Dasgupta and Heal (1979) show that a tax equilibrium can be established when a modal agent *i* in a society with *N* members has a utility function of the form:

$$u_i(x_i, \sum_{j=1}^{N} g_i) = \log\ x_i + \log \sum_{j=1}^{N} g_i \qquad (1.1)$$

where x_i is a private good and g_i a public good. This utility function is subject to the following budget constraint:

$pg_i + x_i \leq 1$ (1.2) where *p* is a rate of transformation from private goods into public goods.

As pointed out by Dasgupta and Heal, transformation from private to collective goods could take place with constant, increasing, or decreasing returns to scale, which could be expressed by p^s. If $s = 1$, the private good can be transformed into the collective good proportionally. If $s < 1$, the conversion takes place more than proportionally (increasing returns). If $s > 1$, the conversion occurs less than proportionally (decreasing returns). The s=1 corresponds to the case assumed by Dasgupta and Heal (constant returns).

A tax equilibrium leading to a balanced budget is achieved if the following terms are added to the budget constraint:

$(p - t_i)g_i + x_i \leq 1 - \tau_i$ (1.3)

where t_i is a subsidy and τ_i is a lump sum tax to pay for it.

Luterbacher and Norrlof (2008) show, that for a utility function u_i defined as a marginally increasing and decreasing function of both the x_i and $\sum g_i$,

$$u_i\ (x_i, \sum_{j=1}^{N} g_i) = exp(\alpha - 1/x_i + -1/\sum_{j=1}^{N} g_i)\ (1.4)$$

a tax equilibrium with the same characteristics as the one established by Dasgupta and Heal, based upon a similar budget constraint, can be determined. The budget constraint is in this case:

$(p^s - t)g_i + x_i \leq 1 - \tau$ (1.5) where the parameter *s* describes how easily private goods can be transformed through the rate *p* into public goods as specified above. Obviously in our case in a developing country $s<1$ whereas in an industrialized country $s>1$. For a proof, see the end of this Appendix.

The function $exp(\alpha - 1/f(x))$ has an S curve characteristic such as in Figure 2.

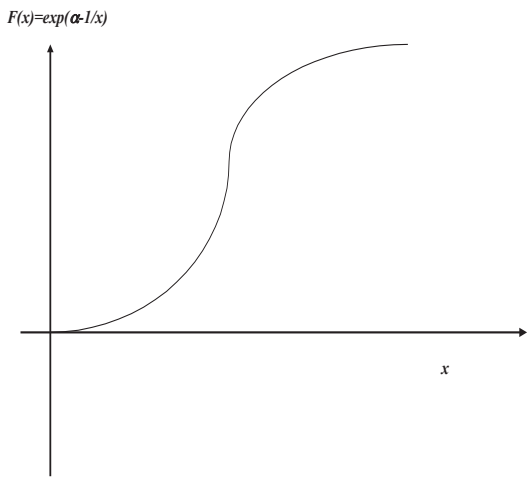

Figure 1

So whereas Dasgupta and Heal show the tax equilibrium result for a convex set, the function above exhibits non-convexities. One can derive utility function (2) from a production function like the one in Figure 1.

Proof of the existence of tax equilibrium for utility function (2)

1. Pareto optimality conditions for utility function (2):

Agent i in society g can maximize u_i as defined in (2) subject to a budget constraint:

$$p^s g_i + x_i \leq 1 \quad (2.1)$$

If every agent anticipates the purchase or production of the amount of collective good $\hat{g}$ by every other agent, for agent i, the problem is then to maximize:

$$exp\{a - 1/x_i + -1/[g_i + (N-1)\,\hat{g}]\}$$

by choosing x_i and g_i subject to the budget constraint (2.1). The necessary—and eventually sufficient since the utility function will, after being initially convex, become concave—conditions for an optimum solution will be:

$$Max\{exp\{a - 1/x_i + -1/[g_i + (N-1)\hat{g}\,]\} + \lambda_i(1 - p^s g_i - x_i)\}$$ with respect to x_i, g_i, and λ_I,

From the first-order conditions, in *equilibrium*, one can assume that $g_i = \hat{g}$ and thus $x_i = \hat{x}$. We therefore have,

$$N\hat{g} = \frac{\hat{x}}{\sqrt{p^s}}$$

using again the budget constraint (2.1), gives for respectively $\hat{g}$ and $\hat{x}$:

$$\hat{x} = \frac{N}{\sqrt{p^s} + N} \quad \text{and} \quad \hat{g} = \frac{1}{\left(\sqrt{p^s} + N\right)\sqrt{p^s}} \qquad (2.2)$$

Which is, at equilibrium, what every agent in the society under consideration is ready to produce or purchase as his bundle of private and collective goods. Since this result is subject to no other rule than the preference of individual agents, it is a *pure market* or *anarchic equilibrium*.

One can notice here that if N is large and p^s is relatively close to or equal to 1, every agent keeps most of his endowment in private goods and that only a very small fraction is devoted to the collective good. However, our formulation of the utility function as S shaped has the advantage of establishing a relationship between the conversion rate p^s and the purchase or production of both private and collective goods.

Thus, if p^s is relatively small, the voluntary provision of a collective good can become relatively high even with large N. Moreover, the expressions above show that, under some kind of "increasing returns" in the acquisition of the common good, or when the conversion rate p^s is relatively low—at least smaller than one—the purchase or production of the collective good is relatively cheap. This allows for a relatively large g per agent even if she consumes or produces high amounts of the private good x.

This illustrates the possibility that under circumstances of very low conversion rates, the production of both private and collective goods might be relatively high. This has an effect on the situation of a given society with respect to others.

Is such an anarchic equilibrium Pareto efficient? To answer the question, one has to treat g as if it were another kind of private good and considered by agent i as if she were alone and thus would maximize:

$exp\ \{a - 1/x + -1/Ng\}$ subject to the same budget constraint $p^s g + x \leq 1$.

The Pareto optimal solution $(\tilde{x}, \tilde{g})$ can be found readily as:

$$\tilde{x} = \frac{\sqrt{N}}{\sqrt{p^s} + \sqrt{N}}, \tilde{g} = \frac{1}{\left(\sqrt{p^s} + \sqrt{N}\right)\sqrt{p^s}} \quad \text{and thus } \tilde{g} = \frac{\tilde{x}}{\sqrt{N}\sqrt{p^s}} \qquad (2.3)$$

The anarchic equilibrium is not Pareto optimal. In fact, the difference between the anarchic equilibrium and the Pareto optimal value is in terms of exponents:

$$\sqrt{p^s}\frac{(\sqrt{N}-1)^2}{N} > 0 \text{ for all } N>1, \qquad (2.4)$$

Expression (2.4) tells us that the anarchic equilibrium is identical with the Pareto optimal outcome whenever $N = 1$. One would expect this since it corresponds to the case where there is just one member of society, or in terms of property rights, one owner who has the incentive to provide for himself in an optimal way.

We will thus also consider here a subsidy t that a social authority will give on the purchase or production of a unit of collective good by agent i and τ a lump-sum tax that the authority imposes on i in terms of her private goods. If $t<0$, the subsidy is in fact a tax and if $\tau<0$, the lump-sum tax becomes a subsidy. Agent i in the absence of any market for externalities maximizes:

$$u_i\,(x_i, \sum_{j=1}^{N} g_i) = exp(a - 1/x_i + -1/(\sum_{j\neq 1}^{N} g_j + g_i)$$

subject to:

$$(p^s - t)g_i + x_i \leq 1 - \tau \quad (2.5)$$

and where agent i chooses only x_i and g_i. At equilibrium, assuming that $\overline{p}^s = p^s - t$:

$$N\overline{g} = \frac{\overline{x}}{\sqrt{\overline{p}^s}} \quad (2.6)$$

To reach the Pareto optimal result (2.3) with, $\tilde{g} = \frac{\tilde{x}}{\sqrt{N}\sqrt{p^s}}$, the net price $\overline{p}^s$ that an agent must pay for the externality should be $\overline{p}^s = \frac{p^s}{N} = \frac{Np^s}{N^2}$. Indeed, introducing this expression into (2.5) leads to the Pareto optimal value (2.3) restated above. Thus, the authority must set the per-unit subsidy of the collective good at $t = \frac{(N-1)p^s}{N}$. The authority must also set a lump sum tax on each agent again with the purpose to reach Pareto optimality as defined by the values of $\tilde{x}$ and $\tilde{g}$ in (2.3). This lump sum tax τ, is thus:

$$\tau = \frac{\sqrt{p^s}\,(N-1))}{N\left(\sqrt{p^s} + \sqrt{N}\right)}$$

Total authority expenditures and revenues can now be computed on this basis. Total expenditures or subsidies for the collective good are:

$$N\tilde{g}t = \frac{N}{\left(\sqrt{p^s} + \sqrt{N}\right)\sqrt{p^s}} \frac{(N-1)p^s}{N} = \frac{(N-1)\sqrt{p^s}}{\left(\sqrt{p^s} + \sqrt{N}\right)} \quad (2.7)$$

Total revenues are:

$$N\tau = \frac{N(N-1)\sqrt{p^s}}{N\left(\sqrt{p^s} + \sqrt{N}\right)} = \frac{(N-1)\sqrt{p^s}}{\left(\sqrt{p^s} + \sqrt{N}\right)}$$ (2.8), which is the same as (2.7).

In other words, under these taxation principles, total expenditures equal total revenues and the collective good budget is balanced, which leads to Pareto optimality. This establishes the existence of the taxation equilibrium. Expression 2.8 allows now the computation of the optimal size in terms of N of a coalition necessary to establish Pareto optimal tax equilibrium. This size is given by:

$$\frac{\partial N\tau}{\partial N} = \partial \frac{\frac{(N-1)\sqrt{p^s}}{\left(\sqrt{p^s}+\sqrt{N}\right)}}{\partial N} = 0 \qquad (2.9)$$

This solution for a maximum eventually leads to:

$$N = -2\sqrt{p^s}(-\sqrt{p^s} - \sqrt{p^s - 1}) - 1 \quad (2.10)$$

N is a function of p^s increasing more than proportionally if $s>1$ and less than proportionally if $s < 1$. This reflects the notion that if the transformation rate from a private to a collective good can be done cheaply, in some sense with increasing returns to scale, then the required coalition to establish it is much less important than when it can only be done at great expense, with decreasing returns.

Population and Resources

1. The individual utility function of the representative agent within an anarchic equilibrium must increase with the growth in *N,* the population.
2. The gap between the anarchic equilibrium and the Pareto optimal situation where resources are not overused should increase as *N* rises.

Both of these conditions are in fact fulfilled. The partial derivative of the utility function u_i under anarchy or open access with respect to *N* is:

$$\partial u_i/\partial N = \partial \exp\{a - 1/x_i + -1/[g_i + (N-1)\hat{g}]\}/\partial N = 1/N^2(p^s + \sqrt{(p^s)}$$

which is always positive.

The gap between the anarchic, open access equilibrium and the Pareto optimal situation is: $\sqrt{p^s}\frac{(\sqrt{N}-1)^2}{N}$. Its partial derivative with respect to *N* is: $\sqrt{p^s}\frac{\left(\sqrt{N}-1\right)}{N^2}$ which is always positive for $N>1$.

Proof that higher marginal utilities for private good consumption lead to lower prices for collective goods

The maximization of the kind of utility function whose arguments are private and collective goods subject to the budget constraint stated above leads to solve the system defined by the following maximization condition:

$$Max\{U_i(x_i, g_i) + \lambda_i(1 - p^s g_i - x_i)\} = \Psi$$

We have thus:

$$\frac{\partial \Psi}{\partial x_i} = \frac{\partial U_i}{\partial x_i} - \lambda_i = 0 \qquad 2.8$$

$$\frac{\partial \Psi}{\partial g_i} = \frac{\partial U_i}{\partial g_i} - \lambda_i p^s = 0 \qquad 2.9$$

$$\frac{\partial \Psi}{\partial \lambda_i} = 1 - p^s g_i - x_i = 0 \qquad 2.10$$

Combining 2.8 and 2.9, we get:

$$\frac{\partial U_i}{\partial g_i} - \frac{\partial U_i}{\partial x_i} p^s = 0 \qquad 2.11$$

and thus:

$$\frac{\partial U_i}{p^s \partial g_i} = \frac{\partial U_i}{\partial x_i} \qquad 2.12$$ [82]

From there, it can be deduced that for the same public good and same marginal utility of it, the marginal utility of the private good varies inversely with the rate of transformation p^s or the price of the collective good. In other words, given a higher marginal utility of U with respect to x the private good, the rate of transformation (price) from the private to the collective good p^s has to be lower, irrespective of the shape of the utility function.

Proof of Pareto optimality for an exchange of private goods from an industrialized country against collective goods from developing or emerging countries within the above utility formulation

Assume that such an exchange takes place with utility functions similar to the ones above. We can thus distinguish between an emerging or developing country D and an industrialized country I. Is the exchange Pareto optimal? We will first examine first the developing country D and then the industrialized country I. We will rewrite relations (2.3), which establish the values for Pareto optimality for $\tilde{x}_D$ and $\tilde{g}_D$ with indices and assume all terms under square roots positive:

$$\tilde{x}_D = \frac{\sqrt{N_D}}{\sqrt{p_D^s} + \sqrt{N_D}}, \tilde{g}_D = \frac{1}{\left(\sqrt{p_D^s} + \sqrt{N_D}\right)\sqrt{p_D^s}} \quad \text{and thus,} \quad \tilde{g} = \frac{\tilde{x}}{\sqrt{N}\sqrt{p^s}}$$

Now if country D gets a transfer, this will mean an increase in $\tilde{x}_D$. Note that such a transfer could be operated privately if the industrialized country I simply gives the developing country D "emission rights," which economic agents from I—where emissions are restricted—can then purchase if they need them. However, these rights could also be acquired through an emission's tax in I that would then simply be used to purchase the collective good, which in this case is the lowering of emissions in D.[83] These two methods are here equivalent in their result.

An increase in $\tilde{x}_D$, however it is financed, always has a positive impact on $\tilde{g}_D$ and thus on the utility function of *D*. However, a purchase of the public good by *I* will mean an increase in the price $p^s{}_D$. It remains to be seen if the increase in $\tilde{x}_D$ more than compensates the increase in $p^s{}_D$. We can check this by adding the partial derivative of $\tilde{g}_D$ with respect to $\tilde{x}_D$ to the (negative) partial derivative of $\tilde{g}_D$ with respect to $p^s{}_D$. This gives:

$$\frac{1}{2\sqrt{N_D}\,p_D^{\frac{3}{2}}(\sqrt{N_D}+\sqrt{p_D^s})^2}(4\sqrt{N_D}\,p^{\frac{3}{2}} - 2\sqrt{N_D}\sqrt{p_D^s} - N_D + 2N_D p_D^s + 2p_D^2)$$

Since the denominator of the fraction is positive, only the numerator has to be investigated. The numerator reduces to:

$$\sqrt{N_D}\left[(2\sqrt{p_D^s}+\sqrt{N_D})(2p_D^s-1)+\frac{2p_D^2}{\sqrt{N_D}}\right]$$

In other words, a sufficient but not necessary condition for the income effect from the private good transfer to be greater than the price effect is that:

$$p_D^s > ½$$

As $N \rightarrow \infty$, this condition will become necessary and sufficient as the second term in the bracket vanishes.

This condition tells us that for the income effect to be prevalent in the developing country the price of the public good there cannot be too low (i.e., lower than ½).

In the industrialized country *I*, the price effect has to be greater than the (loss of) income effect. This should be the case since in

$$\tilde{x}_I = \frac{\sqrt{N_I}}{\sqrt{p_I^s}+\sqrt{N_I}},\ \tilde{g}_I = \frac{1}{\left(\sqrt{p_I^s}+\sqrt{N_I}\right)\sqrt{p_I^s}}$$

both $\tilde{x}_I$, and $\tilde{g}_I$ are negatively affected by an increase in $p_I{}^s$ thus positively by a decrease which would be the case here. More precisely, the exact impact of the effect of the price of the public good decreasing in comparison to the income effect can be determined through the absolute value of the partial derivatives of $\tilde{x}_I$ and $\tilde{g}_I$ with respect to $p_I{}^s$ (for $\tilde{x}_I$ and $\tilde{g}_I$) and $\tilde{x}_I$ (for $\tilde{g}_I$). The sum of absolute values becomes:

$$\left|\frac{\partial \tilde{g}_I}{\partial p_I^s}\right| + \left|\frac{\partial \tilde{x}_I}{\partial p_I^s}\right| - \left|\frac{\partial \tilde{g}_I}{\partial \tilde{x}_I}\right| \succ 0$$

This condition translates into:

$$-\frac{1}{2\sqrt{N_I}\,p_I^{\frac{3}{2}}(\sqrt{N_I}+\sqrt{p_I^s})^2}(4\sqrt{N_I}\,p^{\frac{3}{2}}-2\sqrt{N_I}\sqrt{p_I^s}-N_I+N_I p_I^s+2p_I^2)\succ 0$$

or

$$\frac{\sqrt{N_I}\left[2\sqrt{p_I^s}(1-2p_I^s)+\sqrt{N_I}(1-p_I^s)-\frac{2p_I^s}{\sqrt{N_I}}\right]}{2\sqrt{N_I}\,p_I^{\frac{3}{2}}(\sqrt{N_I}+\sqrt{p_I^s})^2}\succ 0$$

Assuming that all square roots are positive, we only need to look at the numerator because the denominator is positive. For large N or assuming that $N\to\infty$ the numerator is positive provided $p_I^s<1$. Thus, if we assume that an equilibrium price $p_{DI}{}^s$ for the public good $\tilde{g}_{DI}$ which is now "common" between D and I will be established through exchanges between the two regions, this price level has to be between ½ and 1 to be profitable for all. In other words if the price of the public good is higher than ½ and lower than 1, an exchange implying a transfer of private goods from I to D with a concomitant purchase of the public good by I is always Pareto optimal.

Notes

1. Such consequences might involve large-scale migratory movements due to either lowered agricultural productivity or more directly sea-level rise and perhaps also conflicts for the control of resources.

2. For instance, a succession of droughts will change (maybe drastically) the way agricultural production and living conditions are organized.

3. For the 1990s, see: "Recent Climate Change—Annual Average Global Surface Temperature Anomalies 1880–2008," U.S Environmental Protection Agency. See data from NOAA: http://www.epa.gov/climatechange/science/recenttc_triad.html. For the 2000s, see: "NASA–2009: Second Warmest Year on Record; End of Warmest Decade," http://www.nasa.gov/topics/earth/features/temp-analysis-2009.html.

4. Michael Mann et al., "On Past Temperatures and Anomalous Late 20th Century Warmth," *Eos* 84 (2003): 256–58. The scientist Michael Mann compares the growth curve to a hockey stick—almost flat until the latter part of the twentieth century, represented by a sharp increase. See: Michael Mann and Phil D. Jones, "Global Surface Temperatures over the Past two Millennia," *Geophysical Research Letters* 30, no. 15 (2003): 1820.

5. John M. Broder, "Climate Change Seen as Threat to U.S. Security," *New York Times*, August 8, 2009.

6. Josef Schmidhuber and Francesco N. Tubiello, "Global Food Security under Climate change" *Proceedings of the National Academy of Sciences USA* 104, no. 50 (2007): 19703–08.

7. UN News Centre, "Migration Spurred by Climate Change Could Displace Millions–UN-backed study," June 10, 2009, http://www.un.org/apps/news/story.asp?NewsID=31092.

8. Gunvor Jónsson, "The Environmental Factor in Migration Dynamics–a Review of African Case Studies," *International Migration Institute Working Papers* 21 (Oxford, UK: Oxford University, 2010).

9. Dieter A. Häering and Christian Köerner, "CO_2 Enrichment Reduces the Relative Contribution of Latex and Latex-Related Hydrocarbons to Biomass," *Euphoria Lathyris, Plant Cell and Environment* 27, (2004): 209–17.

10. Thomas Homer-Dixon, "Environmental Scarcities and Violent Conflict: Evidence from Cases," *International Security* 19, no. 1(1994): 5–40.

11. Ibid.; Jared Diamond, *Collapse: How Societies Choose to Fail or Succeed* (New York: Penguin, 2004); Paul Collier and Anke Hoeffler, "Greed and Grievance in Civil War," *World Bank Working Paper Series* (2000).

12. Nils Petter Gleditsch and Henrik Urdal, "Ecoviolence? Links Between Population-Growth, Environmental Scarcity and Violent Conflict in Thomas Homer-Dixon's Work," *Journal of International Affairs* 56 (2002): 283-302.

13. IPCC, "The Physical Science Basis," *Climate Change 2007* (Cambridge; 2007), 996.

14. Robert T. Malthus, *An Essay on the Principle of Population* (London: John Murray, 1826).

15. Garrett Hardin, "The Tragedy of the Commons," *Science* 162, (1968): 1243–48.

16. Bonnie McCay and James Acheson, *The Question of the Commons* (Tucson: University of Arizona Press, 1987); Elinor Ostrom, *Governing the Commons: The Evolution of Institutions for Collective Action* (New York: Cambridge University Press, 1990).

17. Partha Dasgupta and G. M. Heal, *Economic Theory and Exhaustible Resources* (Cambridge: Cambridge University Press, 1979).

18. Graciela Chichilnisky, "North-South Trade and the Global Environment," *American Economic Review* 84, no. 4 (1994): 851–74.

19. Ibid. Graciela Chichilnisky's 1994 article provides an elaboration of such a framework.

20. Current land grabs in both Africa and China are an illustration of this process.

21. Ibid.

22. As a reminder, China lost about 30 percent of its GDP and several million people during the Great Leap Forward and the Cultural Revolution.

23. When the European explorers arrived in the mid-eighteenth century, they found a barren place with no trees and a small, dwindling population. See: James A. Brander and M. Scott Taylor, "The Simple Economics of Easter Island: A Ricardo-Malthus Model of Renewable Resource Use," *American Economic Review* 88, no. 1 (1998): 119–38; Diamond, *Collapse*.

24. Dasgupta and Heal, *Economic Theory and Exhaustible Resources*; See Appendix.

25. D.W. Stephens, "Risk and Incomplete Information in Behavioral Ecology," *Risk and Uncertainty in Tribal and Peasant Economies,* ed. Elizabeth Cashdan (Boulder, CO: Westview, 1990).

26. The principal analyses of hybrid risk attitudes are: Raymond C. Battalio et al., "Testing Between Alternative Models of Choice Under Uncertainty: Some Initial Results," *Journal of Risk and Uncertainty* 3 (1990): 25–30; Raymond C. Battalio et al., "Animals' Choices Over Uncertain Outcomes: Some Initial Experimental Results," *American Economic Review* 75, (1985): 597–613; Colin F. Camerer, "An Experimental Test of Several Generalized Utility Theories," *Journal of Risk and Uncertainty* 2, (1989): 61–104; Peter Fishburn and Gary Kochenberger, "Two-Piece von Neumann-Morgenstern Utility Functions," *Decision Sciences* 10 (1979): 503–18; Daniel Kahneman and Amos Tversky, "Prospect Theory: An Analysis of Decisions Under Risk," *Econometrica* 47, (1979): 263–91.

27. Fishburn and Kochenberger, "Neumann-Morgenstern Utility Functions." An everywhere-increasing function is a function whose derivative (or rate of increase) is always positive.

28. For more information on the Engel Curves, refer to Arthur Lewbel, "ENGEL CURVES," in *The New Palgrave Dictionary of Economics,* 2nd edition (Basingstroke, UK: Palgrave-Macmillain, 2007).

29. Jack Hirshleifer, "The Paradox of Power," *Economics and Politics* 3, no. 3 (1991): 177–20.

30. The S-curve analysis and its application to conflict was initiated by Dacey: Raymond Dacey and Kenneth Gallant, "Crime Control and Harassment of the Innocent," *Journal of Criminal Justice* 25, (1997): 325–34). The formulation used below for the critical-risk ratio is based on losses, whereas the formulation used in Dacey is based on gains. These formulations are logically equivalent.

31. A budget constraint is a limit to use of a resource determined by wealth or income in term of that resource. Maximization of utility under constraint is like choosing to buy what I like the most given that I have resources that are limited by my wealth or income.

32. Nash equilibrium is an outcome from which no agent has an incentive to individually deviate.

33. As shown in the Appendix, the distance between the Pareto optimal and the anarchic outcome can be calculated precisely.

34. Lindahl equilibrium is a balanced outcome in terms of the utilization of collective goods by agents. It is generally Pareto optimal. Lindahl equilibrium does not necessarily lead to one, but rather to several equilibrium prices; Dasgupta and Heal, *Economic Theory and Exhaustible Resources*. A Pareto optimal outcome (which might or might not be an equilibrium) is one where making somebody better off can

only make somebody else worse off. It follows that non-Pareto optimal situations are those in which you can make everybody better off without making somebody worse off.

35. Urs Luterbacher, "International Cooperation: The Problem of the Commons and the Special Case of the Antarctic Region," *Synthese* 100, (1994): 413–40.

36. For example, the Carthaginians before Hannibal and the Romans in the late stages of the Western Empire during their decline were racketed by mercenaries.

37. One should remember here that Pareto optimality does not mean equity. Pareto optimality can result in a very unequal distribution of power and wealth in a society.

38. Dasgupta and Heal, *Economic Theory and Exhaustible Resources.* In this work, they point out two cases where tax equilibria exist whereas Lindahl equilibria do not. Moreover, the two equilibria are equivalent only if institutional costs are zero, a most unlikely situation. This point does not extend to carbon markets since everybody pays the same prices in the carbon market, which is therefore not Lindahl equilibrium. Tax equilibrium consists of a government intervention in an economy in the form of taxes and subsidies that guarantees Pareto optimal market equilibrium for both private and collective goods. Tax equilibrium requires a balanced budget in terms of taxes and subsidies.

39. Tax equilibrium consists of a government intervention in an economy in the form of taxes and subsidies that guarantees Pareto optimal market equilibrium for both private and collective goods. Tax equilibrium requires a balanced budget in terms of taxes and subsidies.

40. Tilly, in particular, emphasizes this point. See: Charles Tilly, *Coercion, Capital and European States* (Cambridge, MA: Blackwell, 1992) 41. This is named after the British economist Arthur Pigou (1932). See: Arthur Pigou, *The Economics of Welfare* (London: MacMillan, 1978).

42. Appendix.

43. United Nations, *World Population Prospects 2004: Analytical Report* (Department of Economic and Social Affairs, Population Division, 2004).

44. Ron Lestaeghe, "On the Adaptation of Sub-Saharan Systems of Reproduction," in *The State of Population Theory*, ed. David Coleman and Roger Schofield (Oxford: Basil Blackwell, 1986), 212–38; Julian Simon, *Theory of Population and Economic Growth* (Oxford: Basil Blackwell, 1986), 1–42.

45. Partha Dasgupta, "Population, Consumption and Resources: Ethical Issues," *Ecological Economics* 24, no. 1 (1998): 139–52.

46. Partha Dasgupta, "The Population Problem: Theory and Evidence," *Journal of Economic Literature* 33, (1995): 1879–1902; Dasgupta, "Population, Consumption and Resources: Ethical Issues."

47. Lestaeghe, "On the Adaptation."

48. Dasgupta, "The Population Problem." Recall that Nash equilibrium is an outcome of a game that nobody has an incentive to leave unilaterally. A unilateral move from the outcome makes the given agent worse off.

49. United Nations, *World Population Prospects 2004*.

50. Ellen Wiegandt, "Inheritance and Demography in the Swiss Alps," *Ethnohistory* 24, no. 2 (1977). Wiegandt has shown that when property rights are well defined, the relatively richer families in traditional Swiss villages had more children and the poor ones had fewer, thereby establishing a negative feedback relation between demography and resources.

51. Dasgupta and Heal, *Economic Theory*.

52. In a prisoner's dilemma, game players have a dominant strategy in defection. However, this does not get them to the socially desirable (Pareto optimal) outcome.

53. Urs Luterbacher, *International Relations and Global Climate Change*, ed. Detlef Sprinz (Cambridge, MA: MIT Press, 2001).

54. Margaret A. McKean, "Success on the Commons: A Comparative Examination of Institutions for Common Property Resource Management," *Journal of Theoretical Politics* 4, (1992): 247–81.

55. Partha Dasgupta, "Common Property Resources: Economic Analytics," *Economic and Political Weekly* 40, no. 16 (2005): 1610–22.

56. Dasgupta and Heal, *Economic Theory*.

57. Catherine André and Jean-Philippe Platteau, "Land Relations under Unbearable Stress: Rwanda Caught in the Malthusian Trap," *Journal of Economic Behavior and Organization* 34, (1998): 1–47.

58. Chichilnisky, "North-South Trade."

59. Even though emerging countries are developing quite rapidly they are still quite poor overall: China and India's GDP per capita are still below South Africa's. In addition, there are also really poor developing countries.

60. This is the so-called Berlin mandate. Cf. United Nations Framework Convention on Climate Change FCCC/CP/1995/7/Add.16 June 1995.

61. Robert Stavins, "Why Cancun Trumped Copenhagen: Warmer Relations on Rising Temperatures," *Christian Science Monitor*, December 20, 2010.

62. Cf. United Nations Framework Convention on Climate Change: Document FCCC/CP/1996/15/Add.1 October 29, 1996: 73.

63. As reported in Wayne Morrissey, *Global Climate Change: Adequacy of Commitment under the U.N. Framework Convention and the Berlin Mandate* Congressional Research Service, 96-699-SPR, October 25, 1996, p. 3.

64. The Kyoto Protocol limits emissions trading to developed (industrial) countries.

65. Graciela Chichilnisky was one of the main conceivers of this mechanism. Graciela Chichilnisky, *Saving Kyoto* (London: New Holland, 2009).

66. Byrd-Hagel Resolution of 1997, 105th Cong., 1st sess. (July 1997), http://www.nationalcenter.org/KyotoSenate.html.

67. This is according to data published by Jos Olivier and J.A.H. W. Peters of the Dutch environment assessment agency for 2003; Gene M. Grossmann and Elhanan Helpman, "Protection for Sale," *American Economic Review* 84, no. 4 (1994): 833–50.

68. Grossman and Helpman, "Protection for Sale."

69. This is particularly well explained in an interesting comment on the work of: Graciela Chichilnisky and Geoffrey Heal, "Who Should Abate Carbon Emissions? An International Perspective," *Economic Letters* 44, (1994): 443–49; Graciela Chichilnisky, Geoffrey Heal, and David Starrett, "Equity and Efficiency in Environmental Markets: Global Trade in Carbon Dioxide Emissions," in *Environmental Markets. Equity and Efficiency*, ed. Graciela Chichilnisky and Geoffrey Heal (New York: Columbia University Press, 2000), 46–67; Kristen A. Sheehan, "Who Should Abate Carbon Emissions? A Note," *Environmental and Resource Economics*, 35, (2006): 89–98.

70. Chichilnisky and Heal, "Who Should Abate"; also see the Appendix below.

71. A formal proof of this is given in Graciela Chichilnisky, "A Comment on Implementing a Global Abatement Policy: The Role of Transfers" (paper presented at the International Conference on the Economics of Climate Change OECD/IEA, Paris, June 1993) and restated in Chichilnisky, Heal, and Starrett, "Equity and Efficiency in Environmental Markets: Global Trade in Carbon Dioxide Emissions." Also see a proof for a non-concave utility function (a non convex set) in the Appendix.

72. There is a relation in economics to the "transfer paradox," where a compensation can impoverish the recipient, as emphasized for instance in Herakles M. Polemarchakis, "On the Transfer Paradox," *International Economic Review* 24, no. 3 (1983): 749–60.

73. Leonid Hurwicz, *But Who Will Guard the Guardians?* (Minneapolis: University of Minnesota, 1998).

74. David A. Starrett, "Fundamental Non-convexities in the Theory of Externalities," *Journal of Economic Theory* 4, (1972): 180–99; Dasgupta and Heal, *Economic Theory*; Partha Dasgupta and Karl Goran Mäler, "The Economics of Non-Convex Ecosystems: Introduction," *Environmental and Resource Economics* 26, (2003): 499–525. Non-convexities are present, for instance, for a firm whenever the marginal damages due to the externality are not increasing until the firm goes out of business but only to a certain point after which the firm copes with them and the marginal damages decrease.

75. Hurwicz, *But Who Will Guard;* In Lindahl equilibrium, prices for a given externality are in general not unique. They can become so only if some special additional assumptions are made, such as, for instance, a similarity of preferences among participants. See: Dasgupta and Heal, *Economic Theory*.

76. Dasgupta and Heal, *Economic Theory*; Chichilnisky and Heal, Chapt. 13.

77. Urs Luterbacher, "International Cooperation: The Problem of the Commons and the Special Case of the Antarctic Region," *Synthese* 100, no. 3 (1994): 413-440.

78. Starrett, "Fundamental Non-convexities."

79. James A. Mirrlees, "Optimal Tax Theory: A Synthesis," *Journal of Public Economics* 6, (1976): 327–58.

80. The formal definition of convexity is: Every convex combination of every pair of commodity vectors (here rights) in the set (environment) is in the set.

81. As opposed to convex economic systems, non-convex ones exhibit distortions in production and preferences due to environmental externalities. For instance, the oversupply of natural resources by some developing countries reveals a poor incorporation of environmental constraints into their price structures due to an absence of property rights.

82. A similar demonstration for more collective goods is provided by Dasgupta and Heal, *Economic Theory*, 47.

83. Switzerland has introduced since 2007 a "climate cent," a privately levied tax on gasoline and diesel to constitute a fund that purchases among other things emission reduction certificates abroad. This would be an example of such a taxation method.