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INTERGENERATIONAL PUBLIC GOODS

Strategies, Efficiency and Institutions

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We live in a "brave new world" where allocative decisions on public goods today can have consequences that cross political and generational boundaries. Although the international aspects of public goods have received much attention in recent years, particularly with respect to environmental activities,[1] intergenerational public goods have received relatively scant attention.[2] An intergenerational pure public good (bad) provides benefits (costs) that are nonrival and nonexcludable within and among generations. For example, a genetically engineered medicine that cures cancers can benefit people worldwide during the discovering generation's lifetime and for generations to come. Similarly, lost biodiversity can have adverse global consequences for today's generation and all subsequent generations. Other intergenerational public goods include eradicating disease, curbing global warming, limiting ozone shield depletion, preserving culture, restraining ethnic conflict and developing cultural norms. For ethnic conflicts, atrocities committed by one generation can create hatreds that fuel conflicts for generations to come, as evident in Bosnia, Kosovo, northern Ireland, parts of the Middle East and some areas of Africa. Cultural norms and laws that promote cooperative behaviour within or among generations can have immense intergenerational benefits.

Although it is tempting to apply standard remedies for transnational public goods problems to transgenerational public goods, it is not necessarily effective. For example, fostering greater transnational cooperation can exacerbate intergenerational inefficiency if this cooperation leads to an even larger provision of an activity that benefits the current generation at the expense of future generations (John and Pecchenino 1997; Sandler 1978). Thus the expansion of nuclear energy through international cooperation improves the welfare of contemporaries but creates an even greater nuclear

waste containment problem for future generations. Similarly, foreign aid intended to develop a country's natural resources so as to alleviate poverty—such as World Bank financing of dams in South America—can result in enormous losses to biodiversity, limiting opportunities for future generations. This last example concerns sustainable development, associated with the preservation of natural capital so as to maintain the opportunities of future generations.[3]

Other aspects that distinguish remedies for transnational public goods from those for transgenerational public goods involve bargaining, strategic interactions and institutional design. For intergenerational public goods the natural sequencing of generations has profound implications for the design of institutional structures and the kinds of strategizing that can occur among concerned parties. An earlier generation might, for example, exploit a first-mover's advantage, placing more of the burden for an intergenerational public good on the next generation. The sequencing of generations can affect the bargainers' threat points, associated with a failure to reach an agreement. When institutions are designed to correct for market failures tied to transgenerational public goods, the calculation of net linkage gains depends on the outcome in the absence of an agreement. This status quo point also represents the participants' well-being that must be improved if an institutional arrangement is to make everyone better off. A rich array of strategic interactions exists for intergenerational public goods because collective action problems can arise within nations, among nations, among generations or among both nations and generations.

This chapter has five main purposes. First, it presents a taxonomy of public goods with benefits spanning generational or national boundaries. Second, it describes the implications for economic efficiency of a variety of public goods that affect nations or generations. Third, it explores the strategic aspects of intergenerational public goods. Fourth, it offers design principles for institutional arrangements, intended to address concerns about the allocation of transgenerational public goods. Fifth, the analysis is applied to specific cases of intergenerational public goods throughout.

A number of policy insights derive from this analysis. At the national level, decision-makers are unlikely to achieve optimal levels of these public goods. If intergenerational awareness of public goods spillovers is only encouraged within a country, then that country's well-being may actually deteriorate as others free ride on its enhanced far-sightedness. Thus cooperation and increased awareness of spillovers must have both an international

and an intergenerational dimension for all nations to gain. If institutions are properly designed to provide these intergenerational public goods, then the extent of policy-makers' awareness on both dimensions must be anticipated. Simple club arrangements can efficiently allocate resources for intergenerational public goods with excludable benefits. Markets can operate reasonably well for intergenerational public goods that display a large share of nation-specific or generation-specific benefits. When intervention is needed, supranational structures must be designed to account for associated transactions costs and benefits. Loose or unstructured linkages, which conserve on transactions costs, should be tried first.

A PUBLIC GOODS TAXONOMY

The creation of a taxonomy for public goods that provide benefits across nations or generations poses choices about which attributes of those goods to highlight. Two distinctions are essential for intergenerational public goods—namely, between intragenerational and intergenerational spillovers of benefits and between regional and global spillovers of benefits. The spatial dimension of the public good determines the relevant decision-makers—for example, the executive branch for national public goods, a regional social planner (that is, a hegemon) or individual nations for regional public goods and a world body or regional collectives for global problems. If no further attributes are considered, the resulting 2 x 2 classification scheme is identical to that of Sandler (1997, pp. 67–68). Curbing global warming fits the intergenerational category because greenhouse gases (such as carbon dioxide) have long residency in the atmosphere; it also fits the global category because atmospheric heating affects temperatures world-wide. In contrast, managing a terrorist incident is apt to yield only localized public benefits to the current generation.

This earlier taxonomy can now be extended. Although nonrivalry and nonexcludability can themselves be associated with a whole continuum of categories, a useful approach is to focus on, say, four types of public goods that affect the need for and form of institutional structures to correct for market failures. To expand the 2 x 2 taxonomy to 16 categories, I list pure public goods, impure public goods, club goods, and public goods possessing joint products. For its range of recipients, pure public goods provide benefits that are both completely nonrival and nonexcludable, whereas impure public goods yield benefits that are partially rival and/or partially nonexcludable. If,

say, congestion detracts from the good's benefits available to others, then these benefits are partially rival. An important subclass of impure public goods consists of club goods, which possess partially rival benefits that can be excluded. At a national level, clubs provide an opportunity for members to allocate resources privately to a public good without government intervention. Similarly, nations can form a club to share an excludable public good without the need for a supranational government structure. Thus the International Telecommunications Satellite Organization (Intelsat), a private consortium with nations and firms as members, operates as a club to share a communications satellite network that carries most international phone calls and television networks. A fourth class includes public good activities that yield two or more outputs that vary in their degree of publicness. For example, "tied" foreign aid can, by financing a developing country's infrastructure or fostering its people's well-being, yield public benefits to the recipient and to the world at large. Because the aid is tied to the interests of the donor country, the donor is expected to obtain one or more country-specific benefits from providing its donation. If, for example, a donor is granted military bases on the recipient's soil, then both a security and foreign interest benefit are conferred on the donor.

The 16-cell taxonomy is provided in table 1, complete with four examples of each type. Intragenerational and intergenerational public goods are distinguished by regional and global spillovers, as well as by the four classes of public goods. Insofar as the suppression of a forest fire provides regional purely public benefits to just a current generation, it is placed in the top left-hand cell along with groundwater pollution that can be cleansed within a generation's lifespan. Flood control and animal disease control are also instances of regional pure public goods.

In the pure public column, the cleanup of ocean pollution provides global spillover benefits to the current generation. Weather forecasts of El Niño represent a global public good because this phenomenon affects large portions of the earth. These forecasts are intragenerational because such weather phenomenon are short-lived. Other, more localized weather forecasts would be regional. Atmospheric monitoring stations and the World Court represent additional intragenerational public goods. Insofar as the World Court is open to all nations to hear disputes for settlement, it provides nonexcludable benefits world-wide. The court's ability to resolve a dispute between one set of nations does not limit its ability to address additional disputes between others, so its benefits are also nonrival.

TABLE 1

Taxonomy of public goods based on good's characteristics

		Pure public	Impure public	Club	Joint products
Intragenerational	Regional	• Forest fire suppression • Groundwater pollution cleanup • Animal disease control • Flood control	• Waterways • Rivers • Highways • Local parks	• Common markets • Crisis management forces • Electric grid • Information networks	• Peacekeeping • Military forces • Medical aid • Technical assistance
	Global	• Ocean pollution cleanup • Weather forecasts • Monitoring stations • World Court	• Electromagnetic spectrum allocation • Satellite transmissions • Postal service • Disease control	• Canals • Air corridors • Internet • Shipping lanes	• Foreign aid • Disaster relief • Drug interdiction
Intergenerational	Regional	• Wetland preservation • Lake cleansing • Toxic waste cleanup • Lead emissions reduction	• Acid rain reduction • Fisheries protection • Hunting grounds protection • VOC emissions reduction	• National parks • Irrigation systems • Lakes • Cities	• Peacekeeping • Flood control • North Atlantic Treaty Organization • Cultural norms
	Global	• Ozone shield protection • Global warming prevention • Disease eradication • Knowledge creation	• Overuse of antibiotics • Ocean fisheries • Antarctica protection • Revolution making	• Transnational parks • Geostationary orbits • Polar orbits • Barrier reefs	• Tropical forest preservation • Space colonies • United Nations • Poverty alleviation

Some public goods may fall into more than one category depending on how they are defined. Intergenerational, regional pure public goods include wetland preservation, lake cleansing, toxic waste cleanup and curbing of lead emissions, whereas intergenerational, global pure public goods involve stemming the thinning of the ozone layer, curbing global warming, eradicating disease and creating knowledge. All these examples provide nonrival benefits that are nonexcludable. The removal of a pollutant provides benefits to everyone residing in the region of spillovers. Within this spillover area, everyone receives the benefits from the cleanup. If the impact of the pollution removal is sufficiently long-lived, it can benefit future generations.

In the impure public good column, examples range from waterways that allow for the local transport of goods and services to the overuse of antibiotics that affects the well-being of current and future generations. For all the impure public goods listed, crowding or congestion reduces the quality of services available to users as overall utilization increases. As more vessels ply a waterway, transit time increases. Noise and interference characterize congestion for the electromagnetic spectrum because increased utilization requires that smaller bandwidths separate users. For antibiotics, an intertemporal form of congestion occurs when greater utilization of antibiotics today raises the likelihood that surviving bacteria will develop an immunity, decreasing the future effectiveness of the antibiotics. Acid rain is impurely public because

its dispersion is based on a spatial rivalry—that is, the further a country is from the source of the sulphur or nitrogen oxide emissions, the less of these emissions are deposited on that country's soil (Murdoch, Sandler, and Sargent 1997; Sandnes 1993). A similar phenomenon applies to the emission of volatile organic compounds (VOCs). By causing long-run degradation to the environment, acid rain and VOCs have intergenerational effects. Because exploitation of fisheries and hunting grounds can result in smaller species populations or even extinction, use of these goods also implies intergenerational consequences.

Table 1 lists 16 club goods. For these club goods an exclusion mechanism can charge a toll to users so as to internalize the crowding costs associated with a unit of utilization. If the toll is to achieve efficiency, then the toll must equal the marginal crowding costs that another visit or unit of utilization imposes on the membership. Users' total toll payments equal their visits times the toll per visit; visitors with a strong preference for the club good will visit more frequently and pay higher total payments. Regional club goods include goods—common markets, crisis-management forces, electric grids, national parks, highways—whose users are region specific. In contrast, global club goods—the Panama Canal, straits, air corridors, the Internet, polar orbits—are shared by countries world-wide. The distinction between intragenerational and intergenerational club goods has to do with the nature of congestion and whether there is an intergenerational consequence to utilization. For intergenerational club goods, congestion takes both the standard form, in which utilization today detracts from the consumption experience of current users, and an intertemporal form, in which utilization today affects the quality of the club good for current and future users. The latter form of rivalry is known as depreciation due to utilization (Sandler 1982).

Consider a national park. Once visits surpass a park's carrying capacity—that is, its limit for withstanding use and being able to regenerate to its natural state by the next period—its environment begins to deteriorate. As another example, an irrigation system may build up silt through use, resulting in reduced efficiency or depreciation due to utilization. Yet another global intergenerational club involves the sharing of geostationary orbits some 22,300 miles above the equator, at which altitude a satellite orbits the earth in sync with the earth's rotation, so that the satellite remains stationary over a point on the earth's surface. When placed in this orbital band, only three satellites are required to provide point-to-multipoint service throughout the earth

(except at the poles). Congestion takes the form of atemporal signal interference and the possibility of collisions, which may involve discarded and functioning satellites that drift up to 100 miles. Leaving discarded satellites in orbit, a standard practice, poses an intertemporal crowding externality. Intergenerational club goods can be managed efficiently by a collective of members, called an *intergenerational club* (see below).

The last column in table 1 indicates public goods in which an activity gives rise to two or more jointly produced outputs as benefits. Thus a country's military forces may provide purely nation-oriented goals of civil defence and terrorism crisis management while also deterring aggression at home and against a country's allies. Deterrence is purely public to all allies. Similarly, disaster relief yields a world-wide public benefit by helping a country in need; this relief may also contribute to the providing nation's standing in the world community. If an intergenerational benefit is derived, the good is placed in the two bottom cells of the column. Peacekeeping may give intragenerational or intergenerational benefits; hence its placement in two cells. When peacekeeping inhibits the acquisition of hatred that can be passed from one generation to the next, an intergenerational public good is achieved. Similarly, foreign aid or poverty alleviation may, by improving the health of a country's people, benefit current and future generations. Preserving tropical forests provides intergenerational public benefits on a global scale because of carbon sequestration and biodiversity. Flood control can give more localized joint products that are partly intergenerational in character if a dam is long-lived. By providing scientific discoveries, space colonies may produce global intergenerational benefits. Cultural norms that foster the cooperative provision of public goods may also yield benefits to current and future generations.

Intergenerational Pure Public Goods: Spillover Awareness

To provide a flavour of the allocative efficiency problems posed by an intergenerational public good, a simplified model is sketched in which there are two regions, $r = 1, 2$, with three generations, $j = 1, 2, 3$, in each region. Each generation lives for one period so that, in the initial analysis, there are no overlapping generations within either region. The set of people in the jth generation of the rth region is denoted by Ω_{jr}. As an intergenerational public good, good q is produced by each region in period 1 and then lasts for three periods. In the first and subsequent periods a private good, y, is produced and fully consumed during the period of production; thus the private good has no

intergenerational aspects. Initially, the public good is only allowed to be produced in period 1.

The modelling details are presented in appendix 1. In essence there are three ingredients in the model: a utility function for each individual, a constraint requiring consumption of private goods in each period to equal production of private goods, and a multiperiod, multiregional production possibility constraint. The utility functions represent individuals' tastes for the private good and the intergenerational public good, while the production possibility constraint indicates how much of each good can be produced with available resources at different points in time.

An efficiency criterion is required if the allocative aspects of an intergenerational public good are to be investigated. The concept of intergenerational Pareto efficiency (IPE) is employed and corresponds to a position from which it is not possible to improve the well-being of any person at any point in time without harming some other person in the current or some other generation (Page 1977; Sandler and Smith 1976). The intergenerational Pareto efficiency criterion applies the Pareto principle over time and space because it accounts for all relevant periods. In particular, intergenerational Pareto optimality requires the maximization of the *i*th individual's utility subject to the constancy of all other individuals' utility in the relevant regions and generations.[4] In addition, the production transformation function and the private good production-consumption constraints must be satisfied. To attain intergenerational Pareto efficiency, the provider of the intergenerational public good must account for the marginal benefits that the long-lived public good confers on people in the current *and* future generations in *both* regions (see appendix 1). Thus spillovers of public good benefits to other regions and future generations must be taken into account. Moreover, the required sum of these marginal benefits over regions and generations must be equated to the marginal costs associated with producing the public good in period 1. A similar condition holds for any region that provides the public good. This full awareness of spillovers is labelled *awareness rule 1* (AR1) and serves as an ideal benchmark. Such a far-sighted decision is anticipated only if some centralized social planner—such as a collective serving the two regions' interests—made the allocation decision while taking into account benefit spillovers over space and time. If more regions or generations were affected by the public good, then the marginal benefit must be summed over all relevant regions and generations.

Alternative awareness rules

When the allocative decision about the intergenerational public good is made at the regional or national level, the decision-maker is unlikely to account for the benefit spillovers conferred on other regions and future generations. At least three reduced levels of awareness are possible. First, an interregional social planner or institution can account for interregional spillover benefits but not for intergenerational benefits. In this case awareness rule 2 (AR2) would equate the marginal benefits of only the current generation in the two regions to the marginal costs (see appendix 2).[5] Insofar as AR1 includes more marginal benefit terms than AR2, AR2 implies a lower level of provision because a smaller aggregate marginal benefit is equated to marginal production cost. AR2 corresponds to a myopic supranational institution that is aware of the interregional consequences of the public good decision but is ignorant of the intergenerational consequences.

The next two awareness rules are the most relevant and indicate the provision decision for the intergenerational public good being made by a decision-maker in each region. In this scenario the regional planners or national governments are only interested in the Pareto principle as it applies to their people, so there is no concern for residents outside the region.[6] A third level of awareness has the regional social planners ignoring interregional spillovers while accounting for intergenerational spillovers, so that the marginal benefits are summed only over the region's own current and future generations before being equated to the marginal costs for the public good. For simplicity we assume that regional marginal costs for the public good equal the multiregional marginal costs in AR1, so that a provision comparison can be easily made between AR1 and AR3. Given the smaller number of marginal benefit terms in AR3 relative to AR1, the intergenerational public good is underprovided relative to the ideal. This follows because interregional spillover benefits are ignored.

The fourth level of spillover awareness, AR4, proves to be the most likely result, in which both interregional and intergenerational spillovers are ignored by the regional social planners. When AR4 applies, the provision level for the intergenerational public good is the smallest of the four rules in which only the current generation's gains in the providing region matters.

Diagrammatic representation

To apply a standard graphical apparatus to intergenerational public goods (Cornes and Sandler 1985; Sandler 1992), I assume that the regional planner's

welfare is solely dependent on current residents' utility levels.[7] In figure 1 two (production) constrained iso-welfare contours for region 1's social planner are displayed as curves *II* and *I'I'* for the case where AR4 applies so that each region looks out for just its own first generation. Production of q takes place in both regions, so that $q = q^1 + q^2$ and residents of either region derive a marginal benefit from either region's provision of the public good. For a given level of q^2, say q^2_0, AR4 is satisfied along curve *II* at point *A*, where the slope is zero.[8] Iso-welfare curve *I'I'* represents a higher level of well-being for region 1 insofar as it receives a greater level of q^2 spillins for each level of its own provision of q^1. If the spillins are q^2_1, then AR4 is satisfied along *I'I'* in figure 1 at point *B*, where the iso-welfare contour again attains a zero slope. The curve connecting the zero-sloped points on the various iso-welfare contours for different spillin levels from region 2 is the Nash reaction path, N^1_{AR4}, for region 1. This reaction

FIGURE 1

Nash reaction path for region 1

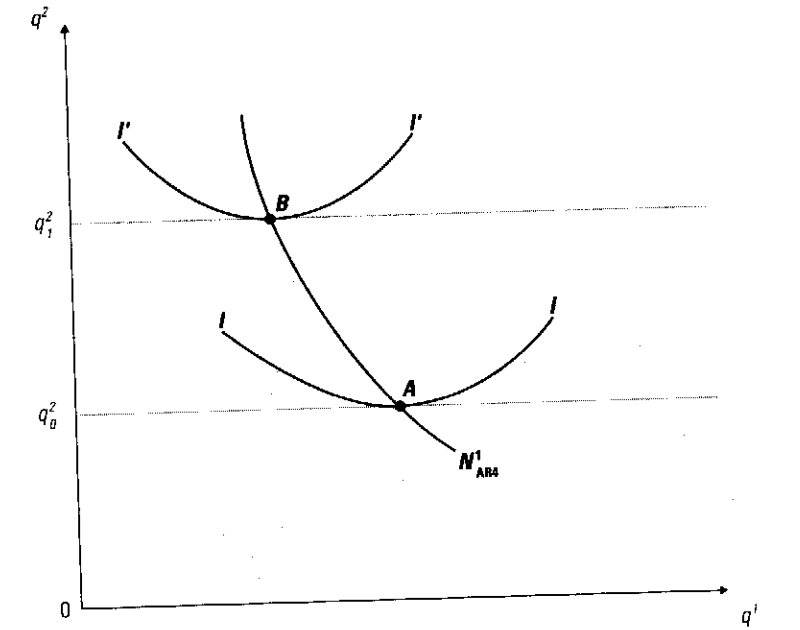
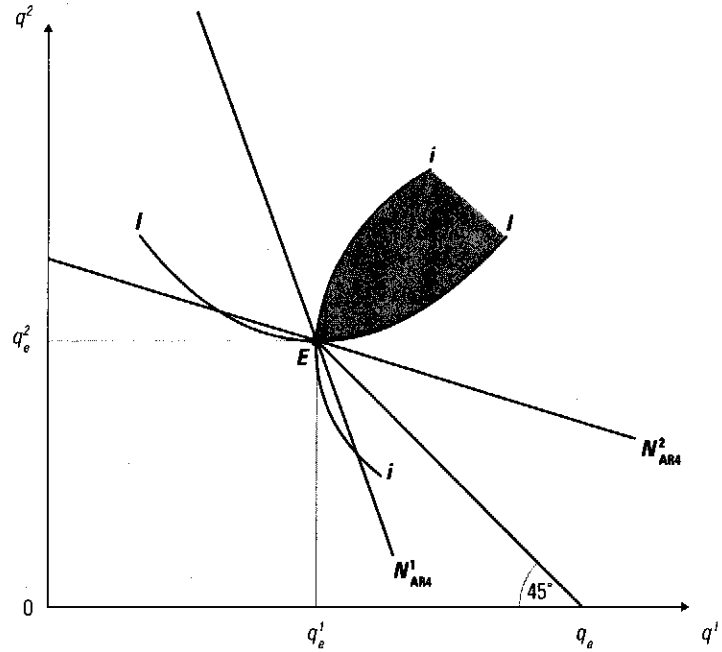


FIGURE 2

Nash equilibrium for two regions



path is typically downward sloping, indicating that as region 2 provides more of the intergenerational public good, region 1 provides less as it free rides on region 2's provision.

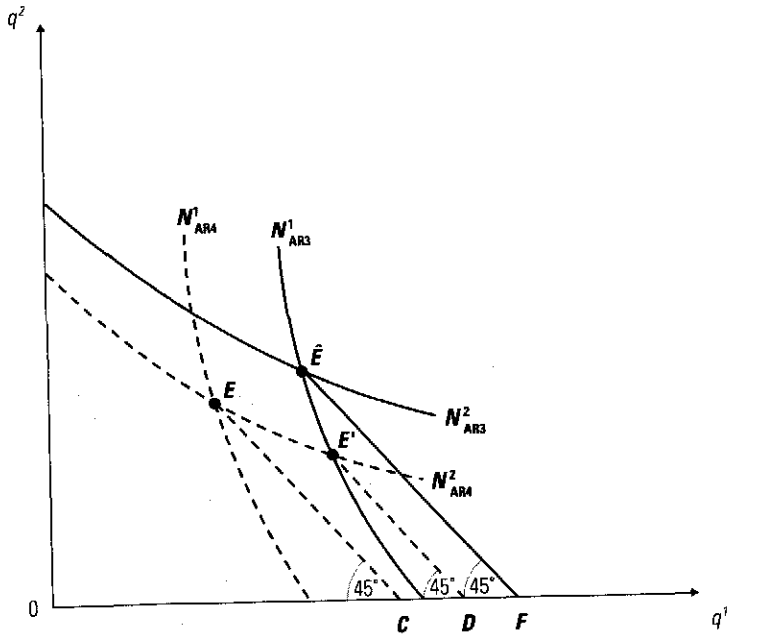
Region 2's iso-welfare contours have their bottom points oriented to the q^2 axis. One such curve, *ii*, is depicted in figure 2. Similarly, region 2's Nash reaction path is derived by connecting these infinite-sloped points—see N^2_{AR4} in figure 2. Region 2's Nash reaction path is also negatively sloped, indicating that region 2 reduces its provision of the intergenerational public good as region 1 increases its provision.[9] If both regions abide by AR4, then a Nash equilibrium results at point *E* in figure 2 with region *r* providing q^r_e for $r = 1, 2$. If we draw a 45 degree line from point *E* to the q^1 axis, then the intercept of this line, q_e, is the total multiregional provision level. To the north-east of point *E* the shaded region between the respective regions' iso-welfare contours

indicates allocations where both regions' welfare can be augmented. The strategic interaction associated with AR4 leads to a Pareto suboptimal outcome at E from which both regions' welfare could be improved if they both accounted for the spillins conferred spatially and temporally.

Suppose that region 1 assumes a more far-sighted view towards its future generation and accounts for intergenerational public good spillovers by satisfying AR3. Further suppose that region 2 continues to satisfy AR4. By abiding by AR3, region 1 includes more marginal benefits in its calculation when deciding its level q^1 for each level of spillins of q^2. As a result region 1's provision of the intergenerational public good will be greater for each level of q^2. This increased intergenerational awareness results in a rightward shift of region 1's Nash reaction path from N^1_{AR4} to N^1_{AR3} in figure 3. After this shift the new equilibrium is at E' where the overall level of the public good has

FIGURE 3

Increased intergenerational spillover awareness



increased from $0C$ to $0D$, so that unilateral far-sightedness augments the overall level of the intergenerational public good. Region 2 is clearly better off because it contributes less to the public good but consumes more of it owing to increased spillins. Region 2's iso-welfare curve (not depicted in figure 3) through point E' is a greater welfare level than the iso-welfare curve through point E. A welfare comparison for region 1 is more troublesome because the iso-welfare contours associated with N^1_{AR3} and point E' are different than those associated with N^1_{AR4} and point E, insofar as the underlying social welfare function for the planner in region 1 has changed. The smaller is region 2's free riding on region 1's increased provision, the more likely that region 1 may also benefit from its increased concern for its future generations. Region 1's enhanced intergenerational spillover awareness could lose its net welfare if region 2's reaction path were sufficiently steep, so that region 1 loses sizable spillins from the other region's strategic response.

A better scenario occurs if region 2 also becomes more aware and also abides by AR3. If this were to occur, then region 2's Nash path would shift to N^2_{AR3} in figure 3 and the equilibrium $\hat{E}$ would result, where the overall level of provision is $0F$, which exceeds $0D$. The distribution of provision burdens at $\hat{E}$ relative to E depends on the relative rightward shifts of the Nash paths. The most likely scenario is that both regions will contribute more and be better off than at E. Because satisfying AR3 does nothing to internalize interregional spillovers, as required by AR1, the equilibrium at $\hat{E}$ does not result in intergenerational Pareto efficiency. Accounting for these interregional spillovers may require some form of supranational linkage between the regions.

Further strategic interactions

The analysis is now extended to investigate strategic behaviour both within a region and between regions for the provision of an intergenerational public good. Again just two regions are assumed, now labelled East and West. We further assume that in the East the young are expected to serve and carry on the wishes of their parents. In contrast, the parenting (earlier) generation often displays a responsibility for the next generation in the West region, and in so doing demonstrates a good deal of future-generation awareness. Thus the East and West labels distinguish between a region with backward-oriented responsibility and a region with forward-looking altruism. Within both regions there are two generations in which the first lives for two periods, $j = 1, 2$, and the second lives only for period 2. Thus generation 1 overlaps in time with generation 2.

The model

A sketch of the underlying model is given from the viewpoint of the East or backward-oriented region. Each generation is now represented by a single individual to simplify the presentation; the reader is invited to view this representative individual as a social planner for his or her generation. Once again a private good (y) and an intergenerational public good (q) are assumed, in which y_E^{ij} denotes the ith Eastern generation's consumption of the atemporal private good in period j and q_E^{ij} denotes the ith Eastern generation's provision of the intergenerational public good in period j. The first Eastern generation's multiperiod utility,

$$1.\quad V_E^1 = V_E^1\left[u_E^{11}(\bullet),\ u_E^{12}(\bullet)\right]$$

depends on the generation's single period utility functions during its lifetime. Eastern generation 2's multiperiod utility contains only $u_E^{22}(\bullet)$. In period 1 Eastern generation 1's consumption of the intergenerational public good is $q_E^{11} + q_W^{11}$ or the provision amount in the first period in both the East and West, where q_W^{11} is determined from abroad. In period 2 generation 1's consumption of the public good is $q_E^{11} + q_E^{12} + q_E^{22} + q_W^{11} + q_W^{12} + q_W^{22}$ or the provision amount in the first and second periods in both the East and West. The first and second generations are constrained by a multiperiod transformation indicating the ability of each generation to trade off production of the two goods.[10]

Each generation chooses its y's and q's to maximize its multiperiod utility function subject to its transformation function.[11] At the Nash solution the first generation has no incentive to provide the intergenerational public good in period 2, so q_r^{12} is zero in both the East and West. This follows because the marginal benefits derived from the intergenerational public good provision in period 1 is always greater than those from provision in period 2 because period 1 provision benefits the provider for two periods rather than one period. When making a multiperiod allocative decision, generation 1 foresees this consideration and provides the public good immediately, thus supplying just the private good in the second period.

Strategic considerations

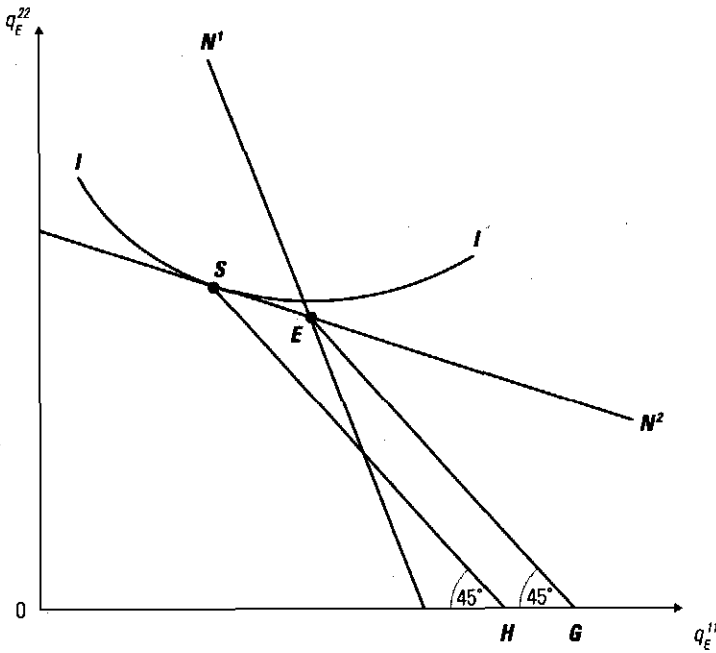
If regional spillovers are taken as given, then strategic behaviour in the East involves the decision to provide q_E^{11} by generation 1 and q_E^{22} by generation 2, given q_W^{11} and q_W^{22}. This can be represented by the standard reaction paths based on the transformation-constrained iso-welfare curves for generations 1 and 2 in the East. In figure 4 q_E^{11} is placed on the horizontal axis and q_E^{22} on

the vertical axis. Nash path N^1 connects the zero-sloped points on generation 1's iso-welfare contours for different levels of q_E^{22} as anticipated to come from generation 2 in the second period of generation 1's lifetime. Also in figure 4, N^2 denotes generation 2's reaction path to spillins of q_E^{11}. These Nash reaction paths assume that the level of interregional spillins from the West are fixed; an increase in these Western spillins would shift both Nash reaction paths leftward as spillins from abroad substitute for the region's own provision. A decrease in these interregional spillins would have the opposite effect.

If each generation in the backward-looking region or East acts according to its Nash reaction path, then the equilibrium is at E in figure 4, where $0G$ represents the aggregate two-period provision of the public asset. The sequencing of the generations allows for an alternative strategic response known as *leader-follower* behaviour (Sandler 1992; Cornes and Sandler 1996),

FIGURE 4

Eastern intergenerational strategizing



in which the first generation acts as the leader and the second as the follower. The leader knows that the follower, who goes second, will take the leader's provision amount as given; hence the follower continues to abide by its Nash reaction path. The leader, however, treats the follower's public good provision, q_E^{22}, as dependent on the leader's choice of q_E^{11} relative to the follower's Nash reaction path. Consequently, the leader attempts to achieve its greatest iso-welfare curve along generation 2's Nash reaction path. In figure 4 the leader-follower equilibrium in the East is S, where iso-welfare curve II is tangent to N^2. At S the aggregate multiperiod level of q_E has fallen from $0G$ to $0H$ as the first generation exploits its first-mover advantage and forces the second generation to assume a larger burden for the intergenerational public good. Generation 1's iso-welfare curve through S is higher than the one (not shown) through point E; the opposite is true for generation 2's welfare.

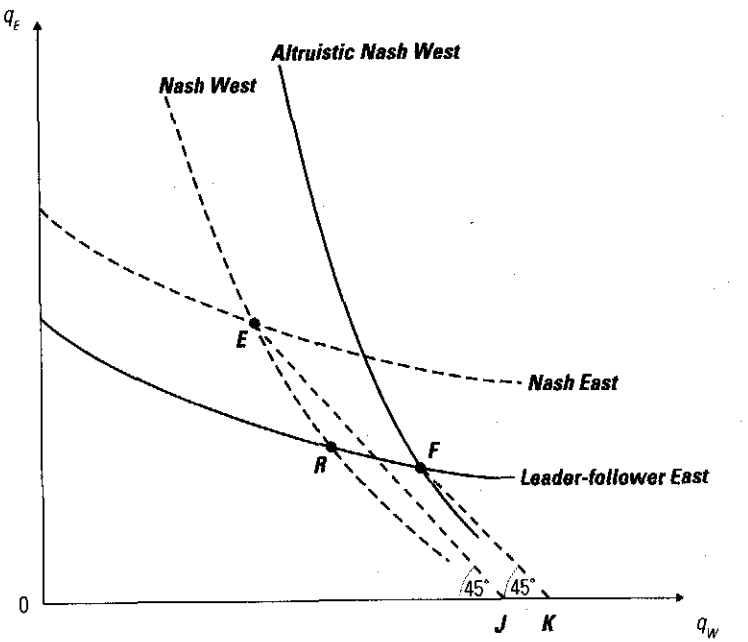
Regions that have very different views of the responsibilities that one generation has for the next may have profound effects on the manner in which resources are allocated to intergenerational public goods. This insight may partly help explain why industrial countries have more strongly supported environmental treaties, such as the Kyoto Protocol on global warming, while some developing countries have been hesitant.[12] Given its generational orientation, the East is apt to engage in a leader-follower strategy. In contrast, the West is anticipated to use a Nash strategy based on altruism to its future generation, much like the AR3 case encountered in the previous section. Figure 5 represents the strategic interactions and their consequences on the East and West; the provision of the intergenerational public good in the West is on the horizontal axis and the provision in the East is on the vertical axis. The dotted Nash West and East curves serve as benchmark cases and indicate the intergenerational response in each multigenerational region for alternative levels of spillins from the other region. In essence these paths depict the equilibrium aggregate quantity (for example, $0G$) of $q_E^{11} + q_E^{22}$ from figure 4 for alternative levels of q_W ($= q_W^{11} + q_W^{22}$), and hence shifts of N^1 and N^2. Each increase in q_W would cause curves N^1 and N^2 in figure 4 to shift to the left and down, so that equilibrium E would move to the south-west, implying a reduced provision of q_E ($= q_E^{11} + q_E^{22}$). As a result the Nash reaction curves relating q_E and q_W in figure 5 are negatively sloped for both the West and East as drawn.

In figure 5 the leader-follower reaction curve for the East is also negatively sloped, because an increase in q_W also displaces the equilibrium S to the south-west in figure 4, thus reducing q_E. Because the aggregate amount

of q_E associated with leader-follower behaviour is always less than that of the Nash equilibrium in the East, the East's leader-follower curve must be below its Nash curve in figure 5. If the West adheres to its Nash path while the East abides by its leader-follower path, then the equilibrium would be at point R, where the aggregate level of the intergenerational public good is less than level $0J$ of the Nash equilibrium. The East would shift more of the burden for the public good onto the West owing to these regions' different dispositions to future generations. This burden-shifting tendency between the East and West is worsened if the West displays altruism towards future generations, analogous to a switch from AR4 to AR3, so that the Nash curve in figure 5 shifts to the altruistic Nash West curve. If this occurs, the equilibrium at F for the two solid paths would result in a greater overall level of q because $0K$ exceeds $0J$. At F the West picks up much of the burden for the

FIGURE 5

East-West intergenerational strategizing



intergenerational public good. If the shifts were larger, a corner solution on the horizontal axis could follow with the East riding free. Whether or not the overall level of q increases at F relative to E hinges on the relative shifts of the two paths. The greater is the shift in the Nash West path relative to the leader-follower East path, the more likely it is that the aggregate level of q will increase.

These differences in intergenerational responsibilities imply that countries in a forward-looking region are more apt to supply such things as disease cures, environmental protection and research breakthroughs. Based on these results, sustainable development is predicted to be more difficult to maintain in backward-oriented countries than in forward-looking countries. Even more disturbing is the realization that efforts by some countries to achieve sustainable development, an intergenerational public good, may encourage other countries to reduce theirs.

Joint products

Many different joint product scenarios are possible. Again consider the basic model of two regions (East and West) and three nonoverlapping generations, each of which lives for one period. Wherever possible the same notation is maintained. An intergenerational public activity (q) is assumed to yield a generation-specific and region-specific benefit (x) and an intergenerational pure public benefit (z). That is, good x benefits only the generation of the region supplying activity q during the generation's lifetime, while the benefits of good z spill over to the other region and generations. Further suppose that activity q is only supplied in the first of three periods. The joint product relations are

$$2.\quad x^{1r} = \alpha^r q^r, \qquad r = E,\ W,$$

and

$$3.\quad z^r = \beta^r q^r, \qquad r = E,\ W,$$

where α^r and β^r are positive constants representing how many units of the respective joint products are derived from each unit of activity q^r. The total amount of the intergenerational public good experienced by an individual in any generation is

$$4.\quad Z = z^E + z^W = \beta^E q^E + \beta^W q^W.$$

During period 1 the utility function of individual i in region r is

$$5.\quad u^{i1r} = u^{i1r}\left(y^{i1r},\ \alpha^r q^r,\ \beta^E q^E + \beta^W q^W\right), \qquad r = E,\ W, \qquad i \in \Omega_{1r},$$

where I have substituted for x^{1r} and Z based on equations 2, 3 and 4. Individuals in generations 2 and 3 have only the private good y and the intergenerational public good Z in their utility functions because they do not supply activity q. The rest of the model is analogous to that described in the second section. As before, the multiperiod production trade-off is between the private good and the public activity.

In the providing generation and region the decision-maker for the intergenerational public good is anticipated to concentrate on the benefits derived by the current generation in just his or her own region. This behaviour implies that the weighted sum of the marginal benefits for the two jointly produced outputs is equated to the marginal costs of activity q.[13] The weights on the marginal benefits reflect the productivity of q in providing the region-specific and the region-wide outputs of x and Z, respectively, as given in equations 2 and 3. If the intergenerational activity is, say, more productive in yielding x than Z, then these region-specific benefits are emphasized to a greater extent when determining how much q to produce. The providing generation fails to account for the benefits that its provision of q supplies to the other region and future generations, leading to suboptimal provision. However, the greater is the generation-specific benefits derived from q, the more motivated is the generation to provide the public activity and the less the need for intervention.

Next, suppose that activity q gives rise to region-specific benefit x that also lasts for three generations. When acting alone, the first generation is still anticipated to focus on its gains from activity q, and, in so doing, ignores intergenerational benefits conferred through both x and Z. This means that unlike previous analyses of joint products, the appearance of provider-specific benefits may worsen suboptimality if temporal spillovers arise with respect to these latter benefits and are also ignored. In calibrating the extent of suboptimality, one must calculate the providing generation's sum of benefits from the public activity as a share of the total benefits received by both regions and all generations.[14] As this share increases towards one so that the providing generation receives most of the gains, the current generation has greater incen-

tives to supply the public activity. Altruism towards future generations can also increase the providing generation's perceived marginal benefits, thus motivating it to account for future generations' spillovers.

The presence of joint products means that increased interregional cooperation through supranational structures may worsen the misallocation of resources. Consider a scenario in which each region receives region-specific private benefits and a jointly produced interregional public bad from an activity. Further, suppose that the private benefit affects only the current generation, while the public bad influences current and future generations. For example, the production of nuclear energy benefits the current generation but gives rise to wastes that place current and future generations world-wide at risk. Similarly, the burning of fossil fuels warms the current generation but adds to the accumulation of greenhouse gases, which may harm current and future generations world-wide. If a supranational link forms that furthers the interests of the current generation in the cooperating regions, then the cooperation-induced increased provision of the public activity adjusts for the current generation's interregional externalities, while increasing the negative externalities to future generations. With joint products, external effects concern regions, jointly produced outputs and generations. When negative externalities are present, agreements and linkages that attend to just one or two of these external-effects dimensions may worsen resource allocation relative to no agreement whatsoever. Some standard remedies may no longer apply when joint products possess alternative temporal characteristics.

Intergenerational clubs

When forming a supranational structure to correct for market failures involving two or more regions, regional policy-makers must consider the transactions costs that accompany any mode of allocation. If these transactions costs are less than the transactions benefits attributable to an allocative mechanism that augments efficiency, then the institution may be warranted (Sandler 1997). Institutional arrangements that economize on transactions costs stand a better chance of being viable. One such institutional arrangement is a club, which can be formed when the public good's benefits are excludable at costs less than the allocative benefits achieved by matching tastes and user fees. Depending on the shared good, club participants can be firms, nations or individuals. For intergenerational club goods the required toll must account for crowding and depreciation losses that a visit imposes at the margin on current and future members. Depreciation due to utilization arises when a current visit affects the quality of the club good now and into the future. Users who visit more frequently pay more in total tolls but pay the same toll per visit.

Thus clubs are able to account for differences in tastes by monitoring visits and charging for each visit based on the associated costs imposed on the membership. If, for example, a visit causes a great deal of depreciation for current and future users, then the toll must be sufficiently high to reflect these losses. Visitors who visit early in an intergenerational club good's lifetime may have to pay relatively large fees for any resulting deterioration of the club good, insofar as any depreciation will affect a large number of subsequent generations and members. As the intertemporal component of the toll rises, individuals will be dissuaded from visiting, thus preserving the good. Toll proceeds are earmarked to maintain and to provide the club good, passed among the generations of members. If the tolls are properly designed, then tolls can finance the club good without the need for outside intervention. Clubs can be owned and operated by members (such as sovereign nations) for their own well-being.

One generation of members can reimburse an earlier generation's investment through equity shares, sold as the club good is transferred between generations. The value of these equity shares depends on the residual value of the club good. If a generation were myopic and ran down the club good's value through depreciation and collected tolls that did not reflect this depreciation, then the myopic generation would receive less in payments to support its retirement when the club asset is traded to the next generation (Sandler 1982). In such a club arrangement the current generation's actions are tied to the future consequences, thus motivating it to far-sighted behaviour. If the club investment were instead raised by debt, then the club's ability to repay its loan would depend on it collecting sufficient tolls to offset any depreciation through maintenance. The ability to refinance the loan between generations depends directly on the residual worth of the shared good—the collateral on which the debt is drawn. When a generation behaves myopically, less money can be raised during refinancing, and hence that generation is made to shoulder the burden of its short-sightedness. In fact, any form of leveraged financing of the club good would provide incentives for the current generation to collect the proper tolls. Intergenerational clubs represent a "private" means for a collective to internalize intergenerational externalities in the form of crowding and depreciation due to utilization.

As an example of an intergenerational club good, consider the Great Barrier Reef off the coast of Queensland, Australia. Visitors to the reef can

be charged a user fee that reflects a visit's crowding effects and its long-run impact on the health of the reef. If these tolls are properly managed to internalize the externality to current and future generations, the visitation rate will be duly restricted to address the intergenerational concerns. The same arrangement can be applied to protect transnational parks (such as game reserves) and historical monuments (such as the Taj Mahal or the Egyptian pyramids). The management of tropical forests for ecotourism can also benefit from the application of club theory. Even population decisions and traffic control in cities can be decided with the help of the theory of intergenerational clubs. Perhaps the ultimate example of an intergenerational club is "spaceship earth", where membership is the world's changing population.

In passing an intergenerational club asset from an old generation to a new generation, the selling of the asset to the next generation helps determine pension assets. These pension revenues will be higher if a generation properly looked after a club good, thus providing motivation for far-sighted behaviour.

Other institutional considerations

When exclusion is not feasible, as in the case of some purely public intergenerational goods, a club arrangement is not an institutional alternative. For chlorofluorocarbon (CFC) reduction the resulting protection of the ozone layer yields benefits that cannot be withheld from nonpayers, now or into the future. Supranational structures (such as international organizations or treaties) intended to correct for the market failure associated with intergenerational public goods must adjust for a number of considerations. First, they must include an intergenerational perspective if the interregional linkage is to address both the spatial and temporal externalities. This intergenerational perspective may be fostered by including overlapping generations of young, middle-aged and old among the decision-makers (John and Pecchenino 1997). As the lifetimes of generations are lengthened by better medicine and nutrition, more generations will overlap at any one time and this can support greater intergenerational awareness.

Second, there is a need for long-lived institutional structures that can take and maintain an intergenerational perspective. Churches, for example, have been particularly adept at passing down religious doctrines from one generation to the next. A common concern (for example, the fear of hell) united generations and drew them together in a similar pursuit. As culture these

church doctrines represent intergenerational public goods. To be effective these institutions must be sufficiently flexible to allow for evolution as generational tastes change over time.

Third, effective institutions for providing intergenerational public goods must supply the current generation with a sufficiently large share of the benefits so that they are properly motivated to act. Finally, there is less need for a formal institutional arrangement when the current generation's share of the public good's benefits is sufficiently large. If the institutional structure providing the public good can remain "loose" or unstructured, then this will economize on transactions costs. A structure is loose if there is no need for an enforcement mechanism, decisions are unanimous, meetings are infrequent and participants' autonomy is preserved (Sandler 1997). By economizing on transactions costs, these structures can then be viable because transactions benefits do not have to be very large to justify the institution.

In the case of ozone depletion, the benefits to the current generation and its immediate descendants were sufficiently large to balance the associated costs, so the current generation initiated drastic cuts in CFC use. The Montreal Protocol and its subsequent amendments to curb CFCs required little in the way of enforcement insofar as nations viewed the associated net benefits from participating as positive. Meetings on the protocol were infrequent and ad hoc. For acid rain the spatial weights relating emissions to depositions meant that the lion's share of a country's emissions befouled its own territory. This realization provided the right incentives to frame a treaty to curb sulphur emissions. If, analogously, a sufficient temporal share of the benefits from providing an intergenerational public good is specific to the current generation, then this bodes well for an action being taken. Any action that can increase the current generation's perceived share of the gain from providing an intergenerational public good will motivate its provision.

While the current generation's share of the benefits appears large from curbing CFC emissions, for which the immediate health threat from enhanced ultraviolet radiation exposure is experienced today, this is not necessarily the case for global warming, for which the adverse effects might not be noticeable for decades. This suggests that the global warming problem does not have the appropriate incentives from an intergenerational viewpoint to ensure proper action. Efforts to resolve uncertainty regarding the benefits associated with an intergenerational public good may increase the current generation's perceived share of benefits by more adequately identifying the immediate gains from an action and, as a consequence, motivate action.

Finally, consider the promotion of sustainable development where efforts are made to maintain the opportunities provided to the next generation (Solow 1986; Toman, Pezzey and Krautkraemer 1995). If the current generation is to form far-sighted transnational agreements, then it must perceive a high share of the resulting benefits. When today's generation has a better understanding of the losses associated with its decisions, its awareness of the ensuing benefits and costs can be fostered. This awareness can be furthered by instituting a change in national income accounting so as to include depreciation to the natural capital stock. Efforts to educate the public about the environmental consequences of today's actions can promote altruism to future generations and, consequently, should bolster sustainable development.

Conclusion

The strategic interaction between generations differs from that within generations. If an intergenerational public good yields benefits that spill over borders and generations, then policies designed to correct for just spatial transnational externalities may worsen the misallocation of resources. This is especially the case if the public activity provides positive near-term benefits and negative long-run costs. Moreover, the natural sequencing of generations gives the present generation a potential first-mover advantage. In a suggestive interregional example, a backward-looking region is depicted as abiding by a leader-follower model in which the current generation relies on the next generation, while a forward-looking region is represented as adhering to Nash behaviour with the current generation applying altruism towards future generations. The final outcome is that the forward-looking region assumes a larger burden than the backward-looking region for providing intergenerational public goods—an outcome that bodes poorly for environmental treaties involving world-wide pollutants.

Actions to increase the perceived share of the intergenerational public good benefits going to the current generation will motivate it to provide the good. Transnational linkages that achieve far-sighted solutions are facilitated if efforts to promote intergenerational awareness are successful for all participants of the linkage. Policies that increase the awareness of only some participants will result in lopsided outcomes where the burden of the intergenerational public good is shouldered by the far-sighted nations. If institutional linkages for providing intergenerational public goods can be kept loose or unintegrated, then transactions costs are economized, and this promotes the institution of the linkage. This looseness can be achieved if the

current generation within each participant perceives significant generation-specific benefits.

Much research remains to be done on intergenerational public goods. For example, more work is needed on the issue of discounting (Doeleman and Sandler 1998). A more complete analysis is also required for representing strategic behaviour among generations. Yet another extension would examine the role of income redistribution policy between and within generations as a means for promoting public good provision.

Appendix 1

Basic model

This appendix describes the basic model used in the second section of the chapter. An individual's utility function is depicted as

$$1a.\quad u^{ijr} = u^{ijr}\left(y^{ijr},\ q\right), \qquad i \in \Omega_{jr},\ j = 1,\ 2,\ 3 \text{ and } r = 1,\ 2.$$

Each of these utility functions is assumed to be strictly increasing, quasi-concave, and twice differentiable. The total quantity of the private good produced during period j, denoted by Y_j, must equal the amount consumed during the j^{th} period, so that

$$2a.\quad Y_j = \sum_{r=1}^{2} \sum_{i \in \Omega_{jr}} y^{ijr}$$

for $j = 1, 2, 3$. In equation 2a the y^{ijr} terms represent the i^{th} individual's consumption of the private good during period j in region r. These individual consumption amounts are summed over the individuals alive during period j in a given region and then over the regions for each period. The multiregional, multiperiod production of the private good is

$$3a.\quad Y = \sum_{j=1}^{3} Y_j$$

or the sum of the production amounts in the three periods. A multiperiod transformation constraint for the two-region economy indicates how a given amount of resources can be transferred between the two production activities:

4a. $F(Y, q) = 0,$

where the multiperiod supply of resources is suppressed. This function is strictly increasing and strictly convex in its arguments to assure that first-order conditions are sufficient for a maximum.

For intergenerational Pareto efficiency the associated Lagrangean expression, L, is:

$$L = u^{111}(y^{111}, q) + \sum_{r=1}^{2} \sum_{j=1}^{3} \sum_{i \in \Omega_{jr}} \lambda^{ijr}\left[u^{ijr}\left(y^{ijr}, q\right) - k^{ijr}\right] - \sigma F\left(\sum_{j=1}^{3} Y_j, q\right),$$

where the sum over i in the second term on the right-hand side excludes the first individual. The λ's and σ are undetermined Lagrangean multipliers, while the k expressions are constant levels of utility. Maximization of the Lagrangean with respect to the y^{ijr} expressions and q yields the first-order condition in (AR1), after simplification to eliminate the Lagrangean multipliers:

AR1. $$\sum_{r=1}^{2} \sum_{j=1}^{3} \sum_{i \in \Omega_{jr}} MRS_{qy}^{ijr} = MRT_{qy}.$$

In equation AR1 the *MRS* expressions represent the marginal rate of substitution of the intergenerational public good for the private good. The marginal rate of substitution is the ratio of marginal utilities of the two goods and indicates the *marginal benefit* or value, in terms of the private good, that an individual derives from the intergenerational public good. From left to right, the superscripts on the *MRS* correspond to the individual, the period and the region. On the right-hand side of equation AR1 the marginal rate of transformation (*MRT*) of the public good for the private good denotes the ratio of marginal costs of the two goods.

Appendix 2

Awareness rules AR2, AR3, and AR4

The three additional awareness rules are as follows:

AR2. $$\sum_{r=1}^{2} \sum_{i \in \Omega_{1r}} MRS_{qy}^{i1r} = MRT_{qy},$$

AR3. $$\sum_{j=1}^{3} \sum_{i \in \Omega_{jr}} MRS_{qy}^{ijr} = MRT_{qy}^{r}, \qquad r = 1, 2$$

AR4. $$\sum_{i \in \Omega_{1r}} MRS_{qy}^{i1r} = MRT_{qy}^{r}, \qquad r = 1, 2$$

where Ω_{1r} is the current generation in region r for AR2 and AR4. The superscript on *MRT* denotes the region.

Notes

1. On transnational public goods, see, for example, Barrett (1993), Bryant (1995), Cornes and Sandler (1996, chapters 17–18), Helm (1991), Murdoch and Sandler (1997), Runge (1993), Sandler (1992, 1996, 1997, 1998) and Sandler and Sargent (1995).

2. The following papers consider intergenerational public goods: Amsberg (1995), Bromley (1989), Doeleman and Sandler (1998), John and Pecchenino (1994, 1997), John and others (1995) and Myles (1997).

3. Recent articles on sustainability include Buiter (1997), Doeleman and Sandler (1998), Howarth (1997) and Toman, Pezzey and Krautkraemer (1995). Solow (1986) distinguishes three types of capital: humanmade, human and natural. For weak sustainability the overall capital stock must be maintained, so any reduction in natural capital must be compensated by an increase in the other kinds of capital. In contrast, natural capital stocks cannot decline when satisfying strong sustainability.

4. This criterion applies a zero discount rate so as to treat benefits to each generation equally. For very long-lived projects this implied that the discount factor of unity is in the spirit of Heal's (1997) call for proportional discounting that places more value on future benefits.

5. The underlying Lagrangean is the same form as that in appendix 1 except that only the utility levels of the first generation are held constant.

6. The transformation function is now region specific and denoted by $F^r(Y^r, q^r) = 0$, where Y^r represents the multiperiod production amount for the private good and is summed over the three periods. Thus Y^r is the multiperiod sum of Y_j^r, which equals the sum of y^{ijr} over just the jth generation, while q^r is the intergenerational public good in period 1 in region r.

7. The underlying social welfare function is assumed to be utilitarian, which consists of a simple sum of the relevant individuals' utility functions.

8. In figure 1 the slope of an iso-welfare curve for region 1 is

$$\left(MRT^{1}_{qy} \Big/ \sum_{i \in \Omega_{11}} MRS^{i11}_{qy}\right) - 1.$$

If this equation is set equal to zero, then AR4 results.

9. In figure 2 the Nash path for region 2 is drawn flatter than the 45 degree line, while the Nash path for region 1 is drawn steeper than the 45 degree line. If both goods are normal with a positive income elasticity less than one, then these slopes result and the Nash equilibrium is unique and stable (Cornes and Sandler 1996).

10. The first generation's multiperiod transformation is denoted by

$$F^{1}_{E}\left(y^{11}_{E} + y^{12}_{E},\ q^{11}_{E} + q^{12}_{E}\right) = 0,$$

while the second generation's transformation function is given by

$$F^{2}_{E}(y^{22}_{E}, q^{22}_{E}) = 0$$

11. The Lagrangean for Eastern generation 1 is

$$V^{1}_{E}\left[u^{11}_{E}\left(y^{11}_{E},\ q^{11}_{E} + q^{11}_{W}\right),\ u^{12}_{E}\left(y^{12}_{E},\ q^{11}_{E} + q^{12}_{E} + q^{22}_{E} + q^{11}_{W} + q^{12}_{W} + q^{22}_{W}\right)\right] - \sigma F^{1}_{E}(\bullet),$$

and the Lagrangean for generation 2 is

$$V^{2}_{E}\left[u^{22}_{E}\left(y^{22}_{E},\ q^{11}_{E} + q^{12}_{E} + q^{22}_{E} + q^{11}_{W} + q^{12}_{W} + q^{22}_{W}\right)\right] - \psi F^{2}_{W}(\bullet).$$

12. Income disparity between the East and West also explains some of the differences in environment-supporting behaviour, but the strategic differences introduced here represent influences that go beyond income disparity to explain alternative environmental policies.

13. This condition is

$$\sum_{i \in \Omega_{1r}} \left(\alpha^{r} MRS^{i1r}_{xy} + \beta^{r} MRS^{i1r}_{zy}\right) = MRT^{r}_{qy},\ r = E, W.$$

14. The intergenerational optimality condition for full awareness is

$$\sum_{j=1}^{3} \sum_{i \in \Omega_{jr}} \alpha^{r} MRS^{ijr}_{xy} + \sum_{r=E,W} \sum_{j=1}^{3} \sum_{i \in \Omega_{jr}} \beta^{r} MRS^{ijr}_{zy} = MRT^{r}_{qy}.$$

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