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AN INTRODUCTION TO SPATIAL DISCOUNTING

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ABSTRACT. Research on the valuation of environmental externalities shows that decision makers tend to discount not only over time but across space. Just as time discounting has implications for intergenerational equity, geographical or spatial discounting has implications for intragenerational equity. Similarly, just as positive time discount rates are warranted by positive net rates of growth of the capital stock, positive spatial discount rates may be warranted by the fact that environmental (or other external) effects of economic activity are diffused at positive rates. This paper introduces the notion of spatial discounting and explores its welfare implications through a simple diffusion model.

1. DISCOUNTING SPACE AND THE VALUATION OF ENVIRONMENTAL EXTERNALITIES

Two separate literatures in environmental economics offer prima fácie evidence that decision makers treat future and distant externalities in a symmetrical way. One concerns the empirical relation between per capita income and various indicators of environmental quality: the 'Environmental Kuznets Curve' (EKC). The other concerns the valuation of spatially differentiated nonmarketed environmental goods and services. Both literatures show that decision makers give less weight to geographically distant effects than to neighborhood effects. Just as people have preferences over time, they have preferences over space also. Moreover, just as preferences over time can be summarized in a rate of time preference and implemented through application of a time discount rate, so preferences over space can be summarized in a rate of geographical preference and implemented through application of a spatial discount rate

The evidence from the EKC literature is indirect. Empirical work on the relation between per capita income and expenditure on environmental public goods has shown that local environmental quality has some of the characteristics of a luxury good. There exists an empirical relationship between per capita

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income and some measures of environmental quality that is similar to the inverted U-shaped Kuznets relation between income and income inequality. As per capita incomes rise, some measures of environmental quality first deteriorate and then improve after some point (Grossman and Krueger, 1993, 1995). A Kuznets relationship has since been found between per capita income and emissions of sulphur dioxide (Seldon and Song, 1994; Shafik, 1994; Panayotou, 1995, 1997), particulates and dark matter (Grossman and Krueger, 1993), nitrogen oxides and carbon monoxide (Seldon and Song, 1994), and carbon dioxide and CFCs (Cole, Rayner, and Bates, 1997).

In addition, Grossman and Krueger (1995) found a Kuznets relation involving various indicators of water quality, including faecal coliform, biological and chemical oxygen demand, and arsenic. Panayotou (1995) and Antle and Heidebrink (1995) found the same general relation between deforestation rates and per capita income, whereas Coles, Rayner, and Bates (1997) extended it to include energy use and traffic volumes. However the evidence does not always run in the same direction. Volumes of municipal waste have been found to be a strictly increasing function of per capita income (Shafik, 1994; Cole, Rayner, and Bates, 1997) and there are conflicting results on solid particulates (Grossman and Krueger, 1995) and carbon dioxide (Shafik, 1994).

What is interesting about the range of evidence is that the EKC relation does not appear to hold for external effects that are distant in either time or space (Arrow et al., 1995; Ansuategi, Barbier, and Perrings, 1998). It implies that people are more concerned about the short-term environmental impacts of economic activity in their own neighborhood than they are about long-term impacts occurring at geographically distant locations. They are both myopic and parochial, discounting both time and space at positive rates. There is prima facie evidence that both rates depend on income. That is, the rate at which people discount the distant and future effects of local consumption varies with per capita GDP.

The evidence from the valuation literature is more direct. There are now numerous attempts to value geographically and temporally distributed environmental amenities and disamenities. The oldest method of valuing geographically distributed nonmarketed amenities—the travel cost method—uses the same techniques as for marketed goods and services delivered at different locations. That is, the value of distant amenities is approximated by the private cost of travel to those amenities, and the difference in the value of distinct sites is just the difference in the cost of travel. Development of random utility models extends the approach to allow estimation of the probability of visiting sites when geographical location is one of a number of site attributes (Smith, 1997), where the decision to visit sites is repeated or sequential (Morey, Shaw, and Rowe, 1991), or where sites may be aggregated (Parsons and Needelman, 1992).

An analogous approach focuses on the valuation of locally undesirable land uses or on averting behavior. This makes it possible to estimate the willingness of people to pay to maintain their distance from disamenities, and so enables estimation of the value of alternative locations for such disamenities (Smith and

Desvouges, 1986; Smith, 1997). Such methods make it possible to derive an expression for people's preferences for consumption over space. Hannon (1987) conjectured that the opposition to undesirable land uses and approval of desirable land uses varies inversely with distance from the decision maker's own geographic location. There is certainly evidence of the effect of undesirable land uses on proximate property values and of people's willingness to pay for increased distance from undesirable land uses (Farber, 1998). Typically, property values are lower the closer properties are to the site of a proposed or actual undesirable land use (landfills, waste incinerators, nuclear and coal fired power plants). This implies positive willingness to pay for distance from such land uses. Mitchell and Carson (1986) showed that the willingness of people to pay to distance themselves from proposed coal fired or nuclear power plants was higher the closer they were to a proposed site. Hannon (1994) used these data to find an exponential rate of decline of willingess to pay of about two percent per mile for coal and about four percent per mile for nuclear plant proposals. Although this is analogous to a spatial discount rate there are still very few attempts to estimate the spatial discount rate implicit in willingness to pay. To date we are aware of only one study specifically designed to estimate the spatial discount rate implicit in individual valuations of spatially differentiated environmental disamenities, that of Steininger (1997).

First, this paper considers the role of spatial discounting in the allocation of resources with geographically distributed nonmarket effects. We think of these as environmental effects, but they may include any geographically distributed effects whose impact depends on distance. This includes various field effects such as demonstration effects and fashion effects. It includes boundary effects of which the development of ghettos or planning blight are common examples. It also includes contagious effects such as the spread of communicable diseases. The common factors in all of these effects are that (a) they are external to the market transactions that cause them, and (b) their strength generally depends on distance from the source. They are also widespread, of considerable significance, and rarely analyzed. We identify the rate of decay in such effects as the basis for spatial discounting and identify a warranted spatial discount rate. By analogy with the time discounting literature (Scheraga and Sussman, 1998), the warranted spatial discount rate is that which exactly compensates for the effects of distance. It may be thought of as an ethically neutral rate.

We then consider the link between spatial discounting and consumption suggested by the EKC and valuation literatures. The notion that time discount rates among the poor may be driven by consumption needs (Perrings, 1989) is empirically tested in a number of case studies (Pender, 1996; Holden, Shiferaw, and Wik, 1998). These show that the poor effectively discount the future at higher rates than the rich. There are no studies of the link between parochialism and consumption. However, we are less concerned about the precise empirical relation between spatial discount rate and consumption than about the implications of a relation of some sort for the warranted or ethically neutral rate.

The paper is organized in five sections. In the next section we consider the basis for spatial discounting, and use this to discuss the notion of the warranted rate. In Section 3 we present a simple model of the role of spatial discounting in the decision process where for ease of exposition we ignore time. In Section 4 we use the model to explore the implications of the existence of a relation between the spatial rate of discount, the geographical spread of effects, and the level of consumption. In the final section we present our conclusions.

2. THE BASIS FOR GEOGRAPHICAL PREFERENCES

At the beginning of this century the debates on the ethics of time discounting focused on the problem of utility discounting and its moral implications. Of particular concern was the notion that preferences over time reflect not only individual or collective impatience to consume, but also a judgment about the responsibility that today's decision makers have for the future consequences of their actions. Positive rates of time preference were taken to imply that members of the current generation choose to bear limited responsibility for any harm they might inflict on future generations. This viewpoint motivated the ethical objections to discounting raised in the past by Ramsey, Pigou, Harrod, Myrdal, and Daly among others. By analogy, positive rates of geographical preference—the spatial equivalent of time preference—reflect not only a preference for consumption at home, but also a judgment about the responsibility that local decision makers have for the distant consequences of their actions. Positive rates of geographical preference imply a preference for local consumption relative to distant consumption so they indicate that the relative deprivation of distant members of the present generation may be a locally desirable outcome. The reference point for evaluating consumption flows that are separated in space and time is consumption 'here and now.'

The utility rate of time discount defines the rate at which present consumption is preferred to future consumption. By analogy, the utility rate of spatial discount captures individuals' preferences for consumption at a given location relative to consumption at some distance from that location. This may refer to their own consumption or to consumption by other members of the present generation. As is the case for time discounting, positive rates of geographical preference imply an ethical judgment about the responsibility of the decision maker for the welfare of others. More particularly, positive rates of geographical preference imply that people care more about those who are close to them than about those who are distant. The picture is obviously complicated by familial, tribal, ethnic, linguistic, or political affiliation (as it is with time discounting). People tend to care more about their family, friends, and neighbors than about others. Furthermore, they may be more tightly constrained in their ability to implement the concern they have for the well-being of those outside of their own location. All that is implied by a positive rate of geographical preference is that consumers place greater weight on 'home' interests than on 'outside' interests. 'Home' in this case may be the household, village, city, region, or nation.

Formally, we denote consumption of those who 'live at' or 'identify with' location h as C_h. If we can identify a utility function, $U(C_0,\dots,C_{h-1}, C_{h'},C_{h+1},\dots,C_n)$, in which well-being depends upon consumption at each of n locations, U_h defines the marginal utility of consumption at location h, and U_{h+1} defines the marginal utility of consumption at location $h + 1$. C_{h+1} may refer to consumption by the decision maker at location $h + 1$ or it may refer to consumption by those who 'live at' or 'identify with' location $h + 1$. This last case is parallel to the intertemporal distinction between consumption by people living now and consumption by people living in the future. Holding consumption at all locations other than h and $h + 1$ constant, it is possible to describe an interlocational indifference curve in the C_h,C_{h+1} plane, the slope of which describes the rate at which decision makers prefer consumption at h relative to consumption at $h + 1$. This defines the rate of geographical preference. The higher the rate the more home-centered or 'parochial' the decision maker.

A rate of time or geographical preference may be warranted if the future or distant effects discounted at that rate may be fully compensated: that is, those effects are valued at their marginal social cost. Utility rates of time discount are argued to be ethically neutral or sustainable only if they do not exceed the net growth rate of the capital stock (Mäler, 1995; Weitzman, 1994). The warranted rate of geographical preference is analogous to this. Positive utility rates of geographical preference are ethically neutral only if they do not exceed the rate at which the geographically dispersed effects of local activity decay with distance. In the case of environmental effects this may be thought of as the rate at which they are diffused or filtered out by the environment.

In what follows we assume that spatial effects decay smoothly, continuously, and monotonically. This is a strong assumption, though no stronger than the analogous assumptions made about rates of growth or regeneration, depreciation or decay. In reality many spatial and temporal effects are not smooth. There are cases where the effects of current activities are not diffused over time or space. For example, biomagnification can lead to the concentration of effects at points distant in both time and space. Emissions into rivers can lead to the concentration of pollutants in downstream sinks. Mixing may mean that air emissions can affect all locations equally. However, for the most part the adverse effects of local activity tend to be a decreasing function of distance from the source.

Environmental effects are transmitted through the flows of mass and energy in biogeochemical cycles. All such flows involve some energy or material cost. That is, they involve losses in transmission. For example, not all of the sulphur dioxide that is emitted from Britain lands in Norway and Sweden, some drops out over the North Sea. Not all the toxins entering a food chain are consumed by species at the top of the chain, some are transformed and excreted by those at an intermediate point in the chain. There are various determinants of the filtering effect of ecosystems on flows of mass and energy through the system, and not all effects are filtered at the same rate. In reality, the decay of effects is neither smooth, continuous nor monotonic. Nonetheless, it is useful to think in terms of a diffusion rate that is uniform at least within the boundaries of a given ecosystem.

Consider a simple case. Let the concentration of some pollutant S depend upon a single space coordinate h and upon time t. That is, $S = S(h,t)$. The classic one-dimensional theory of diffusion holds that the transport of matter across a unit normal area in a unit time is proportional to the gradient of the concentration of matter. This in turn depends on the diffusivity of emissions. In the special case of a constant emission rate we have

$$dS / dt = d / dh(DdS / dh)$$

in which D is the (constant) diffusion coefficient. If the concentration of particles at the origin is $S(0,0)$, then the general solution is

$$S(h,t) = \frac{S(0,0)}{2(\pi Dt)^{1/2}} \mathrm{e}^{-h^2/4D_t}$$

Although this is merely one possible description of the diffusion process, the results can be generalized to include other forms of diffusion.

We are interested in the warranted spatial rate of discount associated with this form of diffusion. The higher the actual rate of discount, the more the distant costs of local emissions are ignored. Intuitively, effects that are discounted at the rate at which the pollutant diffuses will be neutral in their effect. Discount rates that exceed the rate of diffusion imply that the distant costs of local emissions will not be fully taken into account. In this particular case the discounted cost of emissions at the origin is $S(0,0) \exp - (\psi h + \rho t)$ where ψ and ρ denote the space and time rates of discount, respectively. The warranted spatial rate of discount is that at which the discounted cost of $S(0,0)$ is equal to the actual cost of $S(h,t)$. It is found from

$$S(0,0)e^{-(\psi h+\rho t)} = \frac{S(0,0)}{2(\pi Dt)^{1/2}} \mathrm{e}^{-h^2/4Dt}$$

Solving for the spatial rate ψ we have

$$\psi = \frac{h}{4Dt} - \frac{1}{h}\left[\ln\left(\frac{1}{2(\pi Dt)^{1/2}}\right) + \rho t\right] \tag{1}$$

This enables us to identify the elements of the diffusion process that warrant the spatial discounting of the environmental consequences of emissions. A key element is the term $1/h$. This may be defined as the inverse of the geographical spread of ecosystems, that is, the geographical amplitude of the 'life cycle' of those systems. This is the distance over which the disturbance has an effect. For environmental effects it depends on the specific properties of landscape topography, hydrology, climatic conditions, the ecotrophic level, and the dynamic characteristics of the disturbance.

If the effects of some activity are limited in extent to a patch within the biome, the implications for spatial and temporal discounting are very different than if they affect the whole of the contiguous forest. It may be that the inverse of the geographical amplitude of the longest cycle, that of the biome, tells us little that is useful for economic decision making. But if the decision maker's remit extends to the biome rather than the stand we would expect the spatial discount rate applied to be lower. That is what Equation (1) states. If the decision maker is not to ignore the environmental consequences of their actions, the rate of geographical preference should be lower the larger the distance over which emissions have a positive effect. Put another way, the neutral spatial rate of discount will be smaller the greater the distance over which pollution has an effect.

Two other elements of the problem are important: the rate of diffusion and the time discount rate. The first two terms in the square brackets capture the effect of the diffusion process. To get a sense of the balance between the rate of diffusion D and the neutral spatial rate of discount, differentiate Equation (1) with respect to D and simplify, this yields

$$\frac{\partial \psi}{\partial D} = \frac{1}{2D}\left[\frac{1}{h} - \frac{h}{2Dt}\right] \tag{2}$$

The sensitivity of the neutral spatial discount rate to the rate of diffusion will fall as the rate of diffusion rises. However, Equation (2) also shows that whether the spatial rate of discount increases or decreases with the rate of diffusion depends on the geographical spread of effects h relative to their decay over time Dt. Where h is small relative to Dt (e.g., for localized but short-lived effects), the neutral spatial rate of discount rises as the rate of diffusion rises. Where h is large relative to Dt (e.g., for dispersed long-lived effects) the neutral spatial rate of discount falls as the rate of diffusion rises. The relation between the spatial and time rates of discounts is less ambiguous. Differentiating Equation (1) with respect to ρ reveals a direct trade-off with the neutral spatial rate of discount ψ, that is, the spatial rate falls as the time rate rises.

3. GEOGRAPHICAL PREFERENCE AND THE WARRANTED SPATIAL DISCOUNT RATE

To identify the warranted spatial rate of discount in decisions involving geographically distributed environmental effects, we consider a simplified spatial process. In the general case the spatial transmission of effects takes time. Their impact at any distance reflects both temporal and spatial processes—effects are subject to both decay (depreciation) and the results of various environmental filters. Furthermore, in the general case the diffusion of effects depends both on the properties of the environment itself, and on human efforts to abate, filter, or otherwise contain, or reduce the harmful effect of emissions. However, to simplify matters, we abstract from both the intertemporal aspect of the problem and the role of abatement or filtration. This enables us to focus more clearly on the question of spatial discounting.

Utility at location h is described by the function

$$U(h) = U[C(h), S(h)]$$

where $C(h)$ denotes consumption at h and $S(h)$ denotes pollution concentrations at h. We assume that $U_c > 0$, $U_S < 0$, $U_{cc} < 0$, and $U_{SS} < 0$. Assuming that the geographic horizon of decision making is infinite, the decision problem may be written

$$\text{Max}_C \int_{h=0}^{\infty} \mathrm{e}^{-\psi h} U\big[C(h), S(h)\big] dh$$

subject to

$$\frac{dS}{dh} = f\big[C(h), S(h)\big]$$
$$C(0), S(0) \text{ given}$$

This describes the change in pollution density as distance increases. Pollution density increases with the level of consumption at each location and falls(or increases) with the neutralizing (or magnifying) effects of spatially defined environmental processes. For present purposes we assume that $f_c > 0$,$f_S < 0$, $f_{cc} < 0$, and $f_{SS} < 0$. Specifying the problem in this simple form helps to make the relation between optimal levels of consumption and the diffusion process transparent.

The Hamiltonian for the problem is

$$H = U(C, S)\, \mathrm{e}^{-\psi h} = \lambda f(C, S)$$

and the maximum condition and adjoint equation in the first-order necessary conditions are

$$U_c \mathrm{e}^{-\psi h} + \lambda f_c = 0$$
$$\frac{d\lambda}{dh} = -U_S \mathrm{e}^{-\psi h} - \lambda f_S$$

in which $f_c > 0$ defines the marginal damage in terms of pollution concentrations of consumption and $f_s > 0$ defines the marginal rate of change in the stock of the pollutant—the rate of diffusion of the pollutant. To identify the role of the spatial discount rate in the control of the system, we differentiate the maximum condition with respect to location to obtain

$$U_{cc} \mathrm{e}^{-\psi h} \frac{dC}{dh} - \psi U_c \mathrm{e}^{-\psi h} + \frac{d\lambda}{dh} f_c + \lambda f_{cc} \frac{dC}{dh} = 0$$

Using the adjoint equation and bearing in mind that $\lambda = -U_c e^{-\psi h}/f_c$, this yields the following expression for ψ

$$\psi = f_s - \frac{U_s}{U_c} f_c + \frac{dC}{dh}\left(\frac{U_{cc}}{U_c} - \frac{f_{cc}}{f_c}\right) \tag{3}$$

Equation (3) is an efficiency condition. It defines the spatial rate of discount that is warranted by the physical properties of the system given the preferences of the decision maker. It depends on the marginal rate of diffusion of pollution f_s, the marginal pollution damage of consumption f_c, the marginal rate of substitution of consumption for pollution U_s/U_c, and the rate of change in the net marginal benefits of consumption. The last of these is given by the difference between the rate of change in the marginal utility and the marginal environmental damage of consumption.

Consider this further. First, let us define

$$\eta_u = -\frac{U_{cc}}{U_c} C > 0 \tag{4}$$

and

$$\eta_f = -\frac{f_{cc}}{f_c} C > 0 \tag{5}$$

to be the elasticity of the marginal utility of consumption and the elasticity of the marginal environmental damage of consumption, respectively. Let us also define

$$\mu_c = \frac{dC}{dh}\frac{h}{C} \tag{6}$$

to be the spatial elasticity of consumption. Equation (6) defines the sensitivity of the level of consumption to a change in the location of consumption. If consumption falls with increasing distance from 'home', as we assume here, it will be negative. μ_c may be thought of as an index of the geographical specificity of consumption. If the spatial elasticity of consumption is very low, consumption is geographically specific and vice versa. That is, a low spatial elasticity of consumption implies either a strong preference for 'home' consumption or limited scope for 'distant' consumption. By contrast, a high spatial elasticity of consumption implies a weak preference for 'home' consumption.

Given Equations (4), (5), and (6), Equation (3) can now be written

$$\psi = f_s - \frac{U_s}{U_c} f_c - \frac{1}{h}\mu_c(\eta_u - \eta_f) \tag{7}$$

We are interested in the relation between the warranted spatial rate of discount and the rate at which environmental effects are filtered out or diffused within the system. Two propositions follow.

PROPOSITION 1: *Given* $\mu_c < 0$ *the warranted spatial rate of discount* ψ *will be greater than the diffusion rate* f_s *if the elasticity of marginal utility of consumption is greater than the elasticity of the marginal environmental damage of consumption.*

That is, a sufficient condition for the warranted rate to be greater than the capacity of the environment to absorb spatial effects is that the marginal utility of consumption increases at a higher rate than the marginal damage cost of consumption. Because $U_s < 0$, $U_c > 0$, and $f_c > 0$ the term $-f_cU_s/U_c$ is positive. The term $-\mu_c[\eta_u - \eta_f]$ will be positive if $\eta_u > \eta_f$.

PROPOSITION 2: *Given* $\mu_c < 0$ *the warranted spatial rate of discount* ψ *will be less than the diffusion rate* f_s *only if the elasticity of marginal utility of consumption is less than the elasticity of the marginal environmental damage of consumption.*

That is, a necessary condition for the warranted rate to be less than the capacity of the environment to absorb spatial effects is that the marginal damage cost of consumption is greater than the marginal utility of consumption. Because $-f_cU_s/U_c$ is positive $\psi < f_s$ only if $\eta_u < \eta_f$.

This completes our introduction to the warranted spatial discount rate. With this decision model in mind, we now consider the case implied by the valuation and EKC literatures. This is the case where the spatial discount rate is sensitive to income (or to consumption as a proxy for income).

4. INCOME, CONSUMPTION, AND GEOGRAPHICAL PREFERENCE

As before we abstract from the temporal aspects of the decision maker's problem. We assume that the problem has the following structure

$$\mathrm{Max}_c \int_{h=0}^{\infty} \mathrm{e}^{-\psi(C)h} U\big[C(h), S(h)\big] dh$$

subject to

$$\frac{dS}{dh} = f\big[C(h), S(h)\big]$$
$$C(0), S(0) \text{ given}$$

in which $U(.)$ and $f(.)$ have the same form as before. This differs from the problem discussed in Section 3 only in that the rate of geographic preference is now assumed to be a function of consumption C. Consumption is taken as a proxy for income. Therefore, implicitly we assume a savings function that allows consumption to increase with income. For the most part we assume that the spatial discount rate falls when consumption rises, that is, $\psi_c < 0$ and $\psi_{cc} > 0$. However, we do consider the case where $\psi_c > 0$ and $\psi_{cc} < 0$.

The maximum condition and adjoint equations in the first-order necessary conditions for maximizing social utility are now

$$U_c e^{-\psi(C)h} + \lambda f_c - \psi_c h U e^{-\psi(C)h} = 0$$

$$\frac{d\lambda}{dh} = -U_S e^{-\psi(C)h} - \lambda f_S$$

Differentiating the maximum principle with respect to h and using the adjoint equation we have the following expression for the warranted spatial rate of discount

$$\psi = f_s - \left(\frac{f_c U_s + \psi_c U}{U_c - \psi_c hU}\right) + C_h\left(\frac{U_{cc} - \psi_{cc} hU}{U_c - \psi_c hU} - \frac{f_{cc}}{f_c}\right) \tag{8}$$

In Equations (4) and (5) we have defined the elasticity of the marginal utility and pollution damage of consumption to be η_u and η_f, respectively. We also defined the spatial elasticity of consumption to be μ_c in Equation (6). We now define the consumption elasticity of geographical preference to be

$$\eta_\psi = -\left(\frac{U_{cc} - \psi_{cc} hU}{U_c - \psi_c hU}\right)C \tag{9}$$

This enables us to write the warranted spatial rate of discount in the form

$$\psi = f_s - \left(\frac{f_c U_s + \psi_c U}{U_c - \psi_c hU}\right) - \frac{1}{h}\mu_c\left(\eta_\psi - \eta_f\right) \tag{10}$$

This is analogous to Equation (7) and enables us to consider the effect of a relationship between consumption (income) and the spatial rate of discount on the warranted rate relative to the case where $\psi_c = 0$. It also enables us to consider the effect of the geographical spread of environmental effects on the warranted rate.

First, consider the effect of a relation between consumption and the spatial rate of discount on the expression $\frac{f_c U_s + \psi_c U}{U_c - \psi_c hU}$. The value of this expression is sensitive to the sign of ψ_c. If the spatial rate of discount decreases as consumption rises, the effect will be to lower the warranted rate. On the other hand, if the spatial rate of discount increases with consumption, the effect will be to raise the warranted rate.

Second, the effect of a relation between consumption and the spatial rate of discount on the expression $-\frac{1}{h}\mu_c\left(\eta_\psi - \eta_f\right)$ is given by the impact of the level of consumption on the difference between the elasticities of geographical preference and marginal environmental damage $\eta - \eta_f$. Using Equations (9) and (5), note that both numerator and denominator in $\frac{U_{cc} - \psi_{cc}hU}{U_c - \psi_c hU}$ will fall if $\psi_c > 0$, $\psi_{cc} < 0$, and rise if $\psi_c > 0$, $\psi_{cc} < 0$, and that $\frac{U_{cc} - \psi_{cc}hU}{U_c - \psi_c hU} - \frac{U_{cc}}{U_c}$ will be positive (negative) if and only if $\frac{\psi_{cc}}{\psi_c} - \frac{U_{cc}}{U_c}$ is less than (greater than) zero. We summarize this in the following propositions.

PROPOSITION 3: *Given $\mu_c < 0$, if the spatial discount rate falls as consumption increases, ($\psi_c < 0$) consumption growth will cause the warranted rate to fall relative to the rate of diffusion. Conversely, if the spatial discount rate rises as consumption increases, consumption growth will cause the warranted rate to increase relative to the rate of diffusion.*

PROPOSITION 4: *Given $\mu_c < 0$ and $\psi_c \neq 0$, the warranted rate will rise (fall) relative to the rate of diffusion if the consumption elasticity of geographic preference is less (greater) than the elasticity of marginal utility of income.*

Now consider the implications of the geographical spread of environmental effects. From the expression $\frac{f_c U_s + \psi_c U}{U_c - \psi_c hU}$ we see that if $\psi_c < 0$ the warranted rate falls as h rises. In the limit, as $h \to \infty$, $\frac{f_c U_s + \psi_c U}{U_c - \psi_c hU} \to 0$. The effect of h on $\frac{1}{h}\mu_c\left(\eta_\psi - \eta_f\right)$ is less clear (given that h enters both μ_c and η_ψ), but if $C_h \to 0$ as $h \to \infty$, then $\frac{1}{h}\mu_c\left(\eta_\psi - \eta_f\right) \to 0$ as $h \to \infty$. The net effect is that the warranted spatial rate of discount will converge to the rate of diffusion as the geographical spread of effects tends to infinity. The converse of this is that as the geographical spread of effects gets smaller the warranted rate of discount approaches a maximum rate. Once again, we summarize this in the following propositions.

PROPOSITION 5: *If the spatial discount rate falls as consumption rises ($\psi_c < 0$) the warranted spatial rate of discount tends to a maximum ψ_{Max} as the geographic spread of effects tends to zero. Specifically, as $h \to 0, \psi \to \psi_{Max}$ where*

$$\psi_{\text{Max}} = f_s - \left(\frac{f_c U_s + \psi_c U}{U_c}\right) + C_h\left(\frac{U_{cc}}{U_c} - \frac{f_{cc}}{f_c}\right)$$

PROPOSITION 6: *If the spatial discount rate falls as consumption rises ($\psi_c < 0$) and if the marginal effect of distance on consumption C_h tends to zero as $h \to \infty$, the warranted spatial rate of discount tends to a minimum ψ_{Min} equal to the rate of diffusion. Specifically, as $h \to \infty$, $\psi \to \psi_{Min}$ where $\psi_{Min} = f_s$. The marginal rate of diffusion defines the lower bound of the warranted spatial discount rate.*

Finally, we consider the case where the spatial discount rate rises as consumption rises. This is the case where decision makers care less about their effect on distant members of the present generation as their own consumption rises. The EKC literature suggests this is unlikely, and that spatial (and temporal) discount rates may be expected to fall as income or consumption rises (but see Kristrom and Reira, 1996). This said, the relationship between the warranted rate and the spread of effects is surprising.

PROPOSITION 7: *If the spatial discount rate is an increasing function of consumption ($\psi_c > 0$) the warranted spatial rate of discount will tend to a maximum ψ_{Max} as the geographic spread of effects tends to zero, but with a point of discontinuity at $h = \frac{1}{\psi_c}\frac{U_c}{U}$. From Equation (10) at $\psi \to +\infty$ as $h \to \frac{1}{\psi_c}\frac{U_c}{U}$ from above, and $\psi \to -\infty$ as $h \to \frac{1}{\psi_c}\frac{U_c}{U}$ from below.*

This implies that the graph of the warranted spatial discount rate at *h* passes through infinity. It forms two branches of a rectangular hyperbola. The intuition behind this implication is not at all obvious, but may be interpreted as the point of maximum parochial consumption.

5. DISCUSSION AND CONCLUDING REMARKS

It is not surprising that high spatial discount rates have the potential to prejudice the well-being of distant members of the present generation in the same way that high time discount rates prejudice the well-being of members of future generations. Time discount rates above the warranted rate of regeneration or assimilation imply a myopic approach to the management of environmental resources that is potentially dangerous and is certainly inequitable (in intergenerational terms). In the same way, spatial discount rates above the natural rate of diffusion imply a parochial approach to the management of environmental resources that is equally inequitable (in intragenerational terms). Nevertheless, high spatial discount rates may be warranted by high rates of diffusion (or decay) of environmental effects. Where the environmental consequences of emissions are localized and decay quickly, high discount rates may still be ethically neutral in the sense that they appropriately weight the damage to distant members of the present generation resulting from local decisions.

As already noted, the empirical evidence suggests that the relationship between per capita income and various pollutants depends on the timing and the location of the environmental effects of those pollutants. Many atmospheric pollutants first increase and then decrease as incomes rise. However, pollution of drinking water supplies by faecal coliform tends to decline monotonically as per capita incomes rise. Investment in safe sanitation and clean water supplies offers immediate and localized benefits and so tends to be a higher priority than air pollution. Air pollution inflicts costs that are not quite as localized nor as immediate. Accordingly, investment in their control or reduction tends to be deferred by poor countries. At the other end of the spectrum, pollutants whose costs affect only future generations or distant members of the present generation, such as carbon or nuclear waste, tend to increase monotonically as per capita incomes rise (Barbier, 1997). It has been conjectured that this reflects the propensity of decision makers to discount effects that are distant in both time and space, and that the discount rate is a function of per capita income (Arrow et al., 1995; Ansuategi, Barbier, and Perrings, 1998).

Although there is a strong positive correlation between willingness and ability to pay in empirical valuation studies of nonmarketed environmental resources, the evidence on the income elasticity of demand for the range of environmental goods and services involved is not yet conclusive. Seldon and Song (1994) and McConnell (1997) explore the conditions on the income elasticity of demand that give rise to the EKC for atmospheric pollutants. Empirical studies of demand for environmental amenity raise doubts about the notion that environmental quality is in the nature of a luxury good. For example, using data sets generated by a number of European contingent valuation studies, Kristrom and Riera (1996) found income elasticity of environmental improvements to consistently be less than one. Whether environment quality is or is not a luxury good, it is clear that parochialism and poverty are closely linked. Research into the link between time discount rates and poverty shows that people in poverty do indeed discount the future at unusually high rates (Holden, Shiferaw, and Wik, 1998).

In the spatial case, a reduction in consumption may have similar effects. The rate of geographic preference will rise to reflect the importance placed on survival of people nearby, and less weight will be given to the utility of people who are at a greater distance. If the spatial rate of discount is sensitive to income in this sort of way, and particularly if the relation is nonmonotonic, then we may expect to see a relationship between income or consumption and spatially distributed environmental effects that is similar to the EKC.

Finally, we return to the wider implications of spatial discounting. Although we have motivated our choice of a diffusion model by reference to environmental processes, many field, boundary, or contagion effects involve similar processes. Accordingly, the phenomenon has broader implications than those discussed here. Most decisions involving the allocation of public goods involve nonmarketed effects that are implicitly weighted by constituency, and hence implicitly weighted by distance. Social spatial discount rates tend to be reflected in the domain of institutions responsible for public goods. For example, the European principle of subsidiarity specifies that decisions should be taken at the most decentralized level possible. In this case, decentralization, refers to the level at which the external effects of a decision are 'contained' within the jurisdiction of the decision-making body—although this is qualified by the requirement that at the relevant level decision-making bodies should have the capacity to address the problem (see Folmer and Howe, 1991). The principle implies that the geographic and temporal range of institutional responsibility should bear some relationship to the geographic and temporal range of the resources being used. For activities involving very few spatially distributed effects, the principle recommends localized control (Norton and Hannon, 1997; Ehrenfeld, 1993). For activities involving widely distributed effects, the principle recommends commensurately larger institutions. Impacts beyond the legal domain of most institutions tend to be zero-weighted, but efficiency and equity will be enhanced by weighting such impacts to reflect their real consequences. Spatial discounting may be a useful way to approach this issue.

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