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NON-UNIFORM SOCIAL RATES OF DISCOUNT IN NATURAL RESOURCE MODELS: AN OVERVIEW OF ARGUMENTS AND CONSEQUENCES

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ABSTRACT

One of the crucial factors in resource economics is the element of time. In recent years a great many dynamic models have been developed in order to derive optimal decision rules for long-term resource policies. The assessment of the long-term socio-economic net benefits of resource use is however fraught with difficulties due to many uncertainties in models with a long time horizon (e.g., risk, multi-generational tradeoff). In order to take account of the uncertain or hidden effects of a project in a dynamic ecological-economic model one can either try to adjust the costs and benefits of the project at hand or the social rate of discount that is used in the model concerned. In this article the latter approach is adopted in four representative natural resource models pertaining to the environment, the fisheries sector, the forestry sector, and exhaustible resources, respectively. The effects that are internalized in each model relate to the following classes of uncertainty: multiple generations, risk and uncertainty, crowding out effects, and externalities (and intangible effects) of the use of the natural resource. A sensitivity analysis on the implications of a non-uniform social rate of discount is undertaken for these four classes of uncertainties with respect to each of the four models used.

1. A NON-UNIFORM SOCIAL RATE OF DISCOUNT IN ECOLOGICAL-ECONOMIC MODELS

One of the crucial factors in resource economics is the element of time. In recent years a great many dynamic models have been developed in order to derive optimal decision rules for long-term resource policies. The assessment of the long-term socio-economic net benefits of resource use is fraught with

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difficulties due to many uncertainties in models with a long time horizon (e.g., risk, multigenerational tradeoff).

In order to take account of the uncertain or hidden effects of a project in a dynamic ecological-economic model one can either try to adjust the costs and benefits of the project at hand or the social rate of discount that is used in the model concerned. In this article the latter approach is adopted. In previous publications, an extensive literature survey has been made of arguments for and against a varying social rate of discount [1, 2]. The literature revealed that a wide variety of arguments can be found, ranging from intertemporal variation to project specific (and even project component specific) variation of the social rate of discount. All of these arguments will not be repeated in the present article. We simply observe the existence of a diversity of arguments in favor of a varying social rate of discount. In this respect, we discern four main categories of arguments in favor of a non-uniform social rate of discount, viz.,

1. the (intergenerational) equity argument;
2. the uncertainty and risk argument;
3. the financial crowding out argument; and
4. the externalities and intangibles argument.

Each of these four arguments will be discussed very briefly in the next section. Taking for granted the plausibility of these arguments, we will then, in subsequent sections, identify the consequences of using a non-uniform social rate of discount in dynamic ecological-economic models. The following sample of natural resource models has been selected, viz., a materials balance model, an exhaustible resource model, a forestry model, and fishery model. These models are discussed in sections 3 to 6, respectively. For each of these models we will analyze the sensitivity of the results for a non-uniform social rate of discount, based on one or more of the above mentioned four arguments. The article will be concluded with a systematic review table.

2. FOUR ARGUMENTS FOR A VARYING SOCIAL RATE OF DISCOUNT

In this section, the four arguments for using non-uniform discount rates for public projects will be discussed in a concise manner.

The (Intergenerational) Equity Argument

It is often argued that in case of long-term projects the government—as a "trustee of unborn generations"—should use a social rate of discount that is lower than the discount rate reflecting the (individual) opportunity cost of postponing the consumption of goods or services. This is especially emphasized in case of multi-generational evaluation problems, as the usual social rate of discount is co-determined by time preferences of individuals who are neither necessarily concerned with future interests of themselves nor of society as a whole (cf. also the so-called "isolation paradox" [3]).

In the past decade the problem of multiple generations has been quite extensively discussed in view of the exhaustibility of natural resources. The argument for a downward adjustment of the social rate of discount is based on the assumption that individuals have a myopic view on the future and hence tend to underestimate the impacts of current decisions upon long-term welfare related to the use of a finite stock of resources [4-10]. Despite many variations in arguments, it is generally accepted that the interest of future generations may lead to a downward adjustment of the social rate of discount.

The Uncertainty and Risk Argument

Uncertainty and risk provide other arguments for adjusting the social rate of discount [5-16]. A higher risk at the cost side may then lead to an increase in the discount rate. Despite the Arrow-Lind theorem and the pooling argument, it is still widely believed that high risks of public projects may lead to a varying social rate of discount, particularly to avoid an artificial (and thus inefficient) reallocation of investments to the public sector. Lind has strongly argued that it is necessary to use a non-uniform discount rate which is dependent on the specific risks incurred and on ways of financing the project concerned [14, 15].

The Financial Crowding-Out Argument

The way of financing a project (including its impact on the allocation of investment funds) may provide another argument for advocating a varying social rate of discount. Especially the crowding-out effect is relevant in this context: if the social rate of discount is not in agreement with the market rate of interest, public projects may be generated which have a lower profitability than those in the private sector [12, 17]. In this respect the shadow price of capital may be used in order to transform costs and benefits of a public project into private consumption equivalents [15]. Such a shadow price approach (eventually corrected for reinvestment opportunities) provides a plausible way of taking into consideration the specific impacts of a certain public project.

The Externalities and Intangibles Argument

In case of intangible social costs (caused inter alia by externalities), it is often argued that a downward adjustment of the social rate of discount is necessary in order to impose a more strict filtering condition on such projects [12, 13, 18-21]. Alternative approaches have been proposed among others by Lind, who claims that again a shadow price may be assessed for such intangibles [15]. Also an option value approach may be chosen here [22]. It is clear that irreversibility and replenishability of natural resource processes are extremely important in this respect. In conclusion, apart from a straightforward adjustment of costs and benefits of such intangibles, it is in general an acceptable idea to adjust the social rate of discount in case of intangible effects of public projects.

The overall conclusion from this section is modest, but offers an interesting scope for economic analysis: economic theory provides valid arguments to use a varying social rate of discount for public projects (without claiming however that a non-uniform rate of discount is a necessity in public project evaluation). The implications of this viewpoint for natural resource models will be further investigated in the next sections.

The foregoing presentation of four classes of arguments demonstrates that one may, on plausible grounds (i.e., based on the economic literature), justify the use of a non-uniform social rate of discount that varies over different time periods, different projects, or different effects.

In the framework of long-term environmental management decisions, it is worth mentioning that the social rate of discount reflects here the sacrifice of current welfare in favor of a maintenance of future welfare including environmental goods. A low social rate of discount implies, thus, a high value attached to the future. It is evident that the previous mentioned four classes of arguments for using a non-uniform discount rate apply to a large extent also to the evaluation of environmental goods in natural resource models. It is therefore an interesting question as to which arguments are especially relevant in a given environmental policy context and what consequences are expected from an adjustment of the social rate of discount.

3. A MATERIALS BALANCE MODEL

Maeler's dynamic materials balance model describes an economy in which an environmental management agency guards the environmental quality by charging the producers and consumers with a price, q, when they discharge wastes in the environment.[1] This price is unilaterally determined by the agency. The other prices in the model are determined on markets where all producers and consumers are pricetakers. It is assumed that no change occurs in technology or in the size of the population. The model consists of the following equations:

$$\max_{(C,Y)} W = \int_0^T U(C,Y)e^{-rt}dt \tag{3.1}$$

$$\text{s.t.} \int_0^T f[K(t)]\,dt \leqslant S \tag{3.2}$$

$$\dot{K} = I \tag{3.3}$$

[1] Maeler actually uses vectors of prices and goods in his model. Here these are treated as single variables, which does not harm the analysis [23].

$$C + I + \mu K \leqslant f(K) \tag{3.4}$$

$$\dot{Y} = \lambda(1 - Y) - \gamma Z \tag{3.5}$$

$$Z = C + \mu K \tag{3.6}$$

$$K(T) \geqslant K_T,\ \ Y(T) \geqslant Y_T,\ \ K(0) = K_0,\ \ Y(0) = Y_0 \tag{3.7}$$

with:

C = rate of consumption
Y = environmental quality
K = capital stock
S = maximum exploitation of the natural resource allowed during the planning period
Z = total amount of man-made residuals discharged in the environment
μ = rate of depreciation of K
r = rate of discount
λ,γ = parameters.

(3.5) represents the relation between waste discharges and environmental quality. The term $\lambda(1 - Y)$ is to be interpreted as the self-purification of the environment (investments that could change the assimilitive capacity of the environment are not considered).

Using the Pontryagin maximum principle, this problem can be restated as follows:

$$H = e^{-rt}[U+pI+\delta\left\{\lambda(1-Y)-\gamma Z\right\}-p_r(f-S/T)-\alpha(I+C+\mu K-f)-q(C+\mu K-Z)] \tag{3.8}$$

with:

p = price for investment goods
δ = price for environmental quality
p_r = price for natural resources
q = price for waste disposal services
α = corporate profit.

The first order conditions are:

$$H'_C = U'_C-\alpha-q = 0 \tag{3.9}$$

$$H'_I = p-\alpha = 0 \tag{3.10}$$

$$H'_Z = -\gamma\delta+q = 0 \tag{3.11}$$

$$H'_K = -p_r f'_K-\alpha\mu+\alpha f'_K-q\mu = -\dot{p}/p+r \tag{3.12}$$

$$H'_Y = U'_Y-\delta\lambda = -\dot{\delta}/\delta+r\,. \tag{3.13}$$

Environmental and crowding-out effects are incorporated in this model as follows. Equation (3.9) can be interpreted in the sense that the marginal utility of consumption equals the opportunity cost of consumption, which consists of two parts: 1) the value of the omitted capital accumulation, and 2) the disposal cost of consumption residuals. According to (3.11), the latter is equal to the value of the marginal decrease in the quality of the environment caused by the discharge of residuals. In principle, the rate of discount in this model can be adjusted for the externalities and intangibles argument and the financial crowding-out argument.

The risk argument can be applied in this model if the assumption of perfect certainty is relaxed. Considering environmental investments as relatively safe investments one could argue for a downward adjustment of the discount rate.

The intergenerational equity argument can be applied if the time horizon T exceeds the length of a generation. A reduction of the discount rate would lead to a slower decline of both environmental quality and the stock of the natural resource concerned. Thus, the four arguments for a non-uniform social rate of discount can be successfully applied in this model.

4. A DYNAMIC ABIOTIC EXHAUSTIBLE RESOURCE MODEL

This section focusses on the model of Dasgupta and Heal [18]. This model on exhaustible resources reads as:

$$\max_{(C)} \int_0^\infty e^{-rt} U(C) dt \tag{4.1}$$

$$\text{s.t. } \dot{K} = F(K,R) - C \tag{4.2}$$

$$\int_0^\infty R dt \leqslant S_0 \tag{4.3}$$

$$R, S \geqslant 0, \; K(0) = K_0, \; S(0) = S_0 \tag{4.4}$$

with:

C = flow of consumption goods in period t
K = stock of capital in period t
K_0 = initial stock of capital
R = flow of the exhaustible resource in period t
S_0 = initial stock of the exhaustible resource
r = social rate of discount .

Equation (4.1) represents the multiperiod control function. (4.2) denotes the change in the stock of capital. The production function has the following properties: $F'_K > 0$, $F'_R > 0$, $F''_{KK} < 0$, $F''_{RR} < 0$, $F''_{KR} > 0$. Equation

(4.3) limits the accumulated usage of the exhaustible resource to the initial stock. The Hamiltonian of this optimal control problem is:

$$H = e^{-rt}\left[U(C)+p\left\{F(K,R)-C\right\}+(\mu-e^{rt}\lambda)R\right] \qquad (4.5)$$

with:

p = price of a consumption good in period t
λ = present value shadow price of the exhaustible resource.

It is assumed that $\mu \geqslant 0$, $\mu R = 0$, $\lambda > 0$, $\lambda(S_0 - \int_0^\infty R\,dt) = 0$.

The first order conditions are:

$$H'_C = U'_C - p = 0 \qquad (4.6)$$
$$H'_R = pF'_R + \mu - \lambda e^{rt} = 0 \qquad (4.7)$$
$$H'_K = pF'_K = -\dot{p} + pr\ . \qquad (4.8)$$

Equation (4.8) is known in economic literature as the Ramsey rule.

Following Dasgupta and Heal we assume that $R > 0$. Then equation (4.7) reads as follows, if an optimal program exists.

$$\lambda = e^{-rt}pF'_R \qquad (4.9)$$

In order to derive the time path of R, we calculate the derivation of (4.9) with respect to time:

$$\dot{F}'_R/F'_R - r + \dot{p}/p = 0 \qquad (4.10)$$

Substitution of (4.10) into (4.8) yields:

$$F'_K = -\dot{F}'_R/F'_R \qquad (4.11)$$

This can be written as:

$$\dot{R}/R = -\dot{K}F''_{RK}/\frac{R}{K}F''_{RR} + \sigma K F'_K \dot{F}(K,R)/R^2F''_{RR} \qquad (4.12)$$

$$\sigma = -\frac{R}{K}F'_K F'_R/\dot{F}'_K F(K,R) \qquad (4.13)$$

where σ = the substitution elasticity of R and K; $\sigma \leqslant 1$, because the resource is assumed to be essential to production (i.e., it is not possible to substitute completely capital for the exhaustible resource).

The optimal time path for C follows from substitution of (4.6) in (4.8):

$$-\dot{U}'_C/U'_C = F'_K - r \qquad (4.14)$$

which can be rewritten as:

$$\eta(C)\dot{C}/C = F'_K - r \tag{4.15}$$

$$\eta(C) = -\left\{CU''_{CC}/U'_C\right\} \tag{4.16}$$

where $\eta(C)$ is the elasticity of marginal utility, and we assume that:

$$0 < \lim_{C \to 0} \eta(C) < \infty .$$

It can be seen from (4.15) that in an optimal program the growth rate of consumption in this model gets negative when using a positive discount rate. This growth rate rises at a decreasing rate when using a discount rate equal to zero.

For a Cobb-Douglas production function (here F(K,R) with $\sigma = 1$) and an iso-elastic social welfare function (here U(C) with a constant η), Dasgupta and Heal prove that a unique optimal program ($\hat{C}$,$\hat{K}$,$\hat{R}$) exists with the following asymptotic property:

$$\lim_{t \to \infty} \dot{\hat{R}}/\hat{R} = -r/\eta \tag{4.17}$$

(4.17) means that given $r > 0$ the percentage change in the usage pace of R is negative in the long run for the optimal program. Further, $\hat{R}$ is continuous for all $t \geqslant 0$, $\hat{R} < 0$ for all $t \geqslant 0$, and $\hat{R} < 0$ for a starting period with large values for K_0 and S_0 and $\hat{R} > 0$ in the long run. This implies that the resource will not be depleted within a finite period of time, because $\lim_{K/R \to \infty} F'_R = \gamma < \infty$ does not hold true for F(K,R).

The introduction in this model of technological change under uncertainty (meaning the probability that at a certain point in time a new non-reproducible resource will be discovered as a substitute for the old essential resource, R, is set at 1, but the time of this discovery is being treated as a random variable whose probability distribution is exogenously determined) implies the following for the optimality conditions of the model if certain conditions are fulfilled [18]. The optimality condition (4.12) remains unchanged, but in (4.15) the discount rate δ is raised with a term ψ, that varies in time and equals the conditional probability, that the substitute will be discovered at time t given that it has not been discovered prior to t.

The introduction of the above mentioned uncertainty in the model implies given the change in (4.15) that a higher rate of consumption is considered to be optimal than in the old model. This seems intuitively justified, because the resource is no longer a bottleneck for production in the described economy once its substitute is discovered and employed.

Now we come to the question of whether a non-uniform discount rate can be applied meaningfully in this model. As the model covers a very long period of time and involves the social welfare of present and future generations, the intergenerational equity argument can certainly be applied in this model. The social welfare of the future generations can be protected by lowering the rate of discount, so that the optimal time paths of consumption and of the use of the non-living resource decline less progressively. This downward adjustment of the discount rate could be subjected to the probability distribution of the time of the discovery of the substitute: if this discovery will take place in the distant future, then the intermediate generations will be worse off.

The uncertainty and risk argument has in fact been applied by the authors concerning the uncertainty with respect to technological change.

The financial crowding out argument is only relevant in this model in as far as crowding out of future production and consumption is concerned.

External effects of production or consumption can be stimulated (reduced) by an upward (downward) adjustment of the discount [rate]. In order to postpone irreversible effects, that could result from the exhaustion of the resource[2] (which could be optimal in this model, if one does not assume a Cobb-Douglas production function and/or an iso-elastic social welfare function), one could postpone the time of exhaustion. The same procedure can be used to redress negative (ir)reversible environmental effects, that accompany the exploitation and use of this resource (and mutatis mutandis to stimulate positive external effects). In sum, all four arguments for a non-uniform social rate of discount rate can be applied effectively in this model.

5. A DYNAMIC FORESTRY MODEL

In this section a dynamic economic-ecological forestry model based on the Faustmann formula as described by Clark is under investigation [23]. The objective of the model is to determine the optimal rotation for a given species of tree. The commercial value, V, of a single tree is determined by the volume and quality of its timber. V depends on the age of the tree. Assuming that the curve V(t) is known, what is the optimal age at which to fell a tree (or more realistically, a stand of trees of the same age)? If c denotes the cost of felling, then optimizing the present value of the net value of the stand with respect to the felling time, T, i.e.,

$$\max_{(V)} PV = e^{-rt}[V(t)-c] \tag{5.1}$$

yields:

$$\frac{V'(T)}{V(T)-c} - r = 0 \tag{5.2}$$

[2] Examples may be certain medicines, for which this resource constitutes an indispensible ingredient.

with:

V = value of tree stand
c = cost of felling
r = social rate of discount.

Optimizing the present value for more than one rotation requires the inclusion of the site value (i.e., the opportunity cost of investment tied up in the standing trees and in the site), i.e.,

$$\max_{(V)} PV = \sum_{k=1}^{\infty} e^{-k\sigma T} [V(T)-c] = \frac{V(T)-c}{e^{r}-1} \tag{5.3}$$

with respect to T yields:

$$\frac{V'(T)}{V(T)-c} - \frac{r}{1-e^{-rT}} = 0 \tag{5.4}$$

with:

c = cost of felling and planting
k = rotation number

Equation (5.4) can be rewritten in the form

$$V'(T) = r\,[V(T)-c] + r\frac{V(T)-c}{e^{rT}-1} \tag{5.5}$$

where $\frac{V(T)-c}{e^{rT}-1}$ represents the present value of the site value.

Equation (5.5) for the optimal rotation period T is called the Faustmann formula. A rise in the discount rate c.p. results in shortening the optimal rotation. A permanent cost reduction c.p. or a permanent rise in price c.p., will have the same effect.

On the basis of what arguments can a non-uniform social rate of discount be applied effectively? The intergenerational equity argument is applicable in this model if V increases during a rotation that exceeds the length of a generation, say thirty years. Then a downward adjustment of the discount rate can bring about an optimal rotation where the benefits of the stand planted by one generation can accrue to a next generation.

The uncertainty and risk argument could be adopted here: observing that the investment in the forestry project is relatively safe one can apply the social rate of discount that is associated with long run capital bonds. This would extend the optimal rotation.

The financial crowding out argument is applicable if an assumption is adopted concerning the financing of the project. In the Faustmann formula itself the opportunity cost of the use of the land for a tree stand has been incorporated by adjusting the present value equation.

Finally, the externalities and intangibles argument can be internalized by considering the tree stand as an environmental good of which the social value rises in time, and adjusting the social rate of discount accordingly downward so that the optimal rotation is lengthened.

6. A DYNAMIC FISHERY MODEL

In this section a general dynamic fishery model developed by Nijkamp is examined [25]. The model assumes that the natural growth of the fish stock is determined by the stock itself and by exogenous factors that determine the ecological environment (like the quality of water), and that there exists only a limited stock of total fishery capital in each period. It consists of the following equations:

$$\max_{(z_i,c_i)} \; w = \int_0^T e^{-rt} \left[\sum_{i=1}^{I} \left\{ p_i f_i(z_i,c_i) - s_i c_i \right\} \right] dt \tag{6.1}$$

$$\text{s.t. } \dot{z}_i = g_i(z_i,e_i) - f_i(z_i,c_i) \text{ for all i,} \tag{6.2}$$

$$(z_i)_{t=0} = z_i^0 \tag{6.3}$$

$$c_i = c - \sum_{j=1}^{I} c_j \quad \text{where } i \neq j \tag{6.4}$$

with:

p_i = price per unit of fish of species i
z_i = stock of fish of species i
c_i = capital investments of fishery sector i
c = total capital stock of the fishery sectors
s_i = average capital costs per unit in sector i
e_i = exogenous factors (like water quality)
r = social rate of discount
f_i = production function for harvesting fish
g_i = biological growth function.

The corresponding Hamiltonian is equal to:

$$H = e^{-rt} \left[\sum_{i=1}^{I} p_i f_i(z_i, c - \sum_{j=1}^{I} c_j) - s_i(c - \sum_{j=1}^{I} c_j) \right]$$

$$- \sum_{i=1}^{I} \lambda_i \left\{ g_i(z_i,e_i) - f_i(z_i, c - \sum_{j=1}^{I} c_j) \right\} \qquad \text{where } i \neq j \tag{6.5}$$

with:

λ_i = shadow price of a marginal unit of fish stock in terms of net social benefits foregone.

The necessary conditions for an interior optimum are the following:

$$H'_{c_i} = e^{-rt}p_i f'_{ic_i} - e^{-rt}s_i + \lambda_i f'_{ic_i} = 0 \tag{6.6}$$

$$H'_{z_i} = e^{-rt}p_i f'_{iz_i} - \lambda_i g'_{iz_i} + \lambda_i f'_{iz_i} = -\dot{\lambda}_i \tag{6.7}$$

In order to derive the time paths of z_i and c_i, equation (6.6) is rewritten as follows:

$$-\lambda_i = e^{-rt}(p_i f'_{ic_i} - s_i)/f'_{ic_i} \tag{6.8}$$

Its time derivative is:

$$-\dot{\lambda}_i = e^{-rt}\Big[\Big\{-r(p_i f'_{ic_i} - s_i) + p_i f''_{ic_ic_i}\dot{c}_i + p_i f''_{ic_iz_i}\dot{z}_i\Big\} f'_{ic_i} + (f'_{ic_i}\dot{p}_i - \dot{s}_i)f'_{ic_i} - (f''_{ic_ic_i}\dot{c}_i + f''_{ic_iz_i}\dot{z}_i)(p_i f'_{ic_i} - s_i)\Big]/(f'_{ic_i})^2 \tag{6.9}$$

Inserting this equation in equation (6.7), in which λ_i has been substituted using (6.8), gives after several rewritings:

$$\dot{z}_i/z_i = \Big[-p_i f'_{iz_i}(f'_{ic_i})^2 - (g'_{iz_i} - f'_{iz_i})(p_i f'_{ic_i} - s_i)f'_{ic_i} + \Big\{-r(p_i f'_{ic_i} - s_i) + p_i f''_{ic_ic_i}\dot{c}_i + f'_{ic_i}\dot{p}_i - \dot{s}_i\Big\} f'_{ic_i} - f''_{ic_ic_i}\dot{c}_i(p_i f'_{ic_i} - s_i)\Big]/ -f''_{ic_iz_i}s_i z_i \tag{6.10}$$

and

$$\dot{c}_i/c_i = \Big[-p_i f'_{iz_i}(f'_{ic_i})^2 - (g'_{iz_i} - f'_{iz_i})(p_i f'_{ic_i} - s_i)f'_{ic_i} + \Big\{-r(p_i f'_{ic_i} - s_i) + p_i f''_{ic_iz_i}\dot{z}_i + f'_{ic_i}\dot{p}_i - \dot{s}_i\Big\} f'_{ic_i} - f''_{ic_iz_i}\dot{z}_i(p_i f'_{ic_i} - s_i)\Big]/ -f''_{ic_ic_i}s_i c_i \tag{6.11}$$

Now we can address the question of whether a non-uniform rate of discount can be used effectively in this model. In the model the intergenerational equity argument can be applied if the yearly optimal fish catch of species i exceeds the maximum sustainable yield, and the time interval T surpasses thirty years. An upwardly adjusted discount rate for this species then results in a higher optimal stock of species i, if $-(p_i f'_{ic_i} - s_i)f'_{ic_i}/-f''_{ic_iz_i}s_i z_i$ is positive; this is the case if $f'_{ic_i} > s_i/p_i$, assuming that $f''_{ic_iz_i} > 0$. If $f'_{ic_i} < s_i/p_i$, then a higher discount rate will result in a lower optimal stock of species i. The second case holds true for all levels of c_i if s_i/p_i is large enough. If s_i/p_i is not large enough, then a lower discount rate will result in a lower optimal stock for lower levels of capital investment and in a higher optimal stock for higher levels of capital investment after the point where the rising f'_{ic_i} curve intersects with s_i/p_i line in f'_{ic_i}, c_i-space.

The model then is at even with the foregoing observation in the literature that resource conservation is served by a lower discount rate, as long as $f'_{ic_i} < s_i/p_i$.

The financial crowding-out argument can be applied in this model if the assumption of a fixed capital stock of the fishery sectors is dropped, and if these sectors are integrated in the national economy, so that one allows for crowding out by the fishery sectors of investments in other sectors. Lowering the discount rate applied to fishery sectors investments will then result in a lower optimal level of capital investment in these sectors if $f'_{ic_i} < s_i/p_i$.

The same adjustments in the assumptions have to be made in order to make the risk argument applicable in this model. The observation that fishery investments are relatively safe would result in a downward adjustment of the discount rate which would however discourage investments in the fishery sectors if $f'_{ic_i} < s_i/p_i$.

If species i is threatened, then one might consider a strong lowering of the discount rate applied in its fishery backed by a combination of the intergenerational equity, the risk, and the externalities and intangibles argument in order to take notion of its option value, if $f'_{ic_i} < s_i/p_i$.

The discount rate of all I fish species can be lowered based upon the externalities and intangibles argument, if one views the fish population as an environmental good that increases in value in time. The total fish population will then rise as less fish of each species are caught.

In short, each of the four described arguments for a non-uniform social rate of discount can be used effectively in this model.

7. REVIEW OF RESULTS

Table 1 gives an overview of the models discussed in the preceding sections with respect to the applicability of a non-uniform social rate of discount for each of the four previously mentioned arguments. This table is mainly illustrative.

In the table, a distinction has been made between the following aspects of the use of a non-uniform discount rate in the models:

(i) when describing the model, the author mentions explicitly the effects that correspond with each of the four arguments;
(ii) it is possible to adjust the discount rate in the model under discussion for (at least one of)the four arguments; and
(iii) an adjustment of the discount rate inspired by each argument has a substantial impact on the time path of the natural resource concerned.

In conclusion, the four arguments for adopting a non-uniform social discount rate seem to be applicable in most cases and to have a substantial impact on the

Table 1.

	Intergenerational Equity	*Risk and Uncertainty*	*Financial Crowding-Out*	*Externalities and Intangibles*
Materials Balance Model			(i)	(i)
Maeler (1974)	(ii)	(ii)	(ii)	(ii)
	(iii)	(iii)	(iii)	(iii)
Exhaustible Resource	(i)	(i)		
Model	(ii)	(ii)		(ii)
Dasgupta and Heal (1974)	(iii)	(iii)		(iii)
Forestry Model	(i)		(i)	(i)
Clark (1977)	(ii)	(ii)	(ii)	(ii)
	(iii)	(iii)	(iii)	(iii)
Fishery Model			(i)	(i)
Nijkamp (1977)	(ii)	(ii)	(ii)	(ii)
	(iii)	(iii)	(iii)	(iii)

time path of the use of the natural resource. Now one can assume that a non-uniform discount rate can be adopted successfully in natural resource models in general. More generally, one might consider a procedure of evaluation using a non-uniform discount rate to be applicable in other policy models.

REFERENCES

1. D. Gijsbers, P. Nijkamp, and J. Rouwendal, Variabele Discontering: Toepasbaar bij Project-evaluatie?, *Openbare Uitgaven*, pp. 52-60, 1986.
2. D. Gijsbers and P. Nijkamp, A Varying Social Rate of Discount: Review of Arguments, forthcoming.
3. A. K. Sen, Isolation, Assurance, and the Social Rate of Discount, *Quarterly Journal of Economics*, pp. 112-124, 1967.
4. D. Herfindahl and A. V. Kneese, *Economic Theory of Natural Resources*, McMillan Publishing Co., London, 1974.
5. J. V. Krutilla and O. Eckstein, *Multiple Purpose River Development*, Johns Hopkins Press, Baltimore, MD, 1958.
6. S. Marglin, The Social Rate of Discount and the Optimal Rate of Investment, *Quarterly Journal of Economics*, pp. 94-111, 1963.
7. E. Mishan, Economic Criteria for Intergenerational Comparisons, *Futures*, *9*:5, pp. 383-403, 1977.
8. N. Myers, Discounting and Depletion, *Futures, 9*, pp. 502-509, 1977.
9. T. Page, Discounting and Intergenerational Equity, *Futures, 9*:5, pp. 377-382, 1977.
10. D. Pearce, Accounting for the Future, *Futures, 9*:5, pp. 360-364, 1977.
11. K. J. Arrow and R. Lind, Uncertainty and the Evaluation of Public Investment Decisions, *American Economic Review, 60*, pp. 364-378, 1970.

12. W. J. Baumol, On the Social Rate of Discount, *American Economic Review, 58,* pp. 788-802, 1968.
13. R. Haveman, The Economic Evaluation of Long-Run Uncertainties, *Futures, 9*:5, pp. 365-375, 1977.
14. R. Lind (ed.), A Primer on the Major Issues Relating to the Discount Rate for Evaluating National Energy Objects, in *Discounting for Time and Risk in Energy Policy,* Resources for the Future, Inc., Washington, D.C., pp. 58-73, 1982.
15. ———, The Rate of Discount and the Application of Social Benefit-Cost Analysis in the Context of Energy Policy Decisions, in *Discounting for Time and Risk in Energy Policy,* Resources for the Future, Inc., Washington, D.C., pp. 58-73, 1982.
16. W. Vickrey, Principles of Efficiency-Discussion, *American Economic Review, 54,* (Papers and Proceedings), May 1964.
17. D. F. Bradford, Constraints on Government Investment Opportunities and the Choice of Discount Rate, *American Economic Review, 65*:5, pp. 887-899, 1975.
18. P. Dasgupta and G. Heal, The Optimal Depletion of Exhaustible Resources, *Review of Economic Studies,* pp. 3-28, 1974.
19. A. C. Fisher and J. V. Krutilla, Resource Conservation, Environmental Preservation, and the Rate of Discount, *Quarterly Journal of Economics,* pp. 358-370, 1975.
20. D. Pearce, Ethics, Irreversibility, Future Generations, and the Social Rate of Discount, *International Journal of Environmental Studies, 21,* pp. 67-86, 1983.
21. W. Schulze, D. Brookshire, and T. Sandler, The Social Rate of Discount for Nuclear Waste Storage: Economics or Ethics, *Natural Resources Journal, 21,* pp. 811-832, October 1981.
22. C. Nash, Future Generations and the Social Rate of Discount, *Environment and Planning, 5,* pp. 611-617, 1973.
23. K. Maeler, *Environmental Economics,* Resources for the Future, Inc., Washington, D.C., pp. 58-73, 1974.
24. C. W. Clark, *Mathematical Bioeconomics: The Optimal Management of Renewable Resources,* John Wiley & Sons, Inc., New York, NY, pp. 257-263, 1976.
25. P. Nijkamp, *Theory and Application of Environmental Economics, Studies in Regional Science and Urban Economics, 1,* North Holland Publishing Co., Amsterdam, pp. 229-249, 1977.

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