Scand. J. of Economics 99(3), 371–387, 1997

International and Intergenerational Environmental Externalities*

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Abstract

We examine a world in which policymakers' actions in a given country at a given time have long-lived effects on a common resource: the global environment. We consider the first best in which long-lived planners behave cooperatively, then examine the allocation of resources when there is non-cooperation across countries, across time, or both. Finally we analyze the dynamic behavior of the economy along balanced growth paths. It is found that while long-lived international institutions are necessary to internalize all externalities, cooperation at a point in time may be harmful to future generations.

I. Introduction

The planet Earth is an ecosystem on which all life depends. Humankind has divided this ecosystem into sovereign states, and the laws governing each nation define property rights over the resources controlled by that nation. Not all resources are unambiguously controlled by a single nation. Some are jointly held by the global community. Of these some are common property resources that are controlled, at least in part, by international institutions and agreements. Others are open access resources that are controlled by no one. Actions taken by a single country often adversely affect these jointly held resources, and so influence economic well-being in other nations.

While political economy divides nations, mortality divides generations. The resources of an economy at a given time are controlled by policy-makers alive at that time. But environmental and other resources have

*We would like to thank Don Fullerton and an anonymous referee for their very helpful comments. We also thank seminar participants at Boston University, the University of Western Australia, the Australian National University, the University of Sydney and the University of Turin. We take responsbility for all errors. This research was funded in part by NSF Grant # SES-9022825.

value that extend beyond the lifetime of individual agents, so actions taken by current policymakers affect the well-being of future generations.

It follows that environmental externalities may extend across both time and national borders. Examples include: the poisoning of the Mediterranean Sea by effluvium, cf. *The Economist* (1991); global warming due to CO_2 emissions from the burning of fossil fuels, and the related problem of ozone depletion from CFC emissions, cf. Firor (1990), Schelling (1992), Morgenstern (1991) and Nordhaus (1991); and deforestation by acid rain due to SO_2 emissions, cf. Dowlatabadi and Harrington (1990) and Bui (1992). These problems are long-lived and international in nature, so policies of short-lived national governments are unlikely to take full account of either the immediate costs, because of the international effects, or the long-run costs, because of the intergenerational effects.

Various institutions could internalize these externalities. Examples include international treaties such as the Montreal Protocol, and long-lived domestic institutions such as the National Park Service in the U.S. In many cases, such institutions are absent, and where they do exist they are usually imperfect and limited in scope. Treaties are often hindered by domestic political concerns, and may be difficult to enforce. Domestic policymakers meanwhile, have limited ability to commit their successors to policy actions.

We examine a world in which policymakers' actions in a given country at a given time have long-lived effects on a common resource: the global environment. We consider the first best in which long-lived planners behave cooperatively. We then examine the allocation of resources when there is non-cooperation across countries, across time, or both. Not surprisingly, we find that long-lived international institutions are necessary to internalize all externalities. More interestingly, cooperation at a point in time may be harmful to future generations. We analyze the dynamic behavior of the model and find conditions under which it displays balanced growth. Depending on technological parameters, the model can exhibit either growth or decline.

There is a sizeable literature on the international transmission of pollution; see Baumol and Oates (1988) and d'Arge (1974). In contrast to the literature on trade and the environment, we restrict interaction to the individual country's effect on the global environment and the spillover effect from global to local resources.[1] Our work extends Markusen (1975)

[1] See e.g. Eaton and Engers (1992), Ludema and Wooton (1994) and Chichilnisky (1994). Because the two countries produce a single homogeneous good in our model, there is no static incentive for trade, although intertemporal trades (consumption loans) between non-cooperative long-lived planners could still arise; see footnote 11. Our exclusion of trade is close in spirit to Barrett (1991, 1992) and Hoel (1991).

in that we consider coordination problems that arise when nations share and independently affect a common resource, but we assume that global environmental quality is long-lived and affects the productivity of local resources.

We also consider the dynamic general equilibrium effects of the strategic choice of environmental policies. Hoel (1991), Barrett (1991, 1992) and Ihori (1996) examine the strategic behavior of countries in setting unilateral or bilateral policies. Nordhaus (1990), John and Pecchenino (1994), Smulders (1995a) and Bovenberg and Smulders (1995) model environmental issues in dynamic general equilibrium growth models, but in closed economy settings; see Smulders (1995b) for a good review of environmental endogenous growth models. Nordhaus and Yang (1996) develop a dynamic multicountry model, Bac (1996) presents a dynamic two-country game with incomplete information, and Beltratti (1993) models growth in a two-country dynamic model. None of these models considers intergenerational effects, however.[2]

Environmental externalities can arise from either production or consumption, and can enter either preferences or technologies. Thus we have four possible channels for externalities. First, production might directly affect welfare, as when logging leads to extinction of a species that has existence value to consumers. Second, production might affect current or future production possibilities, as when pollution of the ocean reduces stocks of fish. Third, consumption might have external effects on welfare, as when automobile use causes smog, a source of disutility. Fourth, consumption might have external effects on production, as when CO_2 emissions from automobiles cause greenhouse warming and so influence agricultural output.

The distinction between sources of externality is not especially germane to our concerns. We model the externality as a byproduct of consumption, so only the production of consumption goods harms the environment; by changing the technology for environmental improvement we could equivalently view the externality as coming from production.[3] The ultimate impact of the external effect is more significant. When the environment enters agents' utilities, changes in environmental quality alter the marginal rate of substitution between consumption and environment, causing agents to alter their allocation of resources between consumption and environ-

[2] To our knowledge, this is the first paper to address both intergenerational and international environmental externalities, although John, Pecchenino and Schreft (1993) consider both types of externality in a model of the arms race.

[3] In our model the only other use of output is environmental enhancement. In a model with consumption-saving decisions there would be another dimension: saving would defer pollution. We do not view such timing issues as essential.

mental improvement. When external effects operate through the technology, changes in environmental quality affect the total resources available. Our model contains both effects.[4]

Our model is specified in terms of countries and generations. Although these terms can be interpreted literally, we emphasize that they need not be. A country in our setting is the largest coalition that can sustain cooperation with regard to the environment. This could be larger than a single country, perhaps the European Union, or smaller than a country, perhaps a state or region in the U.S.[5] Likewise, a generation in our setting is the set of agents whose welfare is considered by current policymakers. We do not rule out intergenerational altruism; we do allow that it may be incomplete.[6]

We present our model in Section II and our basic analysis in Section III. Section IV contains discussion, Section V examines balanced growth paths, and Section VI concludes.

II. The Environment

Consider two infinite horizon economies — the home and the foreign country — comprised of finitely-lived individuals. Let lowercase letters denote home country variables, starred lowercase letters (*) denote foreign country variables, and uppercase letters denote global variables. We assume that a planner represents each economy, so all variables are economy-wide aggregates. For brevity, we only present the equations for the home country.

A new generation is born at each date t in each country and lives for one period. Population in the home country at date t is denoted by l_t, and grows at rate n: $l_{t+1} = (1+n)l_t$. Each agent possesses one unit of labor.

We distinguish between two interconnected aspects of the environment: environmental *capital* (hereafter capital), K_t, an input into production, and

[4] In Markusen (1975), Luema and Wooton (1992), John and Pecchenino (1994) and John *et al.* (1995), the environment affects utility; in e.g. Beltratti, Chichilnisky and Heal (1993) and Beltratti (1993), it affects technology. Bovenberg and Smulders (1995) and Smulders (1995a) include both channels.

[5] Often there are more than two countries acting non-cooperatively. For our qualitative analysis we require only that there is more than one.

[6] We are agnostic on whether intergenerational or international externalities are actually more important in the world. The Coase theorem might suggest that there is little hope of internalizing intergenerational externalities, since agents of different generations cannot meet. If so, intragenerational externalities are easier to internalize. Conversely, perhaps because of transaction costs from political considerations, countries do not always succeed in behaving cooperatively and, at the same time, it is possible that intergenerational altruism takes care of external effects across time.

environmental *quality* (hereafter quality), Q_t, which affects utility. Agents use capital and labor to produce output, which can be used for consumption or to improve quality. Both quality and capital are global public goods.

Specifically, generation t agents in the home country inherit global capital, K_t. Agents get no utility from leisure and so supply their labor inelastically. Labor and capital are combined to produce output, y_t:

$$y_t = g(K_t)\, l_t, \qquad g'(\cdot) > 0, \quad g''(\cdot) \leq 0. \tag{1}$$

Output can be consumed or used to improve the quality of the environment:

$$y_t = c_t + h_t, \tag{2}$$

where c_t denotes aggregate consumption and h_t denotes the aggregate resources devoted to enhancement of environmental quality. Quality is given by

$$Q_t = v(K_t, h_t, h_t^*), \tag{3}$$

where $v_1(\cdot)$, $v_2(\cdot)$, $v_3(\cdot)$ are all non-negative, and $v_{22}(\cdot) \leq 0$, $v_{33}(\cdot) \leq 0$. Agents have utility defined over (per capita) consumption and end-of-period quality: $U = U(c_t/l_t, Q_t)$; $U_1(\cdot) > 0$, $U_2(\cdot) > 0$, $U_{11}(\cdot) \leq 0$, $U_{22}(\cdot) \leq 0$. We assume that the utility function is identical for agents in both countries. Finally, the environmental capital bequeathed to generation $t+1$ is

$$K_{t+1} = f(Q_t, c_t, c_t^*), \tag{4}$$

where $f_1(\cdot) \geq 0$, $f_2(\cdot) \leq 0$ and $f_3(\cdot) \leq 0$.[7]

III. The Social Planners' Problems

Cooperative Long-lived Planners: Transferable Resources

First consider the case where long-lived planners behave cooperatively. We allow a transfer of T_t units of output from the home to the foreign country. The planners solve the following maximization problem:

$$\max \mathscr{L} = \sum_{t=0}^{\infty} \theta^t \left[v_t l_t U\left(\frac{c_t}{l_t}, Q_t\right) + v_t^* l_t^* U\left(\frac{c_t^*}{l_t^*}, Q_t\right) + \lambda_t (g(K_t)\, l_t - T_t - c_t - h_t) \right.$$

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[7] The timing of our model is such that the benefits of enhancement are realized by the current generation, but the costs of consumption only affect future generations. This particular timing is not crucial. What matters is that the current generation see at least some benefit from enhancement, and that there is also some intergenerational effect. That is, we could easily generalize our model to include consumption as arguments in $v(\ )$, and enhancement as arguments in $f(\ )$ — so some benefit from enhancement occurs with a lag.

$$+\lambda_t^*(g^*(K_t)l_t^*+T_t-c_t^*-h_t^*)+(\mu_t+\mu_t^*)(v(K_t,h_t,h_t^*)-Q_t)$$
$$\left.+(\xi_t+\xi_t^*)(f(Q_t,c_t,c_t^*)-K_{t+1})\right].$$

Here, v_t and v_t^* represent the bargaining strengths of the planners.[8] We assume also that utility in each country is weighted according to the size of the population in each country.[9] The terms λ, λ^*, $(\mu+\mu^*)$ and $(\xi+\xi^*)$ represent Lagrange multipliers. We write the multipliers on the quality and capital constraints as the sum of two terms representing the shadow value of the resource in each country. The first-order conditions from this problem are:

$$\lambda_t = \lambda_t^* \tag{5}$$

$$\lambda_t = v_t U_1(t) + (\xi_t+\xi_t^*) f_2(t) \tag{6}$$

$$\lambda_t^* = v_t^* U_1^*(t) + (\xi_t+\xi_t^*) f_3(t) \tag{7}$$

$$\lambda_t = (\mu_t+\mu_t^*) v_2(t) \tag{8}$$

$$\lambda_t^* = (\mu_t+\mu_t^*) v_3(t) \tag{9}$$

$$(\mu_t+\mu_t^*) = v_t l_t U_2(t) + v_t^* l_t^* U_2^*(t) + (\xi_t+\xi_t^*) f_1(t) \tag{10}$$

$$(\xi_t+\xi_t^*) = \theta[\lambda_{t+1} l_{t+1} g'(t+1) + \lambda_{t+1}^* l_{t+1}^* g^{*\prime}(t+1) + (\mu_{t+1}+\mu_{t+1}^*) v_1(t+1)] \tag{11}$$

plus the resource constraints, where $U(t)$ is shorthand for $U(c_t/l_t, Q_t)$, etc.

Because of the transfer, the shadow value of output is equated in each country (equation (5)). Together with (6) and (7), this implies that the marginal utility of consumption, adjusted for bargaining strength and the effect on the future environment, will be equated in the two countries:

$$v_t U_1(t) + (\xi_t+\xi_t^*) f_2(t) = v_t^* U_1^*(t) + (\xi_t+\xi_t^*) f_3(t). \tag{12}$$

Here, $(\xi_t+\xi_t^*)$ is the shadow value of the future environment. From (5), (8) and (9), the marginal benefit of enhancement is equated across countries:

$$v_2(t) = v_3(t). \tag{13}$$

[8] We include both v and v^* in order to facilitate presentation; obviously it is the relative bargaining strength (v/v^*) that affects outcomes.

[9] This is a convenient normalization; it entails no loss of generality since the v's can be time-varying. Time-invariant v's correspond to utilitarian social welfare functions. If v declines at rate n then the planners value the utility of a representative agent in each period. There is also no loss of generality in the assumption of a single discount rate, since country-specific discount rates could be captures by different rates of change for v and v^*.

The static cross-country conditions (12) and (13) hold in all time periods.

Define $\Sigma mu_t = l_t U_2(t)$ and $\Sigma mu_t^* = l_t^* U_2^*(t)$. From (6), (8) and (10),

$$v_t U_1(t) + (\xi_t + \xi_t^*) f_2(t) = v_2(t) [v_t \Sigma mu_t + v_t^* \Sigma mu_t^* + (\xi_t + \xi_t^*) f_1(t)]. \tag{14}$$

This is the within-country efficiency condition for the two uses of output. The l.h.s. is the marginal benefit from consumption: there is a direct utility benefit, and a cost from reduced capital in $t+1$ (valued at the shadow price $(\xi_t + \xi_t^*)$). The r.h.s. gives the marginal benefit from enhancement. The direct benefit (according to the standard Samuelson approach to public goods) equals the (weighted) sum of marginal utilities in both countries. Enhancement increases capital at $t+1$; this is valued at $(\xi_t + \xi_t^*)$.

Finally, equation (11) gives the dynamic linkage in the model: the value of capital at the end of period t is measured by its discounted contribution to output next period (valued at the shadow price $\lambda = \lambda^*$) plus its discounted contribution to end-of-period quality in $t+1$. From (5), (6), (8) and (11),

$$\xi_t + \xi_t^* = \theta \left(mpk_{t+1} + mpk_{t+1}^* + \frac{v_1(t+1)}{v_2(t+1)} \right) [v_{t+1} U_1(t+1) + f_2(t+1)(\xi_{t+1} + \xi_{t+1}^*)] \tag{15}$$

where $mpk_{t+1} = l_{t+1} g'(t+1)$ and $mpk_{t+1}^* = l_{t+1}^* g^{*\prime}(t+1)$. We obtain a recursive definition of the value of capital at the end of period t. An extra unit of capital yields $mpk + mpk^*$ extra units of output in period $t+1$, and raises quality by an amount equal (in output terms) to $v_1(\cdot)/v_2(\cdot)$. More output means more consumption at $t+1$, but this in turn means lower capital in $t+2$.

Cooperative Long-lived Planners: Non-transferable Resources

Cross-country environmental agreements in practice usually do not include direct transfers of resources. Therefore we now assume that, for political or technological reasons, output cannot be transferred across national borders. The maximization problem is as above, with $T_t = 0$, which implies that the shadow value of output will in general differ across countries ($\lambda \neq \lambda^*$).

Whereas there were previously two cross-country optimality conditions, equating the marginal benefits from enhancement and the marginal benefits from consumption, there is now a single cross-country condition:

$$[v_t U_1(t) + (\xi_t + \xi_t^*) f_2(t)]/v_2(t) = [v_t^* U_1^*(t) + (\xi_t + \xi_t^*) f_3(t)]/v_3(t). \tag{16}$$

The l.h.s. is the (weighted) marginal benefit from higher consumption in the home country when quality falls by one unit; the r.h.s. is the corresponding term for the foreign country. The two are equated because the planners place the same shadow value ($\mu+\mu^*$) on quality. As before, both countries internalize the effect of their own consumption on output in the other country (through the effect on capital). The within-country optimality condition is unchanged (see (14)); the intertemporal condition now reflects the different shadow value of output in the two countries:

$$(\xi_t+\xi_t^*) = \theta[\lambda_{t+1} mpk_{t+1}+\lambda_{t+1}^* mpk_{t+1}^*+(\mu_{t+1}+\mu_{t+1}^*)\, v_1(t+1)]. \tag{17}$$

Non-cooperative Long-lived Planners

Now consider the case of long-lived planners who behave non-cooperatively. In general, such two-player dynamic games are complicated.[10] We focus on the case where agents precommit to a sequence of strategies: agents take as given the complete sequence of strategies in the other country. This specification is very tractable and provides the cleanest comparison with our other cases.

Agents in the home country solve the following maximization problem:

$$\max \mathscr{L} = \sum_{t=1}^{\infty} \theta^t \left[v_t l_t U\left(\frac{c_t}{l_t}, Q_t\right) + \lambda_t (g(K_t)\, l_t - c_t - h_t) + \mu_t (v(K_t, h_t, h_t^*) - Q_t) + \xi_t (f(Q_t, c_t, c_t^*) - K_{t+1}) \right].$$

The first-order conditions from this problem are simply (6), (8), (10) and (11) with all foreign country multipliers (λ^*, μ^*, ξ^*) set equal to zero.

The within-country and intertemporal optimality conditions are

$$v_t U_1(t) + \xi_t f_2(t) = v_2(t)\,[v_t \Sigma mu_t + \xi_t f_1(t)]. \tag{18}$$

$$\xi_t = \theta\left(\Sigma mpk(t+1) + \frac{v_1(t+1)}{v_2(t+1)}\right)(v_{t+1} U_1(t+1) + f_2(t+1)\,\xi_{t+1}). \tag{19}$$

The home country no longer internalizes its effects on the welfare of the other country, so (18) includes the marginal utilities of agents in the home

[10] See Bac (1996) for analysis of such a dynamic game. Our simpler approach is also that adopted by Nordhaus and Yang (1996).

country only, and (19) excludes the value of capital in the foreign country. There are no cross-country optimality conditions.[11]

Short-lived Planners

The analyses for short-lived planners are special cases of the above. First, suppose agents internalize the intra- but not the inter-generational external effects. This problem corresponds to cooperative long-lived planners, with no value placed on the future environment. The first-order conditions are equations (5)–(11) with $\xi = \xi^* = 0$, and are easily interpreted. There is the cross-country efficiency condition for enhancement ($v_2(t) = v_3(t)$), a cross-country condition for the allocation of consumption, reflecting the bargaining power of the planners, ($v_t U_1(t) = v_t^* U_1^*(t)$), and a within-country condition ($v_t U_1(t) = v_2(t)\,(v_t \Sigma mu_t + v_t^* \Sigma mu_t^*)$).

When transfers are not possible, the first-order conditions are those of the long-lived cooperative planners' problem without transfers, with $\xi = \xi^* = 0$. The cross-country efficiency condition for enhancement is $v_t U_1(t)/v_2(t) = v_t^* U_1^*(t)/v_3(t)$; the within-country efficiency condition is unchanged.

Finally, the case of non-cooperative short-lived planners corresponds to the long-lived noncooperative planner case with $\xi_t = 0$. The first-order conditions are (6)–(11) with $\xi = \xi^* = \lambda^* = \mu^* = 0$, yielding a within-country efficiency condition in each country: $U_1(t) = v_2(t)\Sigma mu_t$.

IV. Discussion

International Cooperation

In each period, planners choose the allocation of output between consumption and enhancement. Short-lived non-cooperative planners equate the marginal rate of substitution between consumption and quality to the marginal rate of transformation. Cross-country cooperation without transfers lets the planners internalize the effects of their enhancement on the welfare of agents in the other country. Since enhancement bestows a positive externality, cooperation results in more enhancement and less

[11] This specification excludes borrowing and lending. We could permit consumption loans between the planners, so that (for example) the country which is relatively more patient will initially lend to the other country (run a trade surplus), and will be repaid in later periods. It is straightforward to show that the growth rate of λ must equal the growth rate of λ^* in this case.

consumption in both countries.[12] Greater enhancement bestows external benefits not only on the current generation in the other country, but also on future generations in both countries. Lower consumption likewise bestows an external benefit on future generations. Cooperation increases environmental quality, and so more capital is bequeathed to the next generation. Intragenerational cooperation thus benefits future generations as well as current generations, and so is Pareto improving.

Because both planners place the same shadow value on quality, they equate the ratio of the benefits (in terms of consumption) of a marginal decrease in quality in the two countries to the relative bargaining strength:

$$\frac{U_1(\cdot)/v_2(\cdot)}{U_1^*(\cdot)/v_3(\cdot)}=\frac{v^*}{v}.$$

Other things equal, a country with high bargaining strength will shift few resources from consumption into enhancement. If that country happens to be good at enhancement, much potential benefit from cooperation may be lost.

The Role of Transfers

Transfers allow countries to exploit comparative advantage in enhancement: output is allocated so that the marginal benefit of enhancement is equated in each country ($v_2(\cdot)=v_3(\cdot)$). Bargaining strength then shows up solely in terms of relative consumption levels. In the presence of transfers, however, short-lived cooperation may not be Pareto improving, precisely because of this efficiency gain. With transfers, the planners can reallocate enhancement resources to achieve the same level of quality using less output. Consumption increases, and cooperation can thus result in a *more* degraded environment.[13]

This is a somewhat unusual second-best result. The issue is not that actions impose positive externalities on some and negative externalities on

[12] Provided cooperation is voluntary, this must be true. If the cooperative equilibrium implied that one country consumed more, the other country would be better off not cooperating. In our setting, we can view the threat points from non-cooperation as providing bounds on the relative values of v and v^*.

[13] To prove that such a result is possible, consider an economy that delivers a non-cooperative equilibrium with environmental quality equal to Q' and with $v_2(\cdot)\neq v_3(\cdot)$. Now construct an economy identical to this one, except with $U(c/l, Q)\equiv U(c/l, Q')$ for $Q>Q'$ (and likewise for the foreign country). When the countries cooperate, they will still choose quality equal to Q'. Since $v_2(\cdot)\neq v_3(\cdot)$, they can attain Q' with fewer resources devoted to enhancement. Consumption rises, and future environmental capital therefore falls.

others. Internationalization of the intragenerational externality benefits current *and* future generations. But cooperation entails more than the internalization of externalities; it provides efficiency gains which free up resources for consumption, and so hurt the future environment. Paradoxically, if countries exploit comparative advantage in enhancement, the result may be degradation.

Coordination Failures

Under some circumstances, the Nash game between countries can yield multiple equilibria. This could arise if there is strategic complementarity in enhancement, so that increased enhancement in one country raises the marginal benefit to enhancement in the other country.[14] Countries that do not cooperate might not even attain the best non-cooperative equilibrium.

Intergenerational Altruism

Long-lived planners internalize the effects of one generation's actions on the welfare of future generations. In our setting, this implies a positive shadow value on environmental capital. When allocating resources between consumption and enhancement, such planners recognize that consumption reduces future capital, and that the benefits of enhancement extend beyond a single period. Thus long-lived planners place relatively fewer resources into consumption and more into enhancement, than do their short-lived counterparts. The result is higher capital and output, so steady-state consumption may actually increase.[15]

When long-lived planners also engage in international cooperation, they internalize the effects of both consumption and enhancement on the other country. With equal bargaining strength, agents in the country with the more polluting technology have lower consumption (see equation (12)). For example, suppose home country consumption causes greater pollution: $f_2(\cdot) < f_3(\cdot) < 0$. Then the marginal utility of consumption is higher in the home country. Since both countries possess identical utility functions,

[14] As a simple example, suppose that $g(K) = 1$, and that $l = l^* = 2.5 \Rightarrow y = y^* = 2.5$. Let $Q = hh^*$ and let $U(c, Q) = \ln(c) + Q$. It is easy to show that this economy has three Pareto-ranked symmetric equilibria: $h = h^* \in \{0, 0.5, 2\}$. See Cooper and John (1988) for more on coordination failures.

[15] It is easy to construct examples where this is true. A simple example comes from the functional forms assumed in Section V, setting $\phi\eta = \alpha$, $\gamma = 1$, and assuming that the fraction of resources devoted to enhancement is less than $\alpha/(1-\phi\delta)$.

consumption will be lower in the home country. If, however, $v_t > v_t^*$, this result may be overturned.

V. Dynamics

We now analyze the dynamic properties of this model. We restrict attention to balanced growth paths and so assume some specific functional forms:

$$U(c/l,\ Q) = \sigma \ln (c/l) + (1-\sigma) \ln (Q).$$

$$y_t = g(K_t) l_t = (K_t)^{\gamma} l_t;$$

$$Q_t = v(K_t,\ h_t,\ h_t^*) = (K_t)^{\delta} (h_t)^{\eta} (h_t^*)^{\eta^*};$$

$$K_{t+1} = f(Q_t,\ c_t,\ c_t^*) = (Q_t)^{\phi} (c_t)^{-\alpha} (c_t^*)^{-\alpha^*}.$$

The Model with Transfers

When output can be transferred between countries, balanced growth requires an equal growth rate of output in the two countries.[16] This implies that the ratio of outputs is constant over time. Hence, let $y_t^*/y_t = \rho,\ \forall t$. Without loss of generality, assume $\rho \leq 1$. Along a balanced growth path we can write $T_t = \tau y_t$, so resources in the home country equal $(1-\tau)y_t$ and resources in the foreign country equal $(\rho+\tau)y_t$. We then conjecture a solution where the share of resources going to consumption is constant in each country:

$$c_t = \varphi(1-\tau)y_t; \quad h_t = (1-\varphi)(1-\tau)y_t; \quad c_t^* = \varphi^*(\rho+\tau)y_t;$$

$$h_t^* = (1-\varphi^*)(\rho+\tau)y_t.$$

Substituting this conjectured solution in to the technologies, and simplifying, we obtain the following dynamic equation for capital:

$$K_{t+1} = A(K_t)^{\phi\delta + \gamma(\phi\eta - \alpha) + \gamma(\phi\eta^* - \alpha^*)} (l_t)^{(\phi\eta - \alpha) + (\phi\eta^* - \alpha^*)};$$
$$A = (1-\tau)^{\phi\eta - \alpha} (\rho+\tau)^{(\phi\eta^* - \alpha^*)} (1-\varphi)^{\phi\eta} (1-\varphi^*)^{\phi\eta^*} \varphi^{-\alpha} (\varphi^*)^{-\alpha^*}. \tag{20}$$

We assume $0 < \phi\delta + \gamma(\phi\eta - \alpha) + \gamma(\phi\eta^* - \alpha^*) < 1$.[17] Here $\phi\delta$ represents the natural persistence of capital: when $\phi\delta$ is low, capital depreciates rapidly. The $\gamma(\phi\eta - \alpha)$ term measures the net effect of growth in the home country on the environment; enhancement activities improve the environ-

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[16] If K grows at a constant rate, so do y and y^*. If these rates differ across countries, aggregate output cannot be growing at a constant rate.

[17] If $\phi\delta + \gamma(\phi\eta - \alpha) + \gamma(\phi\eta^* - \alpha^*) > 1$, the model exhibits explosive growth. If $\phi\delta + \gamma(\phi\eta - \alpha) + \gamma(\phi\eta - \alpha^*) < 0$, it exhibits oscillations: a high capital stock at date t degrades the environment and so reduces environmental capital at $t+1$.

ment, but consumption degrades it, so this term can be positive or negative. The $\gamma(\phi\eta^* - \alpha^*)$ term captures the net effect of consumption and enhancement in the foreign country.

is no population growth, the model tends to a steady state. The steady-state level of capital (hence output) is decreasing in φ and φ^*. The effect of transfers on steady-state output depends on the relative size of the two countries and the impact of each country's growth on the environment. Specifically, when $\tau = 0$, $\text{sgn}\,(\partial K/\partial\tau) = \text{sgn}\,((\phi\eta^* - \alpha^*) - \rho(\phi\eta - \alpha))$. If growth is more beneficial on net in the foreign country, transfers will increase steady-state output. If $(\phi\eta^* - \alpha^*) = (\phi\eta - \alpha^*)$, then steady-state output is maximized when post-transfer output is equalized internationally (so $1 - \tau = \rho + \tau$).

If there is population growth, then the model can exhibit balanced growth. From (20), the growth rate of capital is

$$g_k = \frac{[(\phi\eta - \alpha) + (\phi\eta^* - \alpha^*)]n}{1 - \phi\delta - \gamma(\phi\eta - \alpha) - \gamma(\phi\eta^* - \alpha^*)}.$$

Given g_K, the growth rates of output and of quality can be derived: $g_y = g_{y^*} = \gamma g_K + n$; $g_Q = \delta g_K + (\eta + \eta^*) g_y$. Assuming positive population growth, the key determinant of the overall growth rate is thus the net effect of consumption and enhancement on capital. If this effect is positive, the economy exhibits growth. If the effect is negative, the economy exhibits persistent decline.

Environmental capital is a reproducible factor of production. As is now well known from the literature on endogenous growth, we obtain balanced growth with positive population growth rates if the returns to scale associated with the reproducible factor $(\phi\delta + \gamma(\phi\eta - \alpha) + \gamma(\phi\eta^* - \alpha^*))$ are less than unity. (If population is constant in both countries, we have balanced growth only if $\phi\delta + \gamma(\phi\eta - \alpha) + \gamma(\phi\eta^* - \alpha^*) = 1$.) The division of output between consumption and enhancement has level effects but is not a determinant of the growth rate; growth depends only on exogenously given parameters. Whether we obtain sustained growth or sustained decline is purely a technological matter.

We now need to check that our conjectured solution is consistent with the first-order conditions. Given our assumptions on technology, given the conjectures, and using $\lambda = \lambda^*$, the first-order conditions are:

$$\varphi(1-\tau)\lambda_t y_t = \sigma v_t l_t - \alpha(\xi_t + \xi_t^*)K_{t+1}; \qquad (1-\varphi)(1-\tau)\lambda_t y_t = \eta(\mu_t + \mu_t^*)Q_t;$$

$$\varphi^*(\rho+\tau)\lambda_t y_t = \sigma v_t^* l_t^* - \alpha^*(\xi_t + \xi_t^*)K_{t+1};$$

$$(1-\varphi^*)(\rho+\tau)\lambda_t y_t = \eta^*(\mu_t + \mu_t^*)Q_t;$$

$$(\mu_t + \mu_t^*)Q_t = (1-\sigma)v_t l_t + (1-\sigma)v_t^* l_t^* + \phi(\xi_t + \xi_t^*)K_{t+1}$$

$$(\xi_t+\xi_t^*)K_{t+1}=\theta(\lambda_{t+1}y_{t+1}(\gamma+\rho\gamma^*)+\delta(\mu_{t+1}+\mu_{t+1}^*)Q_t).$$

From inspection, these conditions are consistent with balanced growth if the growth rate of $v_t l_t$ equals the growth rate of $v_t^* l_t^*$.[18] Let this growth rate equal g. We already know the growth rates of y, Q and K implied by the technology. Along a balanced growth path, the growth rates of the multipliers are such that the growth rates of λy, $(\mu+\mu^*)Q$, and $(\xi+\xi^*)K$ all equal g.

Let $\Lambda=(1+g)^{-t}\lambda_t y_t$; $\Xi=(1+g)^{-t}(\xi_t+\xi_t^*)K_{t+1}$; $M=(1+g)^{-t}(\mu_t+\mu_t^*)Q_t$; $N=(1+g)^{-t}v_t l_t$; and $N^*=(1+g)^{-t}v_t^* l_t^*$. Here, Ξ, Λ and M are the period zero values of capital, output and quality, weighted by their shadow prices. The first-order conditions in all periods along the balanced growth path are then equivalent to

$$\varphi(1-\tau)\Lambda=\sigma N-\alpha\Xi;\quad (1-\varphi)(1-\tau)\Lambda=\eta M;\quad \varphi^*(\rho+\tau)\Lambda=\sigma N^*-\alpha^*\Xi;$$

$$(1-\varphi^*)(\rho+\tau)\Lambda=\eta^* M;\quad M=(1-\sigma)N+(1-\sigma)N^*+\phi\Xi;$$

$$\Xi=\theta(\Lambda(\gamma+\rho\gamma^*)+\delta M).$$

These equations imply that

$$\Xi=\frac{\theta(N+N^*)(((\gamma+\rho\gamma^*)/(1+\rho))(\sigma+(1-\sigma)(\eta+\eta^*))+(1-\sigma)\delta)}{1-\theta\phi\delta-\theta((\gamma+\rho\gamma^*)/(1+\rho))((\phi\eta-\alpha)+(\phi\eta^*-\alpha^*))}.$$

This expression is increasing in γ, γ^*, η, η^*, θ, ϕ, δ, N, and N^*; it is increasing in ρ iff $\gamma^*>\gamma$; and it is decreasing in α and α^*.[19] Furthermore,

$$\frac{\varphi}{1-\varphi}=\frac{\sigma N-\alpha\Xi}{\eta(1-\sigma)(N+N^*)+\phi\Xi};\qquad \frac{\varphi^*}{1-\varphi^*}=\frac{\sigma N^*-\alpha^*\Xi}{\eta^*(1-\sigma)(N+N^*)+\phi\Xi}.$$

These expressions are decreasing in Ξ: when capital is more valuable, both countries put relatively fewer resources into consumption and more into enhancement. Finally, we can write the transfer rate in terms of φ and φ^*:

$$\tau=\frac{\eta^*(1-\varphi)-\rho\eta(1-\varphi^*)}{\eta^*(1-\varphi)+\eta(1-\varphi^*)}.$$

This is decreasing in φ, η, and ρ, and increasing in φ^* and η^*.

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[18] This will occur, for example, if the planner in each country considers the welfare of a representative agent, so v falls at the rate of population growth and the growth rate of vl is zero. Alternatively, if the planners adopt utilitarian social welfare functions, so v is constant, then the growth rates will be equal if population grows at the same rate in the two countries.

[19] Since $M=(1-\sigma)(N+N^*)+\phi\Xi$, it has the same comparative static properties.

The case of cooperative short-lived planners with transfers is similar. In such a setting $\Xi = 0$. The consumption-enhancement ratio depends only on relative bargaining strength, the productivity of enhancement, and the marginal rate of substitution between consumption and quality. Short-lived planners put more resources into consumption than do long-lived planners.

The Model without Transfers

If output cannot be transferred across national boundaries, then balanced growth is possible even when the growth rates of output differ in the two countries. Consider first the case of long-lived cooperative planners. Conjecturing $c_t = \varphi y_t$ and $c_t^* = \varphi^* y_t^*$, the technologies imply that

$$K_{t+1} = A(K_t)^{\phi\delta+\gamma(\phi\eta\ -\alpha)+\gamma^*(\phi\eta^*-\alpha^*)}(l_t)^{(\phi\eta-\alpha)}(l_t^*)^{(\phi\eta^*-\alpha^*)};$$

$$A = (1-\varphi)^{\phi\eta}(1-\varphi^*)^{\phi\eta^*}\varphi^{-\alpha}(\varphi^*)^{-\alpha^*};$$

$$\Rightarrow g_K = \frac{(\phi\eta-\alpha)n+(\phi\eta^*-\alpha^*)\delta n^*}{1-\phi\delta-\gamma(\phi\eta-\alpha)-\gamma^*(\phi\eta^*-\alpha^*)}.$$

The first-order conditions are derived as before. For balanced growth, we again need the growth rates of $v_t l_t$ and $v_t^* l_t^*$ to be equal. We then find that the qualitative properties of Ξ, the period zero value of capital, are similar to those obtained above, and are identical if $\gamma = \gamma^*$. The solutions for the share of resources devoted to consumption, φ and φ^*, have the same form as before. The analysis for cooperative short-lived planners entails setting $\Xi = 0$ (and does not need equal growth rates of $v_t l_t$ and $v_t^* l_t^*$).

The behavior of long-lived non-cooperative planners is also qualitatively similar. The solution for the growth rate is unaffected. The first-order conditions in the home country are identical to those above with all foreign country parameters set to zero. Consequently, capital is valued less by an individual country than by cooperative planners, so individual countries put more resources into consumption. The analysis for short-lived planners is a special case, since they put no value on capital; as before, this means $\Xi = 0$.

VI. Conclusion

Many environmental problems have international and intertemporal dimensions. The list is long and well known: CO_2 and CFC emissions affect the atmosphere and the stratosphere and so influence future climate and health; loss of biodiversity could mean the loss of new drugs; acid rain crosses international borders and destroys long-lived forests; overfishing of the world's oceans reduces future fish stocks; pollution damages oceans and shared lakes and river basins; air pollution reduces health and productivity; and many others.[20]

We develop a model of international and intergenerational externalities where the environment is a global public good that affects both productivity and welfare. International cooperation without transfers results in greater environmental improvement. Cooperation with transfers may allow countries to exploit comparative advantage in environmental enhancement, which, paradoxically, may lead to greater environmental degradation. Altruistic short-lived agents take account of the long-lived results of their actions. Our model is consistent with either sustained growth or long-run decline.

Recently, many nations have signed a number of international agreements concerning maintenance of the environment. These include the Montreal Protocol, which limits the production of CFCs, and the Biodiversity Treaty, which seeks to protect genetic diversity. Both agreements require an international perspective, because of static externalities, and an intergenerational perspective, since most of the benefit will fall on future generations. Our paper helps explain why transfers have been called for from the developed to the developing world. the main beneficiaries of many agreements, at least in the short-run, are the developed countries, while it is in the developing countries that improving environmental quality may be easier. Thus, the developing world must be compensated for their environmental maintenance expenditures. But our paper also sounds a cautionary note: international agreements with transfers that lack an intergenerational perspective could actually harm the environment.

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[20] Our working paper version of this article, available on request, considered these problems in more detail and provided examples in the context of our model.

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First version submitted April 1995;
final version received October 1996.