INTERNATIONAL ENVIRONMENTAL AGREEMENTS AND THE CASE OF GLOBAL WARMING

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Summary

First, this article uses standard welfare economics to illustrate the market failure and policy coordination problems caused by transboundary pollution problems in general and global warming in particular. Secondly, a brief overview is given of the main results obtained by empirical modeling exercises that combine both cost and damage estimates for global warming. Thirdly, the theoretical conclusions are confronted with the reality of ongoing international climate negotiations and the 1997 Kyoto Protocol is evaluated

from an economic point of view. Finally, some recommendations are made for the design of future climate agreements.

1. Introduction

In recent years the concern about the possibility of an enhanced greenhouse effect as a consequence of the emission of so-called greenhouse gases (GHGs) is rapidly growing. Under a business-as-usual (BAU) scenario without any specific policy to curb emissions of GHGs the Intergovernmental Panel on Climate Change Third Assessment Report expects that global mean temperature will rise by 1.4 to 5.8°C between 1990 and 2100. This would cause the sea level to rise by approximately 0.09 to 0.88 meter over the same period. Precipitation patterns would change drastically resulting in major shifts of agricultural production zones. Also the variability and likelihood of extreme events like hurricanes is projected to increase due to global warming. If one wants to reduce the negative consequences of this enhanced greenhouse effect, emissions of GHGs must be curbed significantly.

The greenhouse effect is a typical example of a global commons problem. Many fossil fuel users emit CO_2 that dissipates into the atmosphere and is mixed uniformly. The ensuing greenhouse effect affects all individuals in all countries of the world. It is well known that in this case individual abatement efforts in a noncooperative laissez-faire equilibrium will not be optimal from a societal point of view. In order to reach a socially optimal solution, international coordination of the GHG abatement efforts of the individual countries is needed.

Observation of reality immediately shows that the quest for cost efficiency (i.e. achieving an emission reduction target in the cheapest possible way) is not the only driving force in international negotiations on the coordination of greenhouse policies. Arguments related to the international income distribution are likely to play an important role. Leaders of developing countries emphasize that their economic situation justifies a lower abatement effort, the more so since the industrial world has been responsible for the large bulk of GHG emissions in the past. The problem is further complicated by the asymmetries related to costs and benefits of greenhouse policies. The negative effects of global warming are spread unevenly over the various parts of the globe and it is even possible that some regions might gain from a moderate temperature increase, at least in the beginning (see *Economics of Sustainable Development: International Perspectives*).

More important for the present discussions on emission abatement burden sharing are the huge international differences in the cost of abating emissions. An efficient worldwide abatement effort requires differentiation of abatement levels between countries. Moreover, in most cases such cost-efficient allocation will require greater efforts from the poorer countries since they are often characterized by relatively low abatement costs. In that case there is a direct conflict between equity and efficiency considerations. The relationship between efficiency and international distribution in the context of international environmental agreements will be an important focus of this chapter.

In Section 2 we introduce a stylized model of climate-economy interactions. This model is a simplified version of the seminal RICE (Regional Integrated Climate Economy) model by William D. Nordhaus. In Section 3 we first describe a reference laissez-faire scenario in which countries do not care much about climate change. This laissez-faire scenario is confronted with a normative burden sharing allocation derived from maximizing a global social welfare function. We discuss the different interpretations that can be given to the maximization of social welfare approach. In Section 4 we confront the theoretical model with reality for the case of global warming. First some general conclusions are drawn from empirical applications of integrated assessment models to global warming. Next, the main elements of the 1997 Kyoto Protocol are reviewed and are evaluated from an economic perspective. Section 5 concludes.

2. An Integrated Assessment Model for Transboundary Stock Pollution Problems

We will use a highly stylized model to describe the economy-environment interaction. The problem of global climate change will serve as an illustration but the model is general enough to accommodate other transboundary pollution problems. We tried to strip the model from all unnecessary details while focusing only on the most pertinent aspects of transboundary stock pollution problems. Stock pollution problems are caused by the accumulated stock of the pollutant in the environment, not by its emission flow as such. The model is a variant of a standard economic model to describe long-term economic growth in function of population growth and technological progress. The standard model is modified to allow for a global negative externality (for instance climate change or destruction of the ozone layer) that is positively correlated with economic production activities.

We denote by $N = \{1, 2, \ldots, n\}$ the set of all countries in the world. It is assumed that there is only one unique good that can be either consumed or used for investment in the productive capital stock. The unique consumption/investment good is produced using capital as the main input. A more general formulation would model explicitly other production inputs, in particular labor. We will assume that other inputs are supplied at fixed amounts and can therefore be subsumed in the functional form of the production function. Let Y_i^t denote production in period t for country i. The production technology is described by an increasing and concave production function:

$$Y_i^t = F_i^t\left(K_i^t\right) = A_i^t f\left(K_i^t\right) \tag{1}$$

F_i^t, the production function for country i at period t, consists of a common function f and a shifting parameter A_i^t that captures exogenous technological progress. This shifting parameter is assumed to increase over time though it might do so at different rates in different countries. More sophisticated models allow for endogenous instead of exogenous technological change.

Capital accumulation is described by a standard dynamic relationship. Next period's capital stock consists of the non-depreciated part of today's capital stock plus current investment. Parameter $0 \leq \delta \leq 1$ stands for the capital depreciation rate, we assume the initial capital stock K_i^1 is given.

$$K_i^{t+1} = [1-\delta] K_i^t + I_i^t \tag{2}$$

Production is assumed to cause emissions of greenhouse gases according to the following relationship:

$$E_i^t = \sigma_i^t Y_i^t - R_i^t \tag{3}$$

where σ_i^t denotes the emission-output coefficient, i.e. the amount of pollutants emitted for every dollar of production. Emission-output coefficients can differ across countries and evolve over time. We will assume an exogenous decrease of this ratio corresponding to an autonomous improvement in energy efficiency. Emissions are in essence proportional to production but can be lowered by investing in specific emission reduction measures like replacing a coal fired power plant by renewable energy sources or investment in more fuel efficient cars. These emission abatement activities are captured by the policy variable $R_i^t \leq \sigma_i^t Y_i^t$. However, emission reduction is costly and this is captured in the model by an increasing and convex emission abatement cost function. The convexity assumption refers to the idea that it becomes ever more expensive to reduce emissions by an extra unit for high levels of abatement.

$$C_i\left(R_i^t\right) \tag{4}$$

Emissions of greenhouse gases accumulate in the atmosphere disturbing the global carbon cycle and causing ultimately climate change. We will capture the complex physical processes in the following general relationship:

$$\Delta T^t = h^t\left(E_N^1, E_N^2, \ldots, E_N^t\right), \qquad \Delta T^1 \text{ given} \tag{5}$$

Temperature change at time t depends upon the global GHGs emission history from period 1 to period t. Capital subscripts will be used to denote the sum of a variable over all individual countries. Hence: $E_N^t = \sum_{i \in N} E_i^t$. We assume that the function h^t is continuously differentiable and increasing in each of its arguments. Behind this simple and general specification is hidden the complex physical reality of the global carbon cycle and temperature change processes.

Temperature change gives rise to a variety of physical impacts like sea level rise, changes in precipitation patterns and extreme weather events and so on. The economic valuation of the damages caused by these impacts is summarized in a so-called climate change *damage function*:

$$D_i\left(\Delta T^t\right) \tag{6}$$

The climate change damage function is assumed increasing and convex in temperature change reflecting the idea that additional damages will become more and more severe for high levels of temperature change, for instance due to nonlinearities in the physics of the carbon cycle and temperature system.

Finally, we can state the resource balance constraint in the economy of country i:

$$Y_i^t - D_i\left(h^t\left(E_N^1, E_N^2, \ldots, E_N^t\right)\right) \geq X_i^t + I_i^t + C_i\left(R_i^t\right) \tag{7}$$

The left hand side can be interpreted as "green" output, i.e. total output net of climate change damages. The right hand side stands for the different uses of this output, i.e. consumption, investment and investment in GHGs emission abatement. This resource balance constraint states that one cannot consume or invest more than overall green production in a particular country and period. This formulation implies that we do not consider trade flows between counties. This assumption is relaxed in many economic analyses but is not crucial for the results we will present in this chapter.

3. The Theory of International Environmental Externalities

We will compare in this section equilibria or solutions for the economic model introduced above. In particular, we will start in Section 3.1 with a noncooperative or laissez-faire equilibrium that describes what would happen if all countries only follow their self-interest. This section is positive or descriptive in nature. Starting from a behavioral assumption, it describes how rational agents will behave. Section 3.2 on the other hand is of a normative or prescriptive nature. It starts by postulating a general societal objective function and seeks an allocation of emission abatement efforts that maximizes this objective function within the constraints of economic possibilities.

3.1. Laissez-faire Equilibrium

Economic analyses of an environmental problem usually start by describing what would happen in the absence of deliberate policies to combat the environmental problem. This is called the *baseline* or *business-as-usual scenario*. In order to define such a baseline scenario, one needs to make a behavioral assumption in order to predict what choices individual countries will make when they are confronted with an environmental problem. Almost all economic approaches assume that economic agents (consumers, producers, governments, countries) pursue their private self-interest. There is some controversy however on how to define self-interest in this respect, especially when dealing with long-term environmental problems like climate change.

For expository simplicity we will assume that individual countries maximize some inter-temporal utility function, in particular a simple discounted sum of future consumption levels:

$$U_i\left(X_i^1, X_i^2, \ldots, X_i^{\Omega}\right) = \sum_{t=1}^{\Omega} \frac{X_i^t}{\left[1+\rho\right]^{t-1}} \qquad (8)$$

This specific choice of objective function entails several implicit assumptions.

- We consider a finite (but very long, say several centuries) time horizon: $\Omega < +\infty$ and linear intertemporal utility function involving exponential discounting. This means that the value in terms of period t consumption of an additional unit of consumption in period $t+1$ is always $1/(1+\rho) \leq 1$, independent of the consumption level. Countries are assumed to be "impatient", they value current consumption more than future consumption. Moreover, their degree of impatience is independent here of their consumption level. Further, it should be noted that there is a lively debate among economists on the exact value of the rate of time preference to be used in the context of climate change and on the appropriateness of exponential discounting in general.
- The formulation in (8) assumes that there exists some hypothetical representative agent that lives for the entire planning period from $t=1$ up to $t=\Omega$. In reality however, one should think of a sequence of several short lived and possibly overlapping agents.
- The objective function (8) assumes away the internal political debate in every country. The choices made by a country depend on the outcome of a political process representing many different and diverse interests. It is well known in economic theory that aggregating those different preferences into one meta-preference might prove problematic.

In spite of its simplicity and restrictive assumptions, we will continue to use objective function (8) since it is common in a large part of the economic literature on climate change and since it allows us to illustrate in the easiest way the fundamental issues involved. The interested reader is referred to the bibliography for more realistic formulations of the problem.

In the absence of international cooperation on environmental policy, we assume that countries will simultaneously maximize the utility of their lifetime domestic consumption paths as given by (8) subject to their economy's resource balance condition (7) and capital accumulation process (2). For simplicity we will assume that strategies are chosen once and for all at the beginning of the planning period and are not to be changed afterwards.

In addition, temperature change and emissions are determined by the relationships in expressions (5) and (3) respectively. The control or policy variables in this dynamic optimization problem are investment I_i^t and emission abatement effort R_i^t. Given a time path for these policy variables, the values of the state variables capital stock K_i^t and temperature change ΔT^t follow directly.

Solving this mathematical problem is beyond the scope of this chapter. We will limit ourselves to giving some flavor of the solution technique and to stating the basic insights. It should be noted here that one needs additional assumptions to resolve the interdependencies between the countries' optimal choices. Since the emissions of one country influence the level of climate change experienced by all other countries, every country needs to make an assumption on the emission behavior of all other countries. This maximization problem gives rise to necessary conditions that characterize the optimal choice of the policy variables in terms of the underlying parameters of the model. Before reviewing the basics of these necessary conditions, we first define a new piece of notation $\kappa_i^t = \sum_{\tau=t}^{\Omega} \frac{D_i'\left(\Delta T^\tau\right)}{\left[1+\rho\right]^{\tau-t+1}} \frac{\partial h^\tau}{\partial E_i^t}$ that stands for the *individual shadow value to country* i *of all domestic future climate change damages due to emitting one additional unit at time* t. This shadow value consists of the discounted sum of all the future environmental damages weighted by the effect of a change of period t emissions on the entire future time path of temperature change ($\partial h^\tau / \partial E_i^t$). The shadow value is a measure for the valuation a country attaches to the expected future climate change damages as a result of a marginal increase in period t emissions. Note that this shadow value decreases in ρ. The more impatient countries are, the lower the valuation they attach to future climate change damages.

3.1.1. Laissez-faire Optimal Investment Path

Using this new notation, the necessary condition driving an individually utility maximizing inter-temporal allocation of investment (and hence capital) boils down to:

$$\frac{\partial F_i^t}{\partial K_i^t}\left[1-\sigma_i^t \kappa_i^t\right] - \delta = \rho \qquad \forall i, \forall t \tag{9}$$

The left hand side of this expression stands for the net return on capital. This return consists of the marginal product of capital minus the depreciation rate. But the return on capital is affected negatively by future climate change damages through the shadow value κ_i^t. The effect of future climate change damages is to depress the return on capital compared to a situation without climate change externality. Along an individually utility maximizing path, the capital stock should be such that net return on capital, corrected for future climate change damages, equals the rate of time preference.

Compared to a situation without climate change damages, condition (9) implies lower production growth rates. Indeed, if climate change does not cause negative externalities, i.e. if $\kappa_i^t = 0, \quad \forall t$, then the optimal investment path is characterized by the so-called **golden rule**: $\frac{\partial F_i^t}{\partial K_i^t} = \delta + \rho \qquad \forall t$. This means that capital should be allocated over time in such a way that at every period, the marginal product of capital (i.e. the product of the last unit of capital invested in that period) equals the depreciation plus time preference rate. However, if climate change matters ($\kappa_i^t > 0$), marginal product of capital should be higher ($\frac{\partial F_i^t}{\partial K_i^t} = \frac{\delta + \rho}{1 - \sigma_i^t \kappa_i^t} > \delta + \rho$) implying a lower capital stock (because the productivity of each additional unit of capital is assumed to decline with higher levels of the capital stock, an assumption reflected by the concavity of the production function) and, as a consequence, lower growth rates.

3.1.2. Laissez-faire Optimal Emission Abatement Path

The necessary condition driving the optimal emission abatement effort can be stated as follows:

$$C_i'\left(R_i^t\right) = \kappa_i^t \qquad \forall i, \forall t \tag{10}$$

The left hand side stands for the marginal cost in order to reduce emissions by an additional ton. In a noncooperative or business-as-usual equilibrium, each country undertakes emission abatement up to the point where its own marginal cost of reducing emissions by one additional ton equals its own individual marginal benefit (i.e. the valuation of avoided climate change damages as reflected by the shadow value κ_i^t) of such an additional unit of abatement.

For the noncooperative or laissez-faire equilibrium, the following conclusions can be drawn:

- It is in every country's self-interest to undertake some emission abatement, even in the absence of international environmental agreements.
- The degree of domestic emission control in a noncooperative equilibrium is a function of expected future marginal climate change damages within the country itself. Damages inflicted upon neighboring states are not taken into account.
- The more impatient countries are (reflected by their rate of time preference or planning horizon), the lower their valuation of future climate change damages and the less emission abatement action they will undertake.
- It is optimal to restrict emissions through two channels. First, a country should lower overall production compared to a scenario without climate change by slowing down the rate of capital accumulation in the economy. Secondly, it should invest in emission control measures up to the point where marginal abatement costs equal expected future marginal damage costs.

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Biographical Sketch

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