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Systematic discounting in climate policy analysis

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**Wirtschaftswissenschaftliche Fakultät
der Eberhard-Karls-Universität Tübingen**

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in
Climate Policy Analysis**

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1. Introduction

The level of the discount rate fundamentally influences the results of benefit-cost analysis concerning global climate change. Even minimal variations can change the outcome dramatically (Manne/Richels (1995), Fankhauser (1995), Hennicke/Becker (1995)). This is due to the large time lag between the start of the climate policy and its impact on climate change.¹ For this reason it is very important to avoid mistakes when determining the discount rate. Because of the relatively long time period involved with climate policy, it has to take into account the interests of the present generations as well as those of the future generations. Therefore the special question arises as to how to set an accurate discount rate in the intergenerational context. Up to now there has been no consensus about the correct way of determining an intergenerational discount rate. In most cases the intergenerational problem is completely ignored. The most common way of investigating long-term problems is to use the convention of a representative agent whose life span is either infinite or assumed to be the length of the relative planning horizon. The relevant discount rate is, therefore, the rate of time preference of this agent ("Ramsey-Model").² We want to demonstrate how to discount intergenerationally within the neo-classical framework, taking its ethical and methodological ideas into account. It is important to note that we do not want to question the applicability of neo-classical benefit-cost analysis. We assume that all valuation problems are solvable. In analyzing global warming, it is necessary to take into consideration that impacts of the climate policy can be measured in units of utility or consumption. Therefore we need to differentiate between the discounting of utility and the discounting of consumption.

Efficient strategies for climate policy are to be derived by using benefit-cost analysis. Therefore we have to examine whether or not social welfare can be improved by changing the initial position. Fair wealth distribution will not be discussed because economic theory is unable to make objective judgements about the impact of redistribution on social welfare. This is the reason, why the discount rate has to be independent of standards concerning intergenerational redistribution. Theoretical measurements of efficiency are the Pareto-principle, the real (or full) compensation principle and the Kaldor-Hicks (potential Pareto-) principle.

The Pareto-principle cannot be fulfilled in global warming policy. It is unavoidable that some generation is made worse off than the status quo. Looking at abatement policy for example, today's generations are discriminated in comparison to tomorrow's because they have to pay for the abatement policy without increasing their utility level. The only exception is, when climate protection is available at zero or negative costs ("no regret policy"). Some investigations state that there are some possibilities for no-regret policies, but a perceptible improve-

¹The European Environment Agency states that "the projected warming to about 2050 is relatively insensitive to changes in global economic activity, or politic initiatives, which may be undertaken between now and 2050." Stanners/Bourdeau (1995), p. 520.

²See Nordhaus (1994), p. 78. The Ramsey-agent maximizes his utility-function with respect to consumption on basis of 1965 for 40 further decades. The agent in the "Global 2100"-Model of Manne/Richels (1992), pp. 119ff plans until the year 2100. In the OECD-GREEN-Model the planning horizon ends 2050, see Lee/Martins/van der Mensbrughe (1994), pp. 13-22.

ment of the climate cannot be reached in that way (Cline (1992), Nordhaus (1991)). Based on the efficiency criterion, one could alternatively ask if climate policy should be rejected completely. In this case, tomorrow's generations would be made worse off in comparison to today's.³

Using the real compensation principle⁴ all disadvantages have to be offset. This criterion cannot work either. In testing whether or not climate policy should be implemented, today's generations would have to be compensated by tomorrow's. This kind of compensation is impossible because of technical problems and because of the public good character of climate policy (Lind (1995)). If we ask "Should global warming policy be rejected?" then tomorrow's generations need to be compensated for their loss. The current returns of additional CO₂-emissions would have to be absorbed sufficiently by implementing taxes. The tax revenue would have to be used for financing very long-term investments. Proceeds from these investments should only benefit generations in 50 or more years. Obviously, this principle is not practical.

Only the Kaldor-Hicks principle allows for relevant statements about global warming policy. Abatement strategies can be identified as efficient, even though there are both winners and losers. Climate policy (and renunciation of climate policy respectively) is advantageous, when the present value of the sum of the net utilities, discounted to the planning time, is positive. The principle is indifferent to redistribution effects which are the consequences of the global warming policy, and which lead to a change in the initial distribution.

2. Discounting Using the 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 ρ). The individual maximizes the sum of the weighted utilities of consumption according to the planning horizon T with reference to the planning time 0 in Ramsey-models:

$$(1) \quad \max U = \int_0^T u(c(t))e^{-\rho t} dt .$$

Equation (1) determines a consumption profile which is valid for all time periods $0, \dots, T$ of the planning horizon.⁵ If we transfer this assumption to other individuals, then the utility of a spe-

³See Mohr (1995) for politicoeconomic aspects of the different formulations of climate policy.

⁴See the different views in Lind (1995), pp. 379-389 and Birdsall/Steer (1993), pp. 6-8 on the one hand and in Page (1983), pp. 68-93 on the other.

⁵The reader should note the difference between this single planning method for all periods in the planning horizon and the possibility to modify the initial planned consumption profile after any period within the planning horizon. Strotz (1955/56), pp. 170ff shows how the initial consumption path is modified if the individuals are able to change their planning decision with respect to consumption. The individuals are acting time inconsistently if they are allowed to change their initial consumption profile and if they are influenced by a pure time preference which does not have an exponential form ("exponential discounting"). The individuals want to bring forward parts of the consumption units which they have initially saved for later periods in their lives. The higher their pure rate of time preference is, the more consumption units they will want to move forward in their lives.

cial good which is available for future generations is worth less than the same good is worth for today's generations in utility units. Discounting now implies an ethical judgement about the position of the generations.⁶ Future generations are worth less, the later they are born. This implicit setting of a norm is inconsistent with the 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: "... utilitarianism 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), p. 14, see Broome (1992) as well). Since the consequences of global warming concern future generations, too, their interests have to be taken into account when investigating efficient climate policy.

Valuation of future generations implies that economic theory gives up its neutrality regarding distributional aspects. Economic theory favours today's generations and discriminates against future generations because of distributional reasons. Judgements regarding climate policy are distorted; there is an innate bias against long-term climate protection. Benefit-cost analysis as a criterion for judging the implementation of global warming policy combines statements concerning efficiency and distributional aspects. However, this is not allowed in neo-classical models. It is necessary to strictly separate distributional aspects from efficiency ones.

Ethical aspects cannot legitimize 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 (Singer) or as an economic good, where the difference-principle could be applied as a fairness norm (Pearce) - the equal treatment of generations is stressed explicitly (Singer (1988), Thero (1995), Kersting (1993), Pearce (1988)). 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.⁷ Cline and Broome argue in the same way in reference to global

The consequence in long-term climate policy is that the longer the individuals live and the more possibilities they have to bring consumption units forward in their lifetimes, the less willing they are to invest in abatement policy.

⁶See already Solow (1974), p. 10: "The choice of a social discount rate is, in effect, a policy decision about that intergenerational distribution."

⁷Hume (1739), p. 538: "There is no quality in human nature, which causes more fatal errors in our conduct, than that which leads us to prefer whatever is present to the distant and remote."; Ramsey (1928), p. 543: "[discounting is] ethically indefensible and arises merely from the weakness of imagination"; Pigou (1929), p. 25: "But this preference for present pleasures does not - the idea is self-contradictory - imply that a present pleasure of given magnitude is any *greater* than a future pleasure of the same magnitude. It implies only that our

warming (Cline (1992), Broome (1992)). Broome further denies - as does Hampicke - 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), Hampicke (1992)).

How can utility discounting be justified in intergenerational comparisons? Schelling states that it is not necessary to solve discounting problems by regarding ethical aspects. The researcher should rather investigate real individual behaviour, which is unambiguous. Most human beings prefer their own consumption in comparison with the consumption of their descendants. It would be unusual if they acted in a different way. Individuals that live today want to discount consumption of future generations with very high rates, because they are thinking of themselves (Schelling (1995)). Utility discounting is implemented because individuals are separating their own utilities from those of other human beings (for criticism on this, see Birnbacher (1988), Hampicke (1992)). This is independent of all time aspects. Individual behaviour can be explained in that way, but it is questionable whether this behaviour influences governmental decisions concerning long-term climate policy. The interests of future generations have at least been taken into account by all member states of the United Nations since the Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992 (UNCED (1992)). Far-sighted acting is necessary in greenhouse politics.

The most important objection against not discounting at all is opportunity-cost-oriented. If we do not discount, the opportunity costs of climate policy would not be taken into consideration. The individual time preference as an empirical fact is represented by the market interest rate. Each investor compares the return on capital of conventional investments with market interest rates. Not discounting induces a crowding-out of investments yielding a positive rate of return. This will be inefficient.⁸ However, the opportunity cost argument can only be accepted if opportunity costs have actually been ignored. In this case, fundamental economic principles would have been violated. Evidently, all opportunity costs have to be considered. However, this should be done by calculating shadow prices of capital and not by discounting (see section 4).

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

telescopic faculty is defective"; Harrod (1948), p. 40: "... pure time preference, a polite expression for rapacity and the conquest of reason by passion."; Georgescu-Roegen (1979), p. 101: "'Let's eat, drink, and be merry today because tomorrow we may die' makes sense, *but only because humans are mortals*".

⁸See for example Nordhaus (1994), p. 125, who stresses: "If investments in equipment or human capital yield 10 percent annually, it would be inefficient to make investments in slowing climate change that yielded only 3 percent."

3. Discounting of Consumption: Growth Discounting

Special aspects may arise in situations of long-term economic growth. Any individual is then able to consume a greater amount in the future than today. In addition, the "law of diminishing marginal utility" is assumed to be valid. As a result, each individual values an extra unit of consumption in the future (t_{n+1}) less highly than the same extra unit of consumption today (t_n). Marginal utility with respect to consumption has decreased because of the rise of the total available consumption units. Equivalence of utilities would have been reached when in t_n the amount of extra consumption is less than in t_{n+1} . That is the reason for a positive discount rate in life-cycle models with positive growth rates, even when the pure time preference rate is zero. The growth-oriented discount rate is determined as the percentage decrease of the individual marginal utility from period t_n to period t_{n+1} because of the increasing consumption level. The discount factor for any utility at period t is equal to $[c(0)/c(t)]^\varepsilon$, where c is the per capita consumption and ε is the (negative) elasticity of marginal utility of consumption.^{9 10}

The 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 constant growth discount rate - as is usual in long-term problems. Thus, the elasticity of marginal utility of consumption and the growth rate of consumption have to be constant. The relevant utility function belongs to the CRRA-type (constant relative risk aversion):

$$(2) \quad U[c(t)] = \frac{c(t)^{1-\varepsilon}}{1-\varepsilon}.$$

The discount rate is given by $(1+g)^\varepsilon$ for constant consumption growth rates g . The term $\varepsilon \cdot g$ is a good approximation for this expression for plausible small values of g . The level of the growth discount rate is given by multiplying the elasticity of marginal utility of consumption with the per capita growth rate of consumption. 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.

In the next step, this individual valuation is transferred to intergenerational comparisons. If a positive growth rate exists, it should be discounted by using a positive rate, and if the growth rate is negative, we should discount negatively. Even the authors who are critical of intergenerational discounting in climate policy acknowledge this argument (Cline (1992)). Discounting now means that a future individual values an extra unit of consumption with a lower

⁹For determining the consumption level in period t , $c(t)$, we can use two different methods. On the one hand we can predict the amount, which any individual is able to consume in period t , using an ex-ante growth-prognosis. The problem is that prophecies can be very vague. On the other hand we can try to predict $c(t)$ by using an ex-post prognosis. Therefore we have to choose how long we want to go back in history in order to extrapolate those values into the future. The problem when using this method is that it could yield unrealistic values for today's circumstances. This implies that these estimates can be very inaccurate as well. Sometimes it is impossible to use traditional values for predicting the future.

¹⁰See Azar/Holmberg (1995), p. 12, Rabl (1996), p. 139, Sterner (1994), pp. 527ff, or Hanley (1992), pp. 39ff. Broome (1992), pp. 65ff states that a growth-oriented discount rate exists in a two-period microeconomical utility-maximizing model.

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 neo-classical model. The same levels of utility are given the same weights, so there exists no difference between generations. The requirement for justice of utilitarianism is actually fulfilled, but only in this case. It is no longer possible to neglect consumption discounting now. Otherwise we would rank future generations higher than today's. Global warming policy appears to be too beneficial. However, if we carry out the benefit-cost analysis in utility units, consumption discounting is unnecessary because all effects of diminishing marginal utility are then taken into account in the utility function itself.

However, 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 of individual welfare is possibly quite modest or even negative (this implies a negative discount rate). The development of the growth rate in the very long-term is most uncertain. Fundamental economical propositions about long-term growth rates differ widely. Neo-classical growth theorists stress "unlimited" technical 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 regarding how to specify a 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 usage of the growth discount rate. Even attempts to estimate the elasticity of marginal utility of consumption should not conceal the fact that utilities are not objectively ascertainable in reality. All the statements are speculative. It is unknown if and how rapidly utility does increase with rising consumption. It is not sufficient to know that there is diminishing marginal utility. It is impossible for politicians to have information about the utility functions of the citizens as well and, therefore, they are unable to control the assumptions of the benefit-cost 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 decreasing of the marginal utility, then there is hardly another possibility for researchers than to ignore the phenomenon of diminishing marginal utility as legitimisation for discounting.

4. The Treatment of Opportunity Costs

Costs of the improvement of climate arise as consumption or as investment losses. The displacement of investments induces a loss of consumption in the future. These losses are the opportunity costs of greenhouse policy. Opportunity costs affect primarily the present genera-

tions, if we investigate short-term investments. However, if long-term investments are concerned, future generations are hit as well.¹¹

If we are arguing by using opportunity costs, we have to guarantee that conventional consumption units can be substituted by environmental goods. In the case that man-made-goods are only weak substitutes for climate policy, then the opportunity costs tend to be low. Substitution of conventional consumption goods and environmental goods is only possible if the environmental quality exceeds an ecological subsistence level EQ_{min} . If this level is not guaranteed, no benefit-cost analysis can be applied. Only policies which ensure that the environmental quality is held above the ecological subsistence level can induce positive utility effects. The same argument justifies a physical, consumption oriented subsistence level (X_{min}). Substitutions are only possible if both subsistence levels are taken into account (see figure 1). Therefore it is very important for the opportunity cost level, and for the result of the benefit-cost analysis, to determine which climate objective should be examined. The higher the level of climate policy is, the more substitutional environmental and conventional goods are, and the greater the possibility is that greenhouse policy is inefficient. However, if the possibility for catastrophic climate changes is sufficiently high, benefit-cost analysis cannot be applied to examine efficient strategies in climate policy.

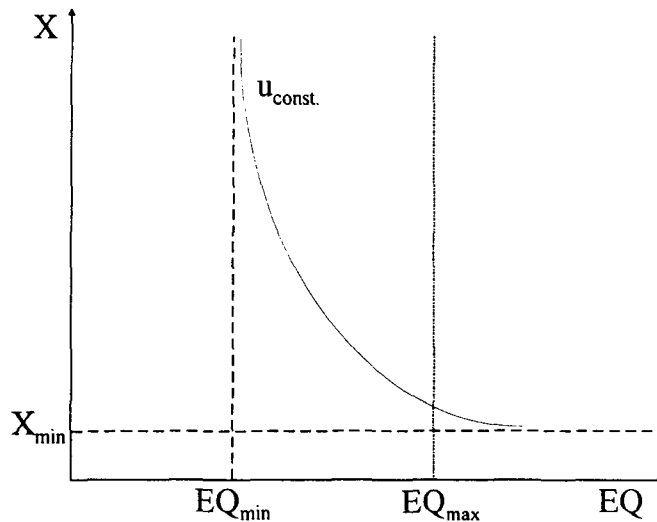


Figure 1: Substitution between conventional consumption goods and environmental goods if both an environmental subsistence level as well as a physical subsistence level exist.

Opportunity costs can be taken into account either by discounting or by direct calculation of the consumption effects of the displaced investments. We want to find out which method is more suitable when examining climate policy.

¹¹If we question whether the renunciation of improvements of the climate is advantageous, we can identify the negative impacts of climate change as costs. These costs appear in losses of consumption as well as in reductions in man-made-capital and in natural capital (deterioration of biodiversity, destruction of the rain forests, degradation, etc.). The returns of displaced investments are opportunity costs when investigating the renunciation of climate policy. The policy concerns future generations and their children and grandchildren.

Discounting method: We are discounting by using the rate of return of those investments which have been displaced by the climate policy. For example, global warming policy shall produce a return in 100 years of E_{100} . If we discount this amount, we are determining the sum of an alternative investment in the present which, continuously reinvested using a constant rate of return (r), would have induced the same wealth at time 100: $I_0 = E_{100}/(1+r)^{100}$. We are handling the returns (and costs) in all other periods exactly the same way. Global warming policy is advantageous if in the present actually fewer investments have been crowded out than could possibly have been displaced by equivalent revenues. If the policy replaces both consumption and investments simultaneously, then we have to use a weighted discount rate which is composed of a time preference rate as well as an opportunity cost rate (Harberger-rule).

However, this approach is inaccurate and unrealistic:

- Present values of consumption and investment units are not comparable. Investments are more valuable than consumption units, because they are augmenting the production capacities in the economy.
- Accumulated capital will never be fully reinvested in most cases. Moreover, it will be partly consumed. No living generation can consume if they reinvest their entire capital income.
- Reinvestment of returns of investments until any future period (generation) is arbitrary. In this case we assume that the real investment process follows the calculation of compound interest rules.
- It is unrealistic that capital which has been accumulated until any future period will be completely consumed at this moment.

Shadow-price of capital methods: Investments provide future consumption units. The negative effect of the displacement of investments is that future consumption goods will not be available. It is possible to estimate intertemporal negative consumption effects directly in order to compare them to the positive consumption effects of the greenhouse policy. Instead of this direct method we can apply simplifying methods which are suggested in the literature to get some shadow-prices of capital (Cline (1992)). Cline uses a method which fakes the annuity of a displaced investment as continuously lost consumption (**annuity-method**) (Cline (1992)): We have to determine the actually displaced investments in a special 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 to 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 capital unit 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 :

$$(3) \quad v_c = a \cdot b \quad \text{where} \quad a = \frac{r(1+r)^n}{(1+r)^n - 1} \quad \text{and} \quad b = \frac{(1+\delta)^n - 1}{\delta(1+\delta)^n}.$$

If r corresponds to δ , the shadow price of capital equals one. This means that the displaced amount of investment is equal to the loss of consumption units. The shadow price of capital v_c is bigger than one whenever the rate of return r exceeds the social rate of time preference δ . Cline uses the following data in his climate model: Lifetime of the investments $n=15$ years, internal rate of return $r=8\%$, and the social rate of time preference (actually the growth discount rate) $\delta=1.5\%$ ($\delta=2\%$). A shadow price of capital of 1.56 (1.50) results. The same shadow price of capital will be used for the investments which have been induced by the climate policy.

The 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.

This contradiction can be avoided if we assume that neither the complete initial capital amount 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 lifetime (**end of lifetime-method**). The internal rate of return of any investment - displaced at the planning time zero and with a lifetime of n years - can be calculated according to:

$$(4) \quad I_0(1+r)^n = E_1(1+r)^{n-1} + E_2(1+r)^{n-2} + \dots + E_n.$$

Discounting by using the social rate of time preference to the planning time and applying to one investment unit the shadow price of capital v_c^* results in:

$$(5) \quad v_c^* = \frac{(1+r)^n}{(1+\delta)^n}.$$

v_c^* exceeds v_c for all $r > \delta$. If we employ Cline's data, the shadow price of capital, v_c^* , is 2.54 ($\delta=1.5\%$) and 2.36 ($\delta=2\%$), 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.

Other methods for determining the shadow price of capital take into account reinvestment of accumulated capital (**reinvestment-methods**). Bradford (1975) uses a model, where the marginal rate of consumption is applied to the 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 Zerbo and Dively (1994). In their model, it is only possible to consume

the returns of investments. A positive marginal propensity to save implies an increasing capital stock throughout the planning horizon.

Bradford investigates 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 wealth s are constant throughout the planning horizon. We standardize the one period investment to unity. The investment in period 0 yields a wealth (W) in period 1 of $W(1)=(1+r)$. This facilitates 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:

$$(6) \quad v_B = (1-s) \cdot \frac{(1+r)}{(1+\delta)} \cdot \sum_{j=0}^n \left[s \cdot \frac{(1+r)}{(1+\delta)} \right]^j \quad \text{where} \quad s \cdot \frac{(1+r)}{(1+\delta)} < 1$$

has to be valid so that v_B converges.¹² In our specification, as in most realistic cases, the expression in equation (6) converges swiftly against the fix value:¹³

$$(7) \quad v_B = \frac{(1-s) \cdot \left[\frac{(1+r)}{(1+\delta)} \right]}{1 - s \cdot \left[\frac{(1+r)}{(1+\delta)} \right]}.$$

We will give up the restrictive assumptions about the constancy of r and s for each period within the planning horizon. The more general case of equation (6) can be represented by:

$$(8) \quad v_B = \gamma_t \cdot \left\{ (1-s_{t+1}) + \sum_{k=2}^{\infty} (1-s_{t+k}) \prod_{j=1}^{k-1} \gamma_{t+j} \cdot s_{t+j} \right\} \quad \text{where} \quad \gamma_{t+j} = \frac{1+r_{t+j}}{1+\delta_{t+j}}.$$

Zerbe and Dively argue - in contradiction to Bradford - in a growing economy (Zerbe/Dively (1994)). Consumption per period and the initial capital stock increase continuously if the marginal propensity to save with respect to the regular income is "normal": $0 < s < 1$. Zerbe and Dively consider a one-period investment as well. Further, they presume a constant r and s . The initial capital stock is standardized to unity. In period 1, the capital stock has increased to $W(1) = (1+r)$. The investor is only allowed to split his income r , the return on investment,

¹²We do not have to sum up all the amounts in the bracket to infinity as mathematical correctness would require, because the values of s , r , and δ in our constellation guarantee that the geometrical series converges rapidly.

¹³Lind (1982), pp. 51-52, has expanded the Bradford-model to multiple period investments. The shadow price of capital determined by equation (7) changes only by inserting an exponent according to the planning horizon to the expressions in the angular brackets (e.g. 10 years).

between 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 within the planning horizon. The capital stock grows continuously according to the rate $r \cdot s$ (for all $s > 0$). Equation (9) gives an overall view of the development of consumption c and wealth W (accumulated initial capital stock) per period:

$$(9) \quad \begin{array}{ll} c(0) = 0 & W(0) = 1 \\ c(1) = (1-s) \cdot r & W(1) = 1 + r \\ c(2) = (1-s) \cdot r \cdot (1+sr) & W(2) = (1+sr) \cdot (1+r) \\ c(3) = (1-s) \cdot r \cdot (1+sr)^2 & W(3) = (1+sr)^2 \cdot (1+r) \\ \vdots & \vdots \\ c(n) = (1-s) \cdot r \cdot (1+sr)^{n-1} & W(n) = (1+sr)^{n-1} \cdot (1+r) \end{array}$$

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

$$(10) \quad v_{zd} = (1-s) \cdot r \cdot \sum_{j=1}^n \frac{(1+sr)^{j-1}}{(1+\delta)^j}.$$

The sum in equation (10) is a geometrical series and converges (see the notes in endnote 12) to a constant value. Equation (10) can be simplified to:

$$(11) \quad v_{zd} = \frac{(1-s) \cdot r}{\delta - s \cdot r}, \quad \text{if } s \cdot r < \delta \text{ ("convergence condition").}$$

Comparing the different methods it can be stated:

- The discounting method is inappropriate for including opportunity costs. This method is logically inconsistent. It is assumed that the growth process can be represented by the calculation of compound interest. This is unrealistic as well. It is necessary to fall back upon shadow price of capital methods.
- The methods of Bradford and Zerbe/Dively cannot be directly compared. The reason is that the marginal propensities to save have different points of reference. Zerbe/Dively require that the capital stock should be at least constant over time, whereas Bradford allows explicitly that the initial capital stock decreases. 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 Zerbe/Dively model signifies an increasing capital stock throughout the whole planning horizon.
- The "reinvestment methods" 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.

- The method of Cline seems to be more realistic than the end of lifetime-method because of the assumption of continuous consumption.
- Altogether we suggest using the Cline method since it seems to be the most realistic one for determining a shadow price of capital.

Next we have to investigate how conventional opportunity cost calculation changes when we extend the analysis to environmental problems. We cannot utilize the private rate of return to determine the opportunity costs correctly in the environmental context. We have to adjust this rate because of the external effects. Investments in conventional capital are often associated with external costs (environmental burdens not concerning the climate). The social rate of return is lower than the private one. Climate protection is related to lower opportunity costs and is more likely to be profitable.

Influencing climate is a long-term process. We have to consider the time lag in climate policy when we are calculating the rate of return. If investments which yield long-term returns are displaced, we have to use the welfare level of future generations as the reference point for the valuation. This level depends upon long-term displacement effects and future environmental conditions. Present interest rates or private rates of return are not (sufficiently) suitable as indicator.

It is problematic to start out from certain reinvestment quotas for determining shadow prices of capital because of the external effects and the long-term aspects. The actual reinvestment behaviour of individuals is oriented towards the private rate of return. This fact is an argument for the usage of the Cline-method as well.

The returns of climate policy investment can partly be interpreted as investment itself, if climate conditions will improve in the future. For example, because of the stopping of global warming irreversible effects like sea level rising, species and ecosystem loss, morbidity and mortality, etc. are prevented. Natural capital is preserved without paying for those "investments". Therefore it is impossible to determine a rate of return for these effects. The shadow price of capital method cannot be applied. The only way to handle the effects correctly is to value the periodical utilities directly and use these values in benefit-cost analyses.

5. A long-term overlapping generations model (OLG-model)

The lifetime of human beings which we have used until now has been implicitly based on two different assumptions: in Ramsey-models only one generation exists, whose lifespan is as long as the planning horizon, and in our models only one new generation is alive in each new period. Both assumptions are unrealistic. Because of that we want to investigate how the

discounting process changes in a world where several generations of different ages are alive simultaneously. To simplify the analysis we reduce the number of generations to 4. Each generation lives for 4 periods. Global warming policy causes (net-)consumption changes in all periods. These effects - consumption increases as well as decreases - are supposed to concern all living generations equally. The valuation of consumption effects is the same throughout the total planning horizon. This means that all the preferences of the 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 1). The oldest generation A lives one more period, the second oldest generation B lives for two further periods and so on. The total consumption per period of all living generations is represented as a column-sum. The discount factor reaches a constant value after a few periods (in this case, as of period t_3 ; generally from the period, which results when we subtract one from the maximum lifetime).

We have to argue as follows in order to fix a present value in the planning time period t_0 : each generation discounts the consumption effects which were induced by an investment in planning time period t_0 to the start of their life. Generation G, for example, discounts their lifetime consumption to period t_3 . To calculate the present value at planning time t_0 we have to discount the determined value 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 generations the value of the discount rate equals δ , the sum of the pure time preference rate and the growth discount rate ("intragenerational discounting"). For applying lifetime consumption to the planning time of the climate policy, we are discounting intergenerationally and cannot use the pure time preference rate.

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_0	$c_1 \cdot \theta^{-1}$	$c_2 \cdot \theta^{-2}$	$c_3 \cdot \theta^{-3}$					$c_0 + c_1 \cdot \theta^{-1} + c_2 \cdot \theta^{-2} + c_3 \cdot \theta^{-3}$
E		c_1	$c_2 \cdot \theta^{-1}$	$c_3 \cdot \theta^{-2}$	$c_4 \cdot \theta^{-3}$				$c_1 + c_2 \cdot \theta^{-1} + c_3 \cdot \theta^{-2} + c_4 \cdot \theta^{-3}$
F			c_2	$c_3 \cdot \theta^{-1}$	$c_4 \cdot \theta^{-2}$	$c_5 \cdot \theta^{-3}$	...	...	$c_2 + c_3 \cdot \theta^{-1} + c_4 \cdot \theta^{-2} + c_5 \cdot \theta^{-3}$
G				c_3	$c_4 \cdot \theta^{-1}$	$c_5 \cdot \theta^{-2}$	...	...	$c_3 + c_4 \cdot \theta^{-1} + c_5 \cdot \theta^{-2} + c_6 \cdot \theta^{-3}$
H					c_4	$c_5 \cdot \theta^{-1}$	...	...	$c_4 + c_5 \cdot \theta^{-1} + c_6 \cdot \theta^{-2} + c_7 \cdot \theta^{-3}$
...						...	...	...	...
Sum	$4 \cdot c_0$	$c_1 \cdot (1 + 3 \cdot \theta^{-1})$	$c_2 \cdot (1 + \theta^{-1} + 2 \cdot \theta^{-2})$	$c_3 \cdot (1 + \theta^{-1} + \theta^{-2} + \theta^{-3})$	$c_4 \cdot (1 + \theta^{-1} + \theta^{-2} + \theta^{-3})$	$c_5 \cdot (1 + \theta^{-1} + \theta^{-2} + \theta^{-3})$	...	...	Σ

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

The model becomes more realistic if we increase the number of generations to about 40. This expresses the maximum remaining lifetime expectancy of the youngest adult generation

world-wide sufficiently. As of period 39 a constant discount factor results. The generations 0 to 39 discount their investment-induced consumption effects directly to the planning time t_0 . This is amended from generation 40 on. Consumption effects which belong to this generation are discounted to the beginning of their lives (period t_1). In order to analyze benefits and costs correctly, we have to discount the present value at period t_1 again to the planning time t_0 by using the growth discount rate. The further the generations live in the future, the bigger is the distance between the birth of any future generation and the planning time period t_0 for the benefit-cost analysis. Thus, the discount factor increases exponentially as well, but at a smaller rate than in the Ramsey-model. The present value of all effects in the OLG-model is always larger than in the Ramsey-model. The differences become more distinct with increasing time distances. We want to have a look at an example to explain these differences. In the Ramsey-model the present value (PV) of a consumption amount of 400 which is available in 100 years and which is discounted using a pure time preference rate $\rho = 3\%$ and a constant growth rate of per capita consumption $g = 2\%$ ($\varepsilon = 1$) is given by:

$$(12) \quad PV_R = \frac{c_{100}}{(1 + \rho + g)^{100}} = 3.0.$$

In the OLG-model, the present value changes. The consumption amount of 400 in period t_{100} is equally distributed amongst all 40 living generations in period t_{100} . Each generation gets an amount of 10 consumption units. The effects which occur in the periods which exceed the maximum life expectancy are discounted by using only the growth discount rate. This expression is symbolized in equation (13) by the factor outside the curved brackets.

$$(13) \quad PV_{OLG} = \frac{1}{(1 + g)^{60}} \left\{ \frac{1}{40} \cdot c_{100} \left(\sum_{i=0}^{39} \frac{1}{(1 + \rho + g)^i} \right) \right\} = 54.9.$$

The present value of consumption amount c_{100} which is available to all in period 100 living generations is about 18-times higher than in the Ramsey-model (54.9 versus 3.0). The difference between the present values will be even greater, if the planning horizon is extended. Planning for 150 years, the present value of the OLG-model is about 77-times higher (20.4) than the present value in the Ramsey-model (0.265). If we plan for 200 future periods the OLG-present value is 329-times higher than the Ramsey-value.

Opportunity costs can be included without difficulties in this concept. The statements change slightly when we use the annuity-method. For discounting we have to use the sum of growth discount rate and pure time preference rate $\delta = \rho + g$. The reason is that we have taken into account all consumption effects of all periods within the planning horizon when we determine the annuity. (If we use the other shadow price of capital methods, we are only allowed to use the growth discount rate for calculating present values if we have to discount effects exceeding the lifetime of the generations).

In summary: The OLG-discounting method is the most suitable in the neo-classical benefit-cost analysis. Intergenerational distributional aspects are taken into consideration, as well as

the complete inclusion of all relevant utility-effects intragenerationally. It is not necessary to apply this method in reality perfectly. 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 benefit-cost analyses.

6. Conclusion

Systematic neo-classical discounting according to its ethical and methodological basis concerning long-term environmental protection prohibits utility-discounting as well as consumption discounting of future generations using the pure rate of time preference. However, intragenerational effects can be discounted by using the pure rate of time preference. Only the OLG-model takes into account both requirements. The question, whether or not future generations' consumption effects should be discounted with a growth discount rate, cannot be objectively answered by researchers. Economic theorists frequently use a cardinal income-utility function, despite the methodological doubts. Opportunity costs have to be included by determining consumption equivalents, especially according to Cline's annuity method. The utility effects for the preserved natural capital have to be measured directly. Efficiency in neo-classical benefit-cost analyses will be improved by using our discounting concept rather than the conventional method. Thus, wrong decisions at the expense of long-term environmental policy will be avoided.

Abstract

We investigate the systematic intergenerational discounting of climate policy on basis of the neo-classical benefit-cost analysis. Reference point is the Ramsey-rule which results from optimal growth theory. The agents live infinitely long. This signifies that intergenerational comparisons do not exist. The resulting rates - the pure rate of time preference, the growth discount rate, and the opportunity cost rate - are examined in detail for their legitimacy regarding intergenerational comparisons. One result of our examination is that utility-based pure time preference rates cannot be justified ethically in intergenerational comparisons. Under certain conditions, the consumption based growth discount rate can be used where intergenerational aspects are concerned. If we discount long-term climate policy effects by using an investment-based opportunity cost rate, we further have to analyze the calculation of consumption equivalents. If we adjust the planning horizon to the life expectancy of human beings, a realistic discounting method would be to use an OLG-model. This method allows each living generation to discount intragenerationally with the sum of the pure time preference rate and the growth discount rate. As soon as intergenerational effects exist, one may only use the growth discount rate to calculate present values.

Keywords: Benefit-cost analysis, climate policy, discounting, overlapping generations, shadow price of capital.

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