Intergenerational Discounting: A new Approach

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Tübinger Diskussionsbeitrag Nr. 145, September 1998

JEL Classification: D5, D6, D9, H4, O1, Q2, Q3.

Keywords: Discounting, Time Preference Rate, Opportunity Cost Rate, Overlapping Generations.

Abstract:

In this paper, we analyze how to utilize discount rates in intergenerational projects. Firstly, neoclassical decision-making is depicted in *Ramsey* and overlapping-generations models (OLG-models). Afterwards we investigate the utilization of time preference rates and opportunity cost rates in an intergenerational framework. The results lead us to the formulation of an adjusted OLG-discounting method of consumption units, taking into consideration intra- and intergenerational aspects. At the end of our paper, we draw some conclusions concerning environmental and resources policy, and sustainability.

1. Introduction

In cost-benefit analyses for evaluating public projects and political programs, all effects have to be related to the time of planning. This is done by discounting. We consider long-term projects which not only concern today's generations, but also affect people living in the remote future. Among these projects are investments in public infrastructure (road construction, provision of drinking water, town and regional planning, provision of natural reserves, etc.), decisions about the usage of exhaustible resources (deposits of oil, natural gas, coal, and minerals) and renewable resources (stocks of animals and plants, soil and groundwater resources), as well as decisions about the pollution of the environment with long-term pollutants (global warming, depletion of the ozone layer, etc.). As a result of discounting, future effects are valued less highly in today's calculations than current effects. This could, in the end, lead to arbitrary distortions in certain cost-benefit analyses. Even small variations of the discount rate can lead to different assessments of the profitability (see figure 1). Therefore, the discount rate has to be chosen with care and in accordance with the principles of cost-benefit analysis.

In our paper, we want to demonstrate which considerations influence the determination of discount rates in long-term projects, keeping in mind that different generations are affected. This is in particular the case with environmental projects, therefore, we mainly use such projects as examples. Nevertheless, our proposals can be utilized to evaluate other undertakings where long-term effects are feasible for different generations, such as infrastructure projects, and (exhaustible and renewable) resource uses

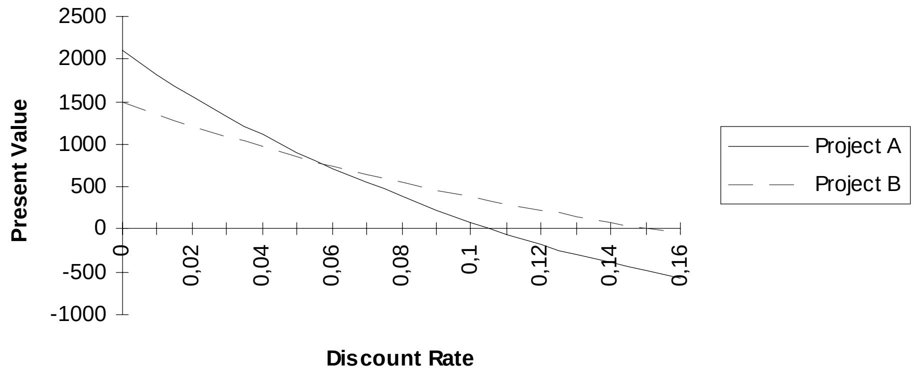

Figure 1: Present values of two projects, dependent on the discount rate. The investigated six-period projects with equal costs in the planning period are given by the following cost-benefit streams (in US-$): Project A: -3,000; -300; -100; 0; 500; 5,000. Project B: -3,000; 900; 900; 900; 900; 900. Using a discount rate of 5.6368 %, both projects have the same present value. Using a lower one, project A is the efficient one, whereas a discount rate larger than 5.6368 % characterizes project B as efficient.

2. The neoclassical approach

The theoretical basis for cost-benefit analyses is found in neoclassical economics. Public projects are designed to increase economic welfare and, therefore, they must pass a cost-benefit comparison. Welfare is considered to increase when the project-induced present value of all benefits exceeds the present value of all costs. In the calculation of the present values, two discount rates can principally be used: the (marginal) social rate of time preference and the (marginal) social rate of opportunity costs. These rates are derived from the assumed behavior of consumers and producers. The **households** prefer present to future consumption. They want to maximize the present value of life-time consumption. They orient their consumption-saving decision on the exogenous market interest rate. If the interest rate exceeds their individual marginal time preference rate, they will reduce present in favor of future consumption. If the market interest rate is below the individual marginal time preference rate, they will expand present consumption at the cost of diminishing future consumption. The adjustments lead to an equilibrium where the market interest rate equals the individual marginal time preference rate. The **enterprises** strive to maximize the present value of the return on investments. The investment decision is oriented on the exogenous market interest rate. If the marginal productivity of capital exceeds the interest rate, increases in capital investment are profitable. If, on the other hand, the interest rate exceeds marginal productivity, investments will be reduced. The triggered adjustment processes lead to the equivalence of marginal productivity and market interest rate. At the same time, an overall economic equilibrium (equivalence of saving and investment) prevails. Because the intertemporal decisions of households and enterprises are brought together by the interest rate which can be used as discount rates instead of the single rates. The following relationship holds: market rate of interest (i) = marginal rate of time preference = marginal productivity of capital.

The simple two-period model is extended to the long term in optimal growth theory (see *Ramsey* (1928) and among others *Bayer/Cansier* (1998), *Lind* (1995)). In these so-called ***Ramsey* models,** a representative individual with an infinite lifespan is assumed. People live as long as the time of utilization of the project extends. The maximization calculus of the representative individual is given by:

$$(1) \qquad \max \int_{t=0}^{\infty} U(C_t) \cdot e^{-\rho t} dt \qquad \text{s.t. } \dot{K}_t = Y_t - C_t \,.$$

$U(C_t)$ represents the utility from consumption bundle C_t in period t. The premise of diminishing marginal utility from consumption holds for the utility function: $dU/dC_t>0$; $d^2U/dC_t^2<0$. ρ symbolizes the pure rate of time preference (utility discount rate), Y_t denotes the national product in period t and $\dot{K}_t$ stands for investment. We concentrate our analysis on the consumer side. Nevertheless, assumptions about the production function have to be taken into account as well. The most important one is that there is diminishing marginal productivity of production with increasing inputs, especially capital: $\partial Y/\partial K>0$ and $\partial^2 Y/\partial K^2<0$. With dynamic optimization, the **Ramsey rule** is provided as first-order optimality condition:

$$(2) \qquad i = \frac{\partial Y}{\partial K} = \delta = \rho + \varepsilon g \,.$$

The discount rate, which equals the market interest rate i, also corresponds to the marginal productivity of capital $\partial Y/\partial K$ (opportunity cost rate) and, respectively, to the aggregated overall economic time preference rate δ, which is composed of the pure time preference rate ρ and the growth time preference rate $\varepsilon \cdot g$. ε stands for the elasticity of marginal utility of consumption (percentage change of marginal utility when consumption is increased by one percent), and g stands for the growth rate of real consumption. The product describes the change in the marginal utility of consumption. During growth, the supply with consumption goods in the future is larger than in the present. Additional consumption goods are, therefore, valued less than in the present due to the higher future individual level of welfare. The situation is the other way round in an economy with decreasing per-capita income (consumption).

A problematic area in the neoclassical model for our analysis is the assumption that the representative individual lives infinitely. For climate protection, for instance, this means that the people living today will bear the necessary costs as well as benefits from the prevention of the greenhouse effect in a hundred, two hundred or more years. This is a considerable simplification. It ignores the fact that the costs and benefits affect different generations. In long-term projects, one always has to consider distributional aspects in addition to the allocative ones.

In **dynastic models** and in **models with overlapping generations (OLG-models)**, the neoclassic approach tries to gain better control of the time problem. In **dynastic models**, an expansion of the individual time horizon to the long term is constructed by the interconnection of the interests of parents, children and grandchildren or of generations with empathic closeness (see e.g. *Blanchard/Fischer* (1989), *Barro/Sala-i-Martin* (1995), *Barro* (1997)). But the cardinal problem remains yet unresolved: no comparisons are made between different generations. Furthermore, these modifications are hardly, or rather never, used in environmental or resource-economic models (see e.g. *Nordhaus* (1994)). Despite the consideration of descendants, in both expansions it is always assumed that their preferences do not differ significantly from their ancestors' ones. In particular, the ancestors' decision for or against a climate-protection measure would be made by the descendants in the same way. This implicitly states that the ancestors take all decisions considering the (potential) existence of their descendants into consideration. Nevertheless their interests only enter the analysis in a considerably reduced scale, and the less weight is given to these considerations the more distant the kinship is.

Overlapping-Generation Models (OLG-Models) take into consideration that people of different age groups are living at the same time (see e.g. *Blanchard/Fischer* (1989)). We want to solely concentrate on the demand side and to maintain the premise of diminishing marginal utility. The production side will be neglected for simplification. But we want to keep in mind that OLG-Models usually analyze general economic equilibria. In the simplest case, only two generations exist, an old and a young one. In its two-year life, each generation maximizes the present value of life-time consumption at the beginning of their respective lives. At the start of a new period, the respective oldest generation dies and a new generation is born. The (up to now) young generation becomes the old one at the same time, and the total number of living generations remains unchanged. The intertemporal budget restriction of the respective generation designates that the young generation earns income from work which can be consumed or saved. The saved amount of income from work plus the accrued interest forms the income of the older individuals. The maximization problem is as follows:

$$(3) \qquad \max \left[U(C_t) + \frac{U(C_{t+1})}{1+\rho} \right] \quad \text{s.t.} \;\; C_t + \frac{C_{t+1}}{1+i_t} = Y_t .$$

The variable i_t symbolizes the exogenously given market interest rate on which every individual in each generation orients its consumption-saving decision. The following necessary condition results:

$$(4) \qquad \frac{\partial U / \partial C_t}{\partial U / \partial C_{t+1}} = -\frac{dC_{t+1}}{dC_t} = \frac{1+i_t}{1+\rho} .$$

The efficiency criterion implies that every individual extends its saving activities until the marginal rate of substitution between consumption today and consumption tomorrow equals the quotient of one plus the market interest rate and one plus the utility discount rate (pure time preference rate). From these considerations, two conclusions inevitably follow: (a) in this model one only saves income if the exogenous (marginal) market interest rate exceeds the individual (marginal) time preference rate, and, if (a) holds, (b) there exists a positive growth discount rate ($\varepsilon \cdot g := i_t - \rho > 0$). Otherwise the opportunity costs of saving exceed the rate of return. In this situation, saving would be economically inefficient because immediate consumption increases individual as well as overall economic welfare more than future consumption (today's savings) does.

In OLG-models, infinite discounting using the pure rate of time preference is prevented. This automatically leads to higher present values of utility during the planning period. The economy always proceeds on its optimal path. All economic variables retain their optimal state in their development paths, which characterizes an all-time equilibrium during positive growth. The calculation of present values of any future consumption effect can be done as shown in Table 1. Generation E, for example, living in the periods t_3 and t_4, values project-induced (marginal) consumption effects c_{t3} and c_{t4} in accordance with their individual calculation of utility maximization. Changes in the overall economic welfare up to period t_3 are taken into account by considering that the generation's welfare increased and, therefore, the level of marginal utility is lower.

Generation	t_0	t_1	t_2	t_3	t_4	t_5	…
A	$U(c_{t0})$						
B	$U(c_{t0})$	$U(c_{t1})\cdot\theta^{-1}$					
C		$U(c_{t1})$	$U(c_{t2})\cdot\theta^{-1}$				
D			$U(c_{t2})$	$U(c_{t3})\cdot\theta^{-1}$			
E				$U(c_{t3})$	$U(c_{t4})\cdot\theta^{-1}$		
F					$U(c_{t4})$	$U(c_{t5})\cdot\theta^{-1}$	
G						$U(c_{t5})$	…
⋮						⋮	⋱

Table 1: Utility effects of a consumption-augmenting investment in period t_0; $\theta\equiv(1+\rho)$.

The dark shaded areas in Table 1 illustrate those time periods in the planning horizon which are of no importance in intergenerational discounting. In contradiction to *Ramsey* models, no individual lives infinitely. However, OLG-models investigate the optimal paths of all relevant macro-variables. All of them are equilibral. No incentives are given to reallocate the individual resources in order to improve individual welfare. Furthermore, public projects affect the total lifetime consumption planning of all individuals. They are taken into account in each individual's utility-maximizing considerations because of perfect foresight. Public projects will only be carried out if the utility-oriented present value passes the cost-benefit criterion. However, perfect foresight and general overall equilibrium are excessively strong assumptions in intergenerational comparisons. Global warming, for instance, has not been recognized as a long-term problem for a rather long time. Therefore, until now market failure has prevailed which forces the previously known optimality paths to be modified. Current replanning would not confirm the originally computed optimality paths of all variables.

In summary, neoclassical *Ramsey* models are not applicable for the valuation of intergenerational effects due to the outlined reasons. In OLG-models, the restrictive and unrealistic assumption of the infinitely-lived individual is given up (as well as the helpful construction of the bequeathing motive or the dynastic models), but the framework of common equilibrium theory in the intergenerational context is not abandoned, which is hardly realistic in the case of public projects with an (extremely) long planning period.

3. Intergenerational Equity and Individual Time Preference Rates

Before discussing different types of discount rates and their legitimization in intergenerational cost-benefit analysis, we want to make some simplifying assumptions for convenience which are valid throughout the rest of the paper. Positive consumption effects are taken into consideration as benefits and negative ones as costs, respectively. This holds, for example, for environmental effects as well. It is possible to take long-term effects into consideration without any uncertainties; they are valued fully and correctly as well. Uncertainty aspects will not be investigated. However, this should be done when determining and valuing consumption effects and not by discounting.

3.1 Pure Time Preference Rate

The most common theoretical assumption is that an individual values the utility of goods the less, the further the consumption takes place in the future. Prospective needs are valued less highly solely because they occur in the future (pure time preference rate ρ). This phenomenon occurs because of individual "myopia", impatience and other influences (see among others *Pigou* (1912), *Harrod* (1948), etc.). Some authors utilize this rate not only because of myopia and impatience, but also due to the predicted remaining life expectancy of individuals (see e.g. *Pearce/Ulph* (1995)).

The pure time preference rate is utilized in optimal growth theory as well as in (exhaustible and renewable) resources models to ensure the convergence of the utility integral. Therefore, it has to be modeled as an exponential utility discount rate. Each (representative) individual maximizes the sum of the weighted utilities of consumption according to the planning horizon (infinity) with reference to the planning time 0 in *Ramsey* models. For instance, equation (1) determines a consumption profile which is valid for all time periods $0,...,\infty$ of the planning horizon, which is dependent on the level of the pure time preference rate.

If we transfer this assumption to different individuals, then the utility of a special good which is available for future generations is worth less than the same good is worth for today's generations in utility units. Discounting utility now implies an ethical judgment about the position of the generations (see e.g. *Solow* (1974)). Future generations are worth less, the later they are born. This implicit setting of a norm is inconsistent with the neoclassical efficiency criteria. These criteria guarantee that individuals are ranked equally, because no individual is allowed to be disadvantaged; respectively the sum of the utilities of all individuals has to be maximized. Looking at the Kaldor-Hicks criterion, this valuation is ethically justified in utilitarianism, which is not interested in improving the welfare of special groups, but rather of all affected persons. All human beings are ranked equally: "... utilitari[ani]sm attaches exactly the same importance to the utilities of all people in the objective function, and that feature ... guarantees that everyone's utility gets the same weight in the maximizing exercise." (*Sen* (1992), see *Broome* (1992) as well). Since e.g. the consequences of global warming concern future generations as well, their interests have to be taken into account when investigating efficient global warming policy.

Valuation of future generations implies that economic theory gives up its neutrality regarding distributional aspects. Economic theory favors today's generations and discriminates against future ones because of distributional reasons. Judgments regarding long-term projects are distorted. There is an innate bias against long-term projects where short-term costs appear and where utilities are feasible mainly at the end of the planning horizon, for example, climate change policy. Cost-benefit analysis mixes statements concerning efficiency and distributional aspects (see e.g. *Mohr* (1995), *Azar/Sterner* (1996)). However, neoclassical models concentrate principally on efficiency aspects. But when investigating long-term projects, it is necessary to strictly separate distributional aspects from efficiency ones.

Ethical aspects cannot be used to legitimatize intergenerational discounting either. It is neither possible to fall back upon the theory of utilitarianism nor upon the Rawlsian fairness theory in order to justify intergenerational discounting. In the various contract-theoretical concepts following Rawls in environmental ethics - environment as a fundamental liberty (see *Singer* (1988)) or as an economic good, where the difference principle could be applied as a fairness norm (see *Pearce* (1988)) - the equal treatment of generations is stressed explicitly. Causes of pure time preference are attributed to human impatience and myopia. These phenomena are connected with weakness of will, weakness of imagination, defective telescopic faculty etc., all of which cannot be ethically accepted as reasons for intergenerational discounting. Well-known authors such as *Hume*, *Ramsey*, *Pigou*, *Harrod*, and *Georgescu-Roegen* reject pure time discounting of future utilities because they regard it as irrational and immoral. Cline and Broome argue in the same way in reference to global warming (see *Cline* (1992), *Broome* (1992)). *Broome* further denies the empirical relevance of the pure preference for the present and states that a positive interest rate can be explained by causes other than time preference (*Broome* (1992)).

Nobody knows if a pure time preference rate really exists and if so, how high it might be. Some authors deny the existence of a positive pure time preference rate (see e.g. *Schumpeter* (1952), *Hampicke* (1992)). Various attempts to estimate the pure time preference rate have produced different results and are not comparable with each other because they mix different influences, e.g. individual versus societal rates, short-term versus long-term rates, utility- and consumption-oriented rates, time preference rates of industrialized and developing countries etc. (see for comprehensive overall views *Pearce/Ulph* (1995) and *Price* (1993)). In economic models of climate protection, a standard rate of 3% is applied (see among others *Nordhaus* (1994), *Manne et al.* (1995), *Nordhaus/Yang* (1996), *Peck/Teisberg* (1994), etc.). *Pearce/Ulph* (1995) mention further studies in which the pure time preference rate tends to be around 1.5%. Experimental behavior-theoretical studies partially result in negative pure time preference rates (see among others *Loewenstein/Prelec* (1992), *Loewenstein/Prelec* (1991), *Kahneman et al.* (1991), *Thaler* (1981)).

With the assumption of a positive pure time preference rate, *Ramsey* models contain a contradiction as well. If the equilibral development goes along with constant population and constant per capita income, then the marginal productivity of capital and the growth time preference rate equal zero and a positive pure rate of time preference cannot exist. In *Ramsey* models, only the growth time preference rate should be applied, even if this contradicts mathematical necessities (convergence of the utility integral to a constant value).

In summary, no convincing reasons exist for discounting the utilities of human beings only because they are living in the future. The ethical basis, the methodology of neoclassical models and the inherent rationality assumptions forbid the application of an individual pure time preference rate where future generations are concerned.

3.2 Growth Discounting

An individual growth discount rate can be determined when we make special assumptions about the utility function and the growth of consumption. We want to work with a CRRA-utility function (constant relative risk aversion) which is characterized by:

$$(5) \qquad U[C_t] = \frac{C_t^{\,1-\varepsilon}}{1-\varepsilon} \; .$$

The discount factor is given by $(1+g)^{\varepsilon \cdot t}$ for constant consumption (real) growth rates g. The term $\varepsilon \cdot g$ is a good approximation for this expression for plausibly small values of g. This shows the equivalence to one component of the ***Ramsey* rule** (see equation (2)). Taking the logarithmic utility function as a special case where $\varepsilon = 1$, the discount rate is equal to the growth rate of per capita consumption.

Growth discounting can be utilized in intergenerational comparisons as well. However, two assumptions have to be fulfilled: diminishing marginal utility with respect to consumption when consumption increases, and long-term growth. If there is negative growth, we have to discount negatively. Even authors who are critical of intergenerational discounting acknowledge this argument (see e.g. *Cline* (1992)). Discounting now means that a future individual values an extra unit of consumption with a lower marginal utility than a present one only because the future individual is wealthier. The utility function is the same for both of them. If we accept this idea, then the growth discounting method is only a necessary condition for maximizing utilities intertemporally in the neoclassical model. The same levels of utility are given the same weights, thus, no differences exist between generations. The requirement for justice of utilitarianism is actually fulfilled, but only in this case. If one did without discounting in this situation, one would rank future generations higher than today's generation if there is a positive growth rate in the economy. Global warming policy appears to be too beneficial. However, if we carry out cost-benefit analyses in utility units, consumption discounting is impermissible because all effects of diminishing marginal utility are taken into account in the utility function itself (see table 1).

We should keep in mind that individual welfare is influenced by both consumption and environmental resources. Despite positive per capita consumption growth rates, it is possible that future individuals' welfare is not significantly higher than the present's because the environmental conditions have deteriorated. The increase in individual welfare is possibly quite modest or even negative. The development of the growth rate in the very long-term is most uncertain. Neoclassical growth theorists stress unlimited technological progress which guarantees a positive long-term growth rate of per capita consumption. On the other hand, ecological economists are critical of future development because of limits of natural resources and the possible endangering of the natural existential basis.

Even reasonable predictions of the growth rate cannot conceal that methodological problems with respect to how to determine utility and how to specify the utility function still exist. The total welfare of an individual is not measurable in cardinal units. This is the most important critical point of view concerning the scientific utilization of the growth discount rate and, therefore, against the usage of neoclassical OLG-models according to section 2. Even attempts to estimate the elasticity of marginal utility of consumption cannot deny the fact that utility is not objectively ascertainable in reality. All of the statements are speculative. It is unknown if and how rapidly utility does increase with rising consumption. Knowing that marginal utility is decreasing is insufficient. It is also impossible for politicians to have information about the utility functions of the citizens and, therefore, they are unable to control the assumptions of the cost-benefit calculation. This implies that it is useless to repeat the computations with alternatively higher or lower rates. Nobody knows which assumptions are meaningful. If there are no clues about the rate of decrease of the marginal utility, then there is hardly another possibility for researchers other than to ignore the phenomenon of diminishing marginal utility as a source of legitimization for discounting.

The growth discount rate is of special relevance when individuals in different countries with, more importantly, different welfare levels are concerned by a project. The not yet fully developed countries strive for high growth in order to catch up vis a vis the industrialized countries. Therefore, one can assume a higher growth time preference rate for those countries. In industrialized countries, the growth time preference rate will be lower due to the already realized higher level of individual and societal welfare.

In summary, neglecting methodological problems of cardinal utility measurement, a positive time discount rate can be founded on a positive GDP/GNP growth rate and consumption growth rate, respectively. Inevitably, this makes it an approximative and subjective procedure. However, the growth rate of GDP/GNP (consumption), can be utilized as a suitable indicator for the growth of individual and societal welfare. If the cost-benefit comparison is undertaken in utility units, the application of the growth time preference rate in discounting is not allowed because the utility units take the decreasing marginal utility directly into account.

4. The Treatment of Opportunity Costs

Equation (2) shows that in a **first-best world** where no distortions of market allocation caused by, for example, government interventions and/or uncorrected market failures, the distinction between the rate of opportunity costs and the rate of time preference is unnecessary. Both rates correspond to each other and equal the exogenous market interest rate i (see above). This

assumption is extremely impractical. In the **real world**, one can see that time preference rate and the opportunity cost rate differ. It has to be assumed that the opportunity cost rate exceeds the rate of time preference. In this case, which rate will be used in the intergenerational context is decisive. One has to take into consideration, though, that the two underlying variables, consumption and investment, are not comparable.
Implementation of a public project requires the usage of scarce resources which have to be taken from other usages. Other consumption goods are forgone directly or indirectly - via the omission of investments. These lost returns represent the opportunity costs of the public project. For discounting it is essential to what extent this displacement directly affects consumption or investment. In the simplest case, we assume that only consumption is displaced. The usual formula for the net present value of a public investment then only contains consumption units, which are to be discounted using the social rate of time preference:

$$(6) \qquad PV = -C_0^* + \frac{C_1 - C_1^*}{1+\delta} + \frac{C_2 - C_2^*}{(1+\delta)^2} + \ldots + \frac{C_n - C_n^*}{(1+\delta)^n} \ ,$$

where the variables are defined as follows: C_t = consumption effects of the public investment, C_t* = lost consumption of other goods, δ = social rate of time preference.
In the realistic case of large long-term public projects, other private investments are displaced as well. These investments would have allowed the provision of consumption goods in future periods, in accordance with their internal rate of return *r*. Application of the **Harberger Rule** demands that total lost consumption and investment, respectively, have to be discounted using a weighted rate composed of the marginal time preference rate and the rate of return of the displaced investments. Let us have a look at an example: due to investment and current expenditures of a public project, 20 % of other private investments (I_t*) are displaced and 80 % of consumption (C_t*), respectively. We obtain the following formula of net present value, applying the discount rate $h = 0{,}8 \cdot \delta + 0{,}2 \cdot r$:

$$(7) \qquad PV = -I_0^* - C_0^* + \frac{C_1 - I_1^* - C_1^*}{1+h} + \ldots + \frac{C_n - I_n^* - C_n^*}{(1+h)^n} \ .$$

This method is logically inconsistent because unequal units are added and subtracted. Displaced investments and displaced consumption are not equivalent. Usually, investment units are of higher value than consumption ones (in second-best economies). Therefore all variables have to be expressed in consumption units in the net-present-value formula.
It is possible to estimate intertemporal negative consumption effects directly, but quite complicated. Instead we can apply simplifying methods which are suggested in the literature to obtain some **shadow prices of capital**. *Cline* (1992) uses a method which represents the annuity of a displaced investment as continuously lost consumption (**annuity method**): we have to determine the actually displaced investments in a particular time period. Next we have to calculate the annuity within the expected lifetime by using the estimated rates of return of the displaced investments. For computing present values at the time where investments have been replaced, we have to use the social time preference rate. The outcome is called the "**consumption equivalent**". If we apply the consumption equivalent to one unit of investment, then the

shadow price of capital, v_c, results. It expresses how much one unit of capital is worth in consumption units. The shadow price of capital of an investment which is characterized by the rate of return r and the lifetime n is given by the annuity a, calculated with the rate of return r, multiplied with the inverse of the annuity b, computed on basis of the social time preference rate δ:

$$(8) \qquad v_C = a \cdot b \quad \text{where} \quad a = \frac{r(1+r)^n}{(1+r)^n - 1} \quad \text{and} \quad b = \frac{(1+\delta)^n - 1}{\delta(1+\delta)^n}.$$

If r corresponds to δ, the shadow price of capital equals one. This is the constellation in neoclassical first-best analysis. Investment and consumption units are valued equally. This means that the displaced amount of investment is equal to the loss of consumption units. The shadow price of capital v_c is greater than one whenever the rate of return r exceeds the social rate of time preference δ and when we argue in second-best economies, respectively. *Cline* uses the following data in his climate model: timespan of the investments n=15 years, internal rate of return r=8%, and the social rate of time preference (actually the growth discount rate g) δ=1.5% (δ=2%). A shadow price of capital of 1.56 (1.50) results.

The main idea of this method is that recovered capital and returns should be continuously consumed according to the annuity. This is contradictory if the rate of return r has been calculated as the internal rate of return, which implies that capital returns have to be permanently reinvested throughout the whole lifetime. However, it is suitable if we use a method for calculating the internal rate of return which takes into account that the investor maintains at least the initial capital stock but wants to consume parts of the real returns of the investment. Generally, this rate is smaller than the original one, but it is more operational.

This contradiction can also be avoided if we assume that neither the complete initial capital stock nor the returns during the lifetime of the investment can be consumed. The initial capital accumulates according to the calculation of compound interest. It is only possible to increase consumption at the end of the investment period (**end of horizon-method**). The internal rate of return of any investment - displaced at the planning period zero and providing additional consumption units throughout the whole timespan of n years - can be calculated according to:

$$(9) \qquad I_0(1+r)^n = C_1(1+r)^{n-1} + C_2(1+r)^{n-2} + \ldots + C_n \ .$$

Discounting to the planning time using the social rate of time preference and applying the shadow price of capital v_{eoh} to one investment unit results in:

$$(10) \qquad v_{eoh} = \frac{(1+r)^n}{(1+\delta)^n}.$$

v_{eoh} exceeds v_c for all $r>\delta$ and for a marginal propensity to save with respect to returns of investment smaller than unity. If we employ *Cline's* data, the shadow price of capital, v_{eoh}, is 2.54 (δ=1,5%) and 2.36 (δ=2%), respectively. The problem with using this method is that the investor cannot consume during the lifetime of the investment. It is only possible for him to consume all accumulated capital at the end of the planning horizon. This is not very realistic, especially if we investigate long-term investments.

In contradiction to those models, *Bradford* (1975) uses a method where the marginal rate of consumption is applied to total accumulated capital. Reductions of the initial capital stock are, therefore, possible. Another way for determining a shadow price of capital has been derived by *Lind* (1982) and *Zerbe/Dively* (1994), respectively. In their model, it is only possible to consume the returns of investments. A positive marginal propensity to save with respect to investment returns implies an increasing capital stock throughout the planning horizon.

Bradford investigates the effects of a one-period investment on the consumption and investment profiles in any of the following (n) periods within the planning horizon, which has been determined exogenously. The rate of return r and the marginal propensity to save with respect to the accumulated initial capital stock (wealth) s are constant throughout the planning horizon. We standardize our investment to unity. The investment in period 0 yields a wealth (W) in period 1 of $W(1)=(1+r)$. This results in a consumption level in period 1 of $c(1)=(1+r)\cdot(1-s)$. The individual saves the amount $s(1)=s\cdot(1+r)$. In period 2, the initial capital stock increases to $W(2)=s\cdot(1+r)^2$. $W(2)$ is split up into consumption $c(2)=(1-s)\cdot s\cdot(1+r)^2$ and saving $s(2)=s^2\cdot(1+r)^2$. Reinvestment of $s(2)$ produces a wealth in period 3 of $W(3)=s^2\cdot(1+r)^3$ which can be used for consumption $c(3)=(1-s)\cdot s^2\cdot(1+r)^3$ or for reinvestment $s(3)=s^3\cdot(1+r)^3$. This process continues throughout the whole planning horizon. If we want to determine the shadow price of capital, we have to discount all consumption amounts of each period to the planning time by using the social rate of time preference. This yields:

$$(11) \qquad v_B = (1-s)\cdot\frac{(1+r)}{(1+\delta)}\cdot\sum_{j=0}^{n}\left[s\cdot\frac{(1+r)}{(1+\delta)}\right]^j \qquad \text{where} \qquad s\cdot\frac{(1+r)}{(1+\delta)}<1$$

has to be valid so that v_B converges. In our specification, as in most realistic cases, the expression in equation (11) converges swiftly against a constant value. The Bradford criterion becomes more realistic when we give up the restrictive assumptions about the constancy of r and s for each period within the planning horizon. This is shown in the original paper of *Bradford* (1975) or in the comments by *Lind* (1982) and *Cline* (1992).

Lind (1982) allows only consumption to such an extent that the initial capital stock is (at least) held constant over the whole planning horizon. Reinvestment has to be undertaken to maintain the initial capital stock. The maximum possible consumption per period is given by the internal rate of return multiplied with the initial capital stock. We want to consider a one-period investment as well, and the initial capital stock is standardized to unity (adaptation of *Lind's* method by *Zerbe/Dively* (1994)). Furthermore, we presume constant r and s. In period 1, the capital stock has increased to $W(1) = (1+r)$. The investor is only allowed to split up his income r, the return on investment, into consumption and reinvestment. Additional consumption of $r\cdot(1-s)$ is available in period 1. The amount $r\cdot s$ will be reinvested and increases the initial capital stock in period 1. Wealth in period 2 is then given by $W(2) = (1+r)\cdot(1+sr)$. Only the return of the capital stock of period 1, $r\cdot(1+sr)$, can be consumed or reinvested in period 2. The investor is able to consume an amount of $C(2) = (1-s)\cdot r\cdot(1+sr)$. Reinvestment in period 2 is given by $S(2) = s\cdot r\cdot(1+sr)$. This procedure continues for all following periods throughout the planning horizon.

The capital stock grows continuously according to the rate $r \cdot s$ (for all s>0). Equation (12) provides an overall view of the development of consumption C and wealth W per period:

$$
(12)\qquad
\begin{array}{ll}
C(0) = 0 & W(0) = 1 \\
C(1) = (1-s)\cdot r & W(1) = 1 + r \\
C(2) = (1-s)\cdot r \cdot (1+sr) & W(2) = (1+sr)\cdot(1+r) \\
C(3) = (1-s)\cdot r \cdot (1+sr)^2 & W(3) = (1+sr)^2 \cdot (1+r) \\
\vdots \qquad \vdots & \vdots \qquad \vdots \\
C(n) = (1-s)\cdot r \cdot (1+sr)^{n-1} & W(n) = (1+sr)^{n-1} \cdot (1+r)\ .
\end{array}
$$

In order to determine the shadow price of capital, we have to discount all consumption units throughout the planning horizon back to the planning period. The relevant discount rate is the social rate of time preference. The shadow price of capital is given by:

$$
(13)\qquad v_L = (1-s)\cdot r \cdot \sum_{j=1}^{n} \frac{(1+sr)^{j-1}}{(1+\delta)^j}\ .
$$

The sum in equation (13) is a geometrical series and converges to a constant value, just like the Bradford-criterion, if $s<\delta/r$.

The methods of *Bradford* and *Lind* and *Zerbe/Dively*, respectively, cannot be compared directly. The reason is that the marginal propensities to save have different points of reference. *Lind* requires that the capital stock should at least be constant over time, whereas *Bradford* explicitly allows the initial capital stock to decrease. If the reinvestment quota in the *Bradford* model is for example 30%, then the capital stock (wealth of the human being) declines rapidly. However, a positive marginal rate of saving in the *Lind* approach signifies an increasing capital stock throughout the whole planning horizon.

The "reinvestment methods" by *Bradford*, *Lind* and *Zerbe/Dively* assume that an investment induces subsequent investments according to a determined mechanism (in compliance with a fixed marginal propensity to save) throughout the whole planning horizon. If we investigate single investments on the other hand, we are reducing potential investment series to pieces. Each displacement of an investment has to be valued by determining its own shadow price of capital. This method is more flexible. It takes into account all kinds of investment effects. Therefore, opportunity costs calculated on this basis are more accurate.

Systematic differences in the level of the rates of return of investments which are displaced can exist between not yet fully developed countries and industrialized countries. In developing countries, the rates of return of certain investments (education, public health, transport, public administration, etc.) are above average. This is caused by the presence of technological deficiencies in comparison to industrialized countries. In developing countries, for example, the same expenditures in climate protection as in industrialized countries would enter a cost-benefit calculation of global climate protection with considerably higher opportunity costs. Together with the relatively high rate of time preference, this would lead to a more reserved valuation of climate protection policy in these countries.

In summary, the cost-benefit analysis would be incomplete and the result would be distorted if the displaced returns of omitted investments were not considered. The profitability of public projects would be overestimated. The expansion of governmental activity would greatly exceed the efficient level. A lot of public investments would be carried out which possess lesser social rates of return than private investments. Virtually all entrepreneurial activity would be suppressed. In the case of long-term public projects such as climate protection, this distortion would not only be disadvantageous for today's generations but for future generations as well because the exaggerated goal of climate protection would face an insufficient capital accumulation (supply with material consumption goods). These objections do not hold any longer if cost-benefit analyses list the project costs in total - even if necessarily simplified - using the shadow price of capital methods.

5. Adjusted OLG-Discounting Model with respect to intergenerational comparisons

Beginning with neoclassical theory, we want to derive a methodology for discounting intergenerationally in a more correct way than the conventional theory does. This will be done in the framework of an OLG-model, taking into account all critical remarks of the previous chapters. Because we use shadow prices of capital to determine opportunity costs, we are able to fully concentrate on time preference rates as discount rates. The necessity of having intergenerational effects in mind when determining present values in the framework of cost-benefit analysis has been outlined by *Kula* (1992), *Kula* (1997) and *Burton* (1993). A more detailed analysis of the following discounting method can be found in *Bayer/Cansier* (1998).
First of all, some simplifying methodological assumptions are required. We want to concentrate our analysis on the consumer side. Production effects and the production process itself shall not be investigated primarily. We demonstrate our method within a partial framework, but we do not leave opportunity costs unconsidered. Therefore, once again, we concentrate our analysis on consumption effects.
Now the technical assumptions. We demonstrate our discounting method in the framework of global warming. The number of generations living simultaneously is three. Each generation lives for three periods. The births and deaths of all generations are defined as follows: The oldest generation A lives one more period and dies at the end of period t_0. Generation D is born at the beginning of period t_1. We want to assume for convenience that these two points in time are identical. The procedure continues: generation B lives two further periods at the beginning of the planning horizon and dies at the end of period t_1 (beginning of t_2), generation C lives for three more periods and dies at the end of period t_2. Global warming policy causes consumption changes in all periods. These effects - consumption increases as well as decreases - are supposed to equally concern all living generations. The valuation of consumption effects is the same throughout the total planning horizon. This means that the preferences of all living generations are constant. The age structure of the population is assumed to be constant throughout the whole planning horizon as well. Greenhouse policy is started in period t_0 (see

table 2 for further details). The total consumption per period of all living generations is represented as the column sum. The consumption discount factor reaches a constant value after a few periods (in this case as of period t_2, but in general from that period, where we subtract one from the maximum lifetime).

Generation	t_0	t_1	t_2	t_3	t_4	t_5	…	t_n	Sum
A	c_0								c_0
B	c_0	$c_1 \cdot \theta^{-1}$							$c_0 + c_1 \cdot \theta^{-1}$
C	c_0	$c_1 \cdot \theta^{-1}$	$c_2 \cdot \theta^{-2}$						$c_0 + c_1 \cdot \theta^{-1} + c_2 \cdot \theta^{-2}$
D		c_1	$c_2 \cdot \theta^{-1}$	$c_3 \cdot \theta^{-2}$					$c_1 + c_2 \cdot \theta^{-1} + c_3 \cdot \theta^{-2}$
E			c_2	$c_3 \cdot \theta^{-1}$	$c_4 \cdot \theta^{-2}$				$c_2 + c_3 \cdot \theta^{-1} + c_4 \cdot \theta^{-2}$
F				c_3	$c_4 \cdot \theta^{-1}$	$c_5 \cdot \theta^{-2}$	…	…	$c_3 + c_4 \cdot \theta^{-1} + c_5 \cdot \theta^{-2}$
G					c_4	$c_5 \cdot \theta^{-1}$	…	…	$c_4 + c_5 \cdot \theta^{-1} + c_6 \cdot \theta^{-2}$
H						c_5	…	…	$c_5 + c_6 \cdot \theta^{-1} + c_7 \cdot \theta^{-2}$
⋮						⋮	⋱	…	⋮
Sum	$3 \cdot c_0$	$c_1 \cdot (1+2 \cdot \theta^{-1})$	$c_2 \cdot (1+\theta^{-1}+\theta^{-2})$	$c_3 \cdot (1+\theta^{-1}+\theta^{-2})$	$c_4 \cdot (1+\theta^{-1}+\theta^{-2})$	$c_5 \cdot (1+\theta^{-1}+\theta^{-2})$	…	…	Σ

Table 2: Benefit and cost effects in a three generation model, $\theta = (1+\delta)$

We argue as follows in order to calculate a present value in the planning period t_0: each generation discounts the consumption effects which were induced by an investment in planning period t_0 to the start of its life. Generation F, for example, discounts its lifetime consumption to period t_3. In order to calculate a present value at planning time t_0, we have to discount the determined value once again to t_0. In this context, we have to take into consideration that the discount factor for fixing the present value at time t_0 can only be comprised of the growth discount rate. Within the generations, the value of the discount rate equals δ, the sum of the pure time preference rate and the growth discount rate ("**intra**generational discounting"). In order to relate lifetime consumption to the planning period of the climate policy, we discount **inter**generationally and thus cannot use the pure time preference rate.

It is important to remember how to handle consumption growth in our discounting model: If there is a positive (consumption) growth rate, we have to discount intergenerationally with a positive growth discount rate. If there is no consumption growth in the economies (g=0), then we cannot discount with a growth discount rate. This implies that all generation-specific present values at the beginning of the lives of each generation have to be taken into account with their values at this time period in order to determine present values in the planning time period t_0. Of course, if there is negative growth in some economies, we have to discount negatively. Future effects have to be valued more highly in today's units because of diminishing consumption possibilities.

The model becomes more realistic if we increase the number of generations to about 40. This will sufficiently express the maximum remaining lifetime expectancy of the youngest adult generation world-wide. The generations living in the periods 0 to 39 discount their investment-induced consumption effects directly to the planning period t_0. This is amended from generation 40 on. Consumption effects belonging to this generation are discounted to the beginning of their lives (period t_1). In order to correctly analyze benefits and costs, we have to discount the present value at period t_1 to the planning time t_0 again by using the growth discount rate. The further the generations live in the future, the bigger the distance is between the birth of any future generation and the planning period t_0 for the cost-benefit analysis. Thus, the discount factor increases exponentially here as well, but with a smaller rate than in the *Ramsey* model. The present value of all effects in the OLG-model is always bigger than in the *Ramsey* model. The difference increases rapidly with increasing time distances.

We want to have a look at an **example** to explain the differences. We assume only one consumption effect with an amount of 400 200 years from now. In the *Ramsey* model, the present value (PV_R) - discounted using a pure time preference rate ρ=3 % and a constant growth rate of per capita consumption g=3 % (ε=1) - is given by:

$$PV_R = \frac{c_{200}}{(1+\rho+g)^{200}} = 3.47\cdot 10^{-3}. \tag{14}$$

In the OLG-model, the present value changes. The consumption amount of 400 in period t_{200} is distributed equally amongst all 40 living generations in period t_{200}. Each generation living in t_{200} receives an amount of 10 consumption units. Determining a present value in our concept is more difficult than in the *Ramsey* model because of the correct treatment of generation-specific consumption effects. The effects occurring in the periods exceeding the maximum life expectancy are discounted by just using the growth discount rate. Effects within the individual lifetimes **can** be discounted by using the growth discount rate as well as the pure time preference rate. The present value of investment-induced consumption effects can be calculated according to equation (15):

$$PV_{OLG} = \sum_{j=0}^{L-1}(L-j)\cdot\frac{c_j / G_j}{\left(1+\rho_j+\varepsilon_j\cdot g_j\right)^j} + \sum_{\ell=1}^{PH}\frac{\sum_{i=\ell}^{\ell+(L-1)}\frac{c_i / G_i}{\left(1+\rho_i+\varepsilon_i\cdot g_i\right)^{i-\ell}}}{\left(1+\varepsilon_\ell\cdot g_\ell\right)^\ell}, \quad \text{where} \quad c_i, c_j = 0 \quad \text{for all} \quad i, j > PH. \tag{15}$$

PH symbolizes the planning horizon of the analyzed investment project and L represents the life expectancy of each generation (in our example L=40). G is the number of generations which live simultaneously. The variables j, i, and ℓ are used as time indices. The first term of the sum considers the intragenerational consumption effects which appear in the planning period for all presently-living generations. In analogy to table 2, we want to assume that the climate protection policy cannot be anticipated by the individuals. Therefore, the living generations will value the project differently from those born after the planning period t_0. It would be easy, however, to assume perfect foresight in our calculation. Consumption effects affecting the generations living in the planning period are then considered and intragenerationally discounted in accordance with their life expectancy. The fracture in the numerator of the second term of the sum in equation (15) expresses the intergenerational consumption effects of the generation born after the planning period t_0. As these effects are discounted to the beginning of the lives of the respective generation only, the intragenerational present value has to be related to the planning period as well in order to evaluate the social profitability as perceived in the planning period. This is done by discounting using the growth time preference rate in the denominator of the fraction on the right-hand side of equation (15). We still have to consider the fact that intragenerational effects which become relevant after the end of the planning horizon cannot be taken into account in our calculation. Therefore consumption effects c_i or c_j (where $i, j > PH$) are not taken into consideration.

Looking at our example, a PV_{OLG} results as 0.6532. This is about 188 times larger than the *Ramsey* one. If the consumption effect takes place in t_{300}, then the OLG-present value is about 3.319 times larger than the *Ramsey* one (PV_{OLG}=0.03399; PV_R=1.024·10^{-5}). The difference diminishes if the consumption effect occurs in t_{100}. The OLG present value is about 10.6 times larger than the *Ramsey* one (PV_{OLG}=12.554; PV_R=1.179).

Looking at another example will help to illustrate our approach more clearly: we use a social time preference rate δ of 5 %, but the components vary. In the first case, ρ is assumed to be 3 % and g equals 2 %. In the second case, the discount rates are the other way round: ρ=2 % and g=3%. Of course, the Ramsey present value is the same in both cases: PV_R^{100}=3.042; PV_R^{200}=0.0231; PV_R^{300}=1.759·10^{-4}. Different components in the *Ramsey* rule do not change the overall results. However, this is not true in our OLG-model: in the case where ρ=3 % and g=2%, the following present values result: PV_{OLG}^{100}= 33.16; PV_{OLG}^{200}= 4.58; PV_{OLG}^{300}=0.63. In the 100 year case, the OLG-value is about 10.9 times larger than the *Ramsey* one. The differences become more distinct with increasing timespans: the present value is about 198 times larger in the 200 year case and about 3,582 times larger in the 300 year case. This changes in the second case, where ρ=2 % and g=3 %. The present values in the OLG-model are given by: PV_{OLG}^{100}=14.66 ; PV_{OLG}^{200}=0.763 ; PV_{OLG}^{300}=0.0397. This implies that the differences between the *Ramsey* and the OLG-present values become smaller: For the 100 year planning horizon, it is about 4.8 times larger, about 33 times larger in the 200 year case, and about 226 times larger in the 300 year case. This is due to the larger growth rate in the second case which is used for intergenerational discounting. This example shows clearly that our approach is more accurate than the *Ramsey* one. Although the *Ramsey* present value is the same in both cases, the profitability of the project can vary. This has to be taken into account in intergenerational decisions.

Opportunity costs can be included in this concept without difficulty. When using the shadow price of capital methods of *Bradford*, *Lind*, *Zerbe/Dively*, and the end of horizon method, we have to differentiate between discounting intra- or intergenerationally. For intragenerational shadow prices of capital, we can take the growth and the pure time preference rate into account: δ=ρ+g. If the evaluation project provides consumption effects for future generations, we are only allowed to use the growth discount rate for calculating present values: δ=g. Thus, we have to utilize different time preference rates with respect to discount intra- and intergenerational effects, respectively, when we determine shadow prices of capital as well. The statements change slightly when we use *Cline's* annuity method. In order to discount, we have to use the sum of the growth discount rate and the pure time preference rate $\delta = \rho + g$. The reason is that we have taken all consumption effects of all periods within the planning horizon into account and distribute additional consumption units equally according to the total time preference rate of the generation which plans the project, when we determine the annuity.

We want to have a special look at the differences of the analyzed discounting models. Therefore, the main characteristics of our approach are compared to the neoclassical OLG-model in section 2:

- We concentrate our analysis on project-induced consumption effects. This means that our approach does not require the general equilibrium assumption. We are able to judge projects as they are, without referring to lifetime consumption planning in the past. Therefore, the assumption of perfect foresight is not necessary, which makes our approach more realistic.
- The adjusted OLG-model is strictly consumption-oriented, taking consumption as a suitable indicator for (individual and societal) welfare. No cardinal utility measurement of generation-specific utilities in one hundred, two-hundred or more years is necessary.
- Opportunity costs can be taken into account in a very convenient way by determining the shadow prices of capital. The unsolvable problem in second-best economies - to determine "the" correct discount rate (opportunity cost oriented or time-preference oriented) in neoclassical models - is not relevant.
- Decision makers are able to take varying growth rates into account utilizing our approach. The usage of a single discount rate can easily be avoided. This makes our discounting model more powerful in empirical studies than the conventional neoclassical models.
- Our approach is more explicit with respect to discounting than the neoclassical one, where the discounting process is a consequence of the assumed behavior of all affected generations. In particular market failures in the long-term can be analyzed in a more correct way using our approach than with the neoclassical one. The whole discounting process itself is more transparent for intertemporal decision makers with our approach than with the implicit adaptation mechanism in neoclassical models.

In summary, the OLG-discounting method fits best in neoclassical cost-benefit analysis. Intergenerational distributional aspects are taken into consideration, as well as the complete inclusion of all relevant intragenerational utility effects. It is not necessary to perfectly apply this method in reality. Our simple model using the assumption of a finite lifetime of equally concerned generations provides much better results than the *Ramsey* model and is sufficient for empirical cost-benefit analyses.

We implicitly demand the usage of variable (growth) discount rates when we use our OLG-model. The traditional method of utilizing a constant discount rate can only be maintained if there is constant (real) growth in all investigated economies throughout the planning horizon.

This seems to be very unrealistic and, therefore, we want to relax this assumption. In our model, we have to take predicted (real) growth rates for all economies into account. Thus, the analyses using our discounting model get much better results than traditional cost-benefit analyses using a constant discount rate in intergenerational comparisons.

6. Political Summary

The failure to comply with the intergenerational aspect in discounting leads to an underestimation of long-term projects and political programs in cost-benefit analysis. Different project types are affected to differing extents by this discrimination. In infrastructure projects such as the construction of new railroad lines or highways, the main costs are incurred in the present, but the benefits are realizable in the short run as well. In the medium run, the benefits already outweigh the costs, so that generations living in the present still do benefit, and not only those born in the future. A substantial part of the effects of the projects is valued correctly. The underestimation of these long-term projects and thus the distortion of the decision as compared to short-term public projects is rather moderate in this case. This is different in the case of very long-term projects in which beneficiaries and cost bearers diverge. This holds true, for instance, for decisions about global climate protection, the protection of the ozone layer, and the conservation of biodiversity. Even small variations of the discount rate can result in negative net present values in this case. Actions designed to reduce greenhouse emissions, for example, will only contribute to an improvement of climate in 50 or more years. The costs enter today's planning decision with full weight, while the benefits of the far future are taken into account only to a very decimated extent.

We want to have a closer look at the model calculations done by *Nordhaus* (1994) - **the DICE-model** (Dynamic Integrated model of Climate and the Economy). With respect to discounting, *Nordhaus* assumed that there is an infinitely-lived agent with a constant pure time preference rate of 3 %. The overall discount rate diminishes from 6.5 % at the starting point to about 4.5 % in the year 2105. The difference between the two rates is characterized as the growth discount rate. Simulations with the original coding show that the optimal (efficient) climate protection policy leads to a reduction of the global average temperature by 0.2° C by the end of the next century as compared to the business-as-usual (bau) emission path without climate-protection measures (increase in the optimal case: 3.1° C, in the bau-case: 3.3° C). However, these are temperature increases for which natural scientists fear irreversible interference with the entire ecosystem all over the world (see e.g. *Houghton* (1994)). Our own sensitivity calculations with different discount rates show, on the other hand, that the variation of discount rates results in drastic changes in the optimal emission rate: in the year 1995, the optimal rate of reduction of greenhouse gases is 8.8% (related to the base year 1965 in the model) in the original model. If one relinquishes utility discounting, this rate increases to 38.3%. Also, by using a utility discount rate of one percent (two percent) p.a., a higher optimal emission reduction rate than in the original coding of 19.6% (12.5%) results. At higher rates, fewer emissions are reduced - 5.1% (ρ=5%); 2.7 % (ρ=8 %); and 1.9 % (ρ=10 %). This shows

that the choice of the discount rate can, ceteris paribus, lead to the result that drastic greenhouse gas mitigation as well as the (almost total) renunciation of this may be efficient.
The same holds for projects with high future costs, however, with the opposite sign. Nuclear power plant projects can serve as an example. The relatively current benefits face high future costs resulting from the shutdown of production plants and the risks of the final deposition of nuclear waste.

In decisions regarding the **usage of natural resources**, the level of the discount rate plays an important role as well (see e.g. *Cansier/Bayer* (1998)). For exhaustible resources, according to the Hotelling rule, an optimal exploitation path results if the growth rate of the price path of the resource equals the pure time preference rate. We want to demonstrate the considerations of a representative household. It wants to maximize the utility of a given stock (S) of the resource intertemporally by consuming the quantity R_t in time period t. The usual assumption of diminishing marginal utility holds for the utility function. Resource exploitation diminishes the given stock which is taken into consideration as a condition for utility maximization in equation (16). $\dot{S}$ symbolizes the first time derivative of the resource stock. The maximization problem is given by:

$$(16) \qquad \max \int U\big(C(R_t)\big)e^{-\rho t}dt \qquad \text{s.t.} \quad \dot{S} = -R\,.$$

The higher the discount rate is, the quicker the resource is exploited. Resource users wish to use the resource early in their lifetime. This leads the resource exploiters to begin immediate exploitation because of rising prices. Interests of future generations are neglected if the resource exploitation is so fast that the stock is already exhausted when they are born. If this is due to an excessively high pure time preference rate, this implies an intergenerational inefficient resource use path. The process moves more slowly, if the pure time preference rate is lowered. Households do not demand such high quantities of resources in the present as in the first case. This means that the resource stock can be utilized longer than in cases with higher pure time preference rates. The consideration of the intergenerational aspect would lead to a slower exploitation of the resource, which means a time advantage in research and development of substitutes.
In decisions regarding how to utilize renewable resources discounting with the pure time preference rate leads to higher current withdrawal quantities as well. The intertemporal utility maximizing problem is as follows:

$$(17) \qquad \max \int U\big(C(R_t)\big)e^{-\rho t}dt \qquad \text{s.t.} \quad \dot{S} = g(S) - R\,.$$

In comparison to the exhaustible resources approach where no growth of the resource during the planning period is assumed, the maximization problem changes. According to $g(S)$, there is natural growth of the renewable resource. For example, the resource stock is constant if the exploitation in period t equals the newly grown quantity: $g(S) = R$. By the way, this maximization problem is the same one as the *Ramsey* model of optimal capital accumulation given in equation (1), where capital is interpreted as a renewable resource. In addition to the pure time preference rate, a growth discount rate exists which can be the reason for a positive

discount rate in intertemporal utility maximization even if the pure time preference rate is set to zero.
Following the neoclassical model of optimal usage of stocks, higher withdrawal quantities will be shown as efficient, the higher the discount rate is, and the extinction of stocks of renewable as well as exhaustible resources will be reached even earlier. The supply position of generations in the far future is not regarded. Intergenerational discounting, on the other hand, recommends that renewable resource stocks are preserved and can be used for a long(er) time.

Another important political aspect concerns the different methods of discounting in **industrialized and developing countries**. Because of the lesser welfare situation in developing countries, their growth time preference rate is generally higher than in industrialized countries. The renunciation of consumption today weighs heavier than in industrialized countries. In addition, the return of investments is usually essentially higher due to the technical pent-up demand, so that one has to calculate with higher opportunity costs, especially in environmental protection measures. The different positions face one another in decisions about global environmental projects such as climate protection. This poses the question in which way projects should be discounted. Proceeding on the assumption of the conditions in industrialized countries, this conflicts with the interests of the developing countries because climate protection is evaluated too positively for them. This is just the reverse when the valuation is done according to the conditions prevailing in developing countries. For industrialized countries, climate protection would be considered to be too expensive. The contrasts will be mitigated if one proceeds from weighted growth rates (and if emerging opportunity costs are taken into account in the valuation of the projects with the help of shadow prices). However, a two step approach seems to be the most suitable one: starting point is the single economies or economic regions. The regional costs and benefits are discounted using the specific discount rates of the regions. This results in a project-specific present value for every region, taking into consideration the actual consumption increases and decreases, respectively, connected with the project and the adequate discount rate. In a second step, these present values are aggregated. Here, for instance, political necessities can be taken into account. If a positive global present value results, the project is efficient under cost-benefit considerations.

Since the member countries of the United Nations, during the Conference on Environment and Development held in Rio de Janeiro (1992), categorized their economic and environmental policies under the leading idea of **sustainable development**, it is also of interest in which way the discounting problem is related to the strategies of sustainable development. In economics, the neoclassical concept of weak sustainability (of a constant total capital stock) and the ecological-economic concept of strong sustainability (of a constant natural capital stock) are conflicting (see e.g. *Pearce et al.* (1989), *Pearce/Turner* (1990)). A development is regarded as sustainable in the neoclassical concept if per capita welfare remains constant over time. Man-made goods and nature are substitutes. Long-term interventions in nature (exploitation of exhaustible resources, exploitation of renewable resources exceeding the natural rate of regeneration, global deterioration of the environment which exceeds the natural assimilation

capacity, etc.) are always justified when the utility reduction incident is compensated for by a corresponding excess supply with man-made goods. Renunciation of climate protection would be sustainable in this sense, for instance, if the returns of CO_2-emissions not only contribute to an increase in actual consumption, but also enable investments which supply future generations with additional man-made consumption goods, thus compensating for the disadvantages due to climate damages. Further conditions under which constant utility is possible are described by the Hartwick rule (see *Hartwick* (1977)). The ecological economists call for the preservation of the vital functions of nature. These could not be substituted by artificial goods.
Both concepts exclude cost-benefit analyses and thus discounting. In the case of interference with the environment, a compensation in form of man-made investment is called for, or a degradation of the stock of environmental quality is not allowed. There is no room for economic considerations. Both concepts are not realistic. Nature is neither completely substitutable by man-made goods, nor are these substitution possibilities totally lacking. Besides it is not understandable why the supply of mankind in the far future should always be at least constant (or better) as compared to today's supply. In light of this, an intermediate conception of sustainability can be formulated: in the long run, certain economic as well as ecological minimum standards should be met. Such critical values should be determined for the degree of pollution of environmental media (health standards for human beings, animals, and plants), for the stocks of renewable resources (animal and plant stocks, survival conditions for populations and feeding standards for mankind) and for the usage of exhaustible resources. This concept offers the possibility of free decisions between provision with man-made goods and the usage of the environment. Each generation can put more weight on economic growth or environmental quality according to its preferences. The only condition is that the decisions of today’s generation do not hurt the ecological and economic minimum standards of future generations. Beyond the minimum standards, optimizing decisions can be made according to cost-benefit analysis. Sustainable and intergenerational discounting do not necessarily exclude each other.

The closing remarks make clear how important the correct choice of the discount rate is in the intergenerational context. In empirical cost-benefit analyses, therefore, the reasons for this choice always have to be provided, namely whether it is oriented on the opportunity costs or on the time preference of the population. The respective rates have to be carefully investigated before being introduced in the impending cost-benefit analysis. Only this procedure guarantees realistic findings. The usage of an unreflected (constant) discount rate represents reality insufficiently. Sensitivity calculations with bigger or smaller discount rates cannot overcome this shortcoming either: the cardinal problem, namely the choice of the correct discount rate(s) for the project to be realized, cannot be solved by doing so. If the level of the discount rate is contestable, it is impossible to judge whether a measure is (in-)efficient. The fixing of a discount rate simply to make calculations feasible has to be rejected due to the same reasons, especially if intergenerational effects are to be evaluated.

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