Discounting Environmental Benefits to Future Generations: Implications of a Coordinating Debt Policy and Tax Distortions in the Capital Market

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Abstract

The standard approach to evaluating a long-term project is to use the social rate of time preference (SRTP) to discount the benefits to future generations. A difficulty with this approach is that there is no consensus on the values of the required parameters that reflect intergenerational equity concerns. Assuming the existence of a coordinating debt policy, this paper establishes a project evaluation rule that identifies Pareto improving projects and is therefore free of value judgement. This paper goes beyond the existing analysis of intergenerational discounting by exploring the implications of tax distortions in the capital market that drives a wedge between the marginal productivity of capital (the gross rate) and the consumer's interest rate (the net rate). Our project evaluation criterion is stricter than that recommended in government guidelines, causing fewer environmental projects to be accepted.

Keywords: discount rate; intergenerational equity; intergenerational transfers; climate change; distortionary taxation; marginal cost of funds

1. Introduction

The discount rate plays a critical role in the cost-benefit analysis of projects with costs and benefits distributed over time. However, a consensus has not been reached on which discount rate to use. The lack of consensus is at least partly due to the fact that the issue of choosing an appropriate discount rate can arise in very different contexts. For example, the earlier debate on the "social discount rate" took as its starting point the tax wedge between the marginal productivity of capital (the gross rate) and the consumer's interest rate (the net rate), and looked at discounting as an issue of optimization in a second-best world. Noticeably in that context, a project's costs and benefits in different periods were assumed to occur to the same generation, and therefore the focus of the debate was about efficiency rather than intergenerational equity.[1] More recently, however, as long-term environmental effects of global warming, radioactive wastes and loss of biodiversity started to draw serious attention from policy makers and the public, the discussion of discounting has focused on intergenerational equity and/or uncertainty as the major factors that determine the discount rate for environmental benefits to future generations.

In this paper, we address the issue of how to discount the environmental benefits to future generations. The question asked is: assuming that we are able to determine an environmental

[1] There are three main approaches to discounting in this context. The so-called social opportunity cost of capital (SOC) approach establishes that the appropriate discount rate should be a weighted average of the net rate and the gross rate, with the weights determined by the fractions of resources drawn from private consumption and private investment, respectively (Sandmo and Dreze 1971, Harberger 1972, and Pestieau 1975). The shadow price of capital (SPC) approach is intended to implement the widely accepted "folk principle" for multi-period project evaluation, which states that if a project's costs and benefits have been converted to consumption equivalents over time, then the consumer's interest rate should be used to discount the converted cost-benefit flows (Marglin 1963, Feldstein 1964, Bradford 1975, Lind 1982, and Liu 2011). The marginal cost of funds (MCF) approach proposes to discount project benefits (expressed in terms of willingness to pay) at the net rate, to discount project costs – including any indirect revenues from the project as negative costs – at the gross rate, and to multiply the present value of costs by an MCF associated with the marginal financing before it is compared with the present value of project benefits (Liu 2003, and Burgess 2013). As observed by Zeckhauser and Viscusi (2008), however, the controversy over the social discount rate in this context seems to have never completely resolved.

project's benefits to future generations with certainty and that other forms of uncertainty are also absent, what should be the evaluation procedure – including the implied discount rate – for the project?[2]

Within this context, the currently dominant approach to discounting is to use the social rate of time preference (SRTP) to discount a project's benefits to future generations. The discount rate – i.e. the SRTP – is used here as an expression of ethical judgment on how the consumption of a future generation should be weighted relative to that of the current generation. The SRTP has two main components, corresponding to the two reasons why consumption of a future generation might be given a lower weight than that of a present generation. First, the utility value of a future generation may be valued less than the utility value of the present generation by a decision-maker because the decision-maker – inevitably belonging to the present generation – is present-biased. This "pure time preference" component of the SRTP is represented by a pure time preference rate (i.e., the utility discount rate). Second, due to economic growth and diminishing marginal utility of consumption, an additional unit of consumption by a future generation has less utility value than an additional unit of consumption by the present generation. This "growth" component of the SRTP equals the product of the elasticity of marginal utility of consumption and the growth rate of per capita consumption. In other words,

$$SRTP = \rho + \theta g \,, \qquad (1)$$

[2] We focus on the benchmark situation of certainty so that the analysis is not further complicated by the matter of uncertainty. It goes without saying that the complication of uncertainty can be added to the analysis after there is a better understanding of intergenerational discounting for the simpler situation of certainty. See Weitzman (1998 and 2010) for discounting arising from uncertainty about future productivity, Gollier (2002 and 2010) for discounting arising from uncertainty about future growth rates in consumption and environmental quality, and Howarth (2003) and Becker et al. (2010) for discounting arising from uncertainty about environmental benefits to future generations. See also Traeger (2009) for separate roles played by risk aversion and intertemporal substitution in discounting arising from uncertainty.

where ρ is the rate of pure time preference, θ is the (absolute value of) elasticity of marginal utility of consumption, and g is the growth rate of per capita consumption.[3]

The SRTP approach to discounting has a well-recognized implementation difficulty. That is, the two parameters representing value judgement regarding intergenerational equity – the pure time preference rate ρ and the elasticity of marginal utility θ – cannot be obtained in an objective way.[4] As a manifestation of lack of consensus on the values of ρ and θ, consider several well- known economic studies of Greenhouse Gas (GHG) emissions: Cline (1992) uses $\rho = 0$ and $\theta = 1.5$; Nordhaus (1994) uses $\rho = 3\%$ and $\theta = 1$; Stern (2007) uses $\rho = 0.1\%$ and $\theta = 1$; and Nordhaus (2008) uses $\rho = 1.5\%$ and $\theta = 2$. These differences in parameter values have significant policy implications. For example, Cline (1992) found that a 40% reduction in GHG emissions is beneficial while Nordhaus (1994) found that only modest emissions abatement can be justified on economic grounds.

As a result, while the discounting guidelines of federal oversight agencies acknowledge the theoretical guidance of the SRTP approach to long-term discounting, they could only offer a very rough range for the intergenerational discount rate. For example, the Office of Management

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[3] For a detailed discussion of the SRTP approach to discounting, see Dasgupta (2008) and Arrow et al. (2012). By explicitly considering a felicity utility function that has both a consumption variable and an environmental quality variable, more recent studies following the SRTP approach add a third component in the SRTP expression that is associated with the growth in environmental quality and the substitutability between produced goods and environmental quality (Hoel and Sterner 2007, Traeger 2011 and Gueant et al. 2012). The SRTP formula (the Ramsey Rule) can also be extended by considering uncertainty in the consumption growth rate (Gollier 2002, Howarth 2003, Cochrane 2005, Weitzman 2007, Ackerman et al. 2009 and Liu 2012).

[4] See IPCC (1996) and Arrow et al. (2012). Some economists believe that ρ and θ can be estimated from the Ramsey rule based on observed market behavior. A criticism of this revealed preferences view (the descriptive view) is that observed intertemporal choices in the marketplace are based on individual preferences, which may not be the same as the preferences of the social planner (Azar and Sterner 1996 and Howarth 1996). Other economists believe value judgement regarding intergenerational equity can/should be made outside economics (the prescriptive view). As a highly representative example, Ramsey (1928) believes that utilities of different generations should be weighted equally hence $\rho = 0$. But this still leaves the value of θ undetermined. As pointed out by Asheim and Buchholz (2003), ρ and θ are inseparable in determining a particular notion of intergenerational equity.

and Budget (OMB) (OMB 2003) suggests using market-based discount rates – a low rate of 3% and a high rate of 7%, which correspond to the after-tax net rate and the before-tax gross rate, respectively – for short-term discounting, and using a "lower but positive discount rate" for long-term discounting.

Our approach in this paper to discounting the environmental benefits to future generations views the choice of a discount rate as a matter of efficiency rather than intergenerational equity. Our starting point is to note that future generations can be made better off either through efforts of environmental protection or through debt reduction that reduces their tax burdens. These two generational policies of the government – environmental protection and debt management – need to be coordinated to achieve economic efficiency. Assuming the existence of a coordinating debt policy (i.e., the existence of compensating intergenerational transfers), this paper establishes a project evaluation rule that identifies Pareto improving projects and is therefore free of value judgement. Our analysis goes beyond the existing analysis of intergenerational discounting by exploring the implications of tax distortions in the capital market that drive a wedge between the marginal productivity of capital (the gross rate) and the consumer's interest rate (the net rate).[5]

We find that a project is Pareto improving – along with appropriate adjustments in the debt policy – if and only if the net present value calculation with the following features yields a

[5] There are previous studies that view the choice of a discount rate for intergenerational discounting from the perspective of efficiency by assuming the existence of compensating intergenerational transfers and reach the conclusion that the market interest rate should be used for discounting the environmental benefits to future generations. For example, see Howarth and Norgaard (1993), IPCC (1996), and Horowitz (2002). To the best of our knowledge, however, all such studies have made the unrealistic assumption that there is no tax distortion in the capital market, bypassing the central issue that generates the original social discount rate debate in the first place (also see footnote 1 and the text from which it is derived). Our (Pareto) efficiency approach to intergenerational discounting in the presence of the tax distortion in the capital market is similar in spirit to the efficiency approach to policy analysis in the presence of distortionary taxation (Coate 2000, Christiansen 2007, and Hendren 2014).

positive value: (i) generational benefits should be first divided by a factor representing the marginal cost of funds (MCF) that is generally larger than one; (ii) both the project costs and the MCF-adjusted generational benefits should be discounted at the gross rate; (iii) the indirect revenue effects of the project should be accounted for and the indirect revenues in different periods should be treated as negative costs.

Our criterion has three main implications for intergenerational discounting, all of which suggest a project evaluation criterion that is stricter than that recommended in OMB (2003). First, in contrast to the OMB recommendation that the long-term discount rate should be even lower than the net rate, the basic discount rate in our criterion is the much higher gross rate. Second, our criterion implies that, before applying the gross rate for discounting, a project's environmental benefits to future generations should be divided by an MCF factor, which is shown to be typically larger than one. Third, our criterion emphasizes the importance of estimating the indirect revenues from an environmental project and incorporating them as offsets to the direct financial costs of the project. Because the indirect revenues of an environmental project could be negative, the "net" costs of the project may be higher than its direct financial costs.

The paper is organized as follows. A cost-benefit rule that is used to assess long-term projects' efficiency (in the sense of Pareto) is established in Section 2. This is the main part of the paper where each generation is assumed to have a single willingness to pay (the generational benefit) for an environmental protection project, and the focus is on how these generational benefits should be discounted. In Section 3, a detailed intragenerational analysis is provided, which explains how the generational benefits in Section 2 are obtained through an intragenerational discounting process. Moreover, the MCF for each generation is formally defined, and it is shown that its value tends to be larger than one. Then in Section 4, we provide further discussions concerning the feasibility of intergenerational transfers through changes in government's debt policy, the numerical values of the parameters in our criterion, consistency between inter- and intra-generational discounting, and a new rationale for declining discount rates. Finally, the paper concludes in Section 5.

2. A Cost-Benefit Rule Identifying Pareto-Improving Long-Term Projects

The question asked in this section is: How should an environmental protection project be evaluated – including what is the appropriate discount rate for the project's benefits to future generations – given the availability of debt reduction (intergenerational transfers from the current to future generations) that can also be used to improve the welfare of future generations? What makes this question more interesting as well as more challenging in this paper is that we explicitly consider the tax distortion in the capital market that causes the marginal productivity of capital (the gross rate) to be higher than the consumer's interest rate (the net rate).

Project Evaluation Environment

For the evaluation of long-term projects that affect many generations, we adopt a framework of overlapping generations.[6] Individuals are assumed to be identical within a generation, but may differ across generations. We identify each generation by its birth year, i.e., generation 0, generation 1,…, and so on. To simplify the notation, we assume that all generations have the same size. For the same reason, we assume that both the gross rate and the net rate, denoted r_g and r_n respectively, stay constant over time, which in turn implies that the tax rate on capital income is constant. The preexisting tax distortion in the capital market that creates a wedge between r_g and r_n was the main driver behind the original debate on the social discount rate (see footnote 1), but has largely been overlooked by the more recent literature on intergenerational discounting. Further, as explained in the introduction, we abstract from any uncertainty that may complicate the discussion of discounting (see footnote 2).

Let generation t collectively pay a *one-time* lump-sum tax LT^t in year t (at the time of the generation's birth), where the superscript t indicates that the tax is specifically levied on generation t.[7] Due to the preexisting capital income tax, government also collects capital income taxes in each year. Let KT_t be the total amount of capital income taxes collected in year t, where the subscript t indicates that KT_t includes all capital income taxes collected in year t (from all individuals/generations living in year t). Without loss of generality, assume that income from productive capital and income from government bonds are subject to the same tax treatment from the capital income tax. Then the before-tax interest rate that the government must pay bond holders in order to make government bonds competitive is r_g.[8] Therefore, the government's budget constraint can be written as

$$\sum_{t=0}^{\infty} \frac{(LT^t + KT_t)}{(1+r_g)^t} = D_0 + \sum_{t=0}^{\infty} \frac{E_t}{(1+r_g)^t}, \tag{2}$$

where D_0 is the total initial debt, and E_t is the total government expenditure in year t.

The financial costs of a project can be generally represented by the cost stream $C_t, t = 0,1,\cdots$, where C_t is the required financial cost in year t. The benefits from the project are generation-specific, and can be expressed as $B^t, t = 0,1,\cdots$, where B^t is generation t's total

[6]For a more technical analysis of project evaluation in the context of overlapping generations, see Liu et al. (2004).
[7] In Liu et al. (2004), it is shown that, for a very general environment, generation-specific lump-sum taxes, such as LT^t here, can be implemented through time-varying head taxes that are levied in each year on all individuals (of multiple generations) that live in that year.
[8] In a capital market where certainty is assumed, the equilibrium net-of-tax rate of return should be the same across different forms of assets (including productive capital and government bonds). Since it is assumed that the bond

willingness to pay, in terms of period t consumption, for the project (or its outputs). Note that we again use a superscript t to indicate that B^t is the generation t specific benefit. The final set of relevant effects of a project consist of the project's indirect revenues. Because of the preexisting capital income tax, undertaking a project may cause changes in private savings and hence affect capital income tax revenues in different years due to interactions between the project's outputs and private sector behavior.[9] Denote the project's indirect revenue stream as $IR_t, t = 0,1,\cdots$, where IR_t is the additional capital income tax revenue in year t caused by the project. To summarize, the effects of a project can be represented by $(C_t, B^t, IR_t), t = 0,1,\cdots$. These are project-specific inputs for project evaluation. B^t and IR_t will be formally identified in the next section.

The Cost-Benefit Rule for Intergenerational Evaluation

The purpose of the intergenerational evaluation is to determine whether it is beneficial to undertake a project represented by $(C_t, B^t, IR_t), t = 0,1,\cdots$, where C_t is the required financial cost in year t, B^t is the project's benefits to generation t, and IR_t is the project's indirect revenue in year t from its impact on saving behavior.

Since generation t's benefits from the project are B^t, the maximum additional lump sum tax that can be collected in year t from generation t without making the generation worse off is also B^t. Then, it might seem that, to determine the potential for Pareto improvement, we could just check whether the discounted sum of such increases in generational lump sum taxes,

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returns have the same tax treatment as the returns from productive capital, the before-tax rate of return for government bonds equals the gross rate earned by productive capital before tax.

[9] For example, if a project's output can also be purchased in the market, then expecting such a benefit in the future would reduce one's savings as well as the capital income tax revenue, and hence the indirect revenue is negative.

$\sum_{t=0}^{\infty}\frac{B^t}{(1+r_g)^t}$, is greater than the discounted sum of project costs, $\sum_{t=0}^{\infty}\frac{C_t}{(1+r_g)^t}$, where the discount rate is the gross rate as in the government budget constraint (2).

The problem with this simple cost-benefit rule, however, is that it fails to take into account the preexisting tax distortion in the capital market.

First, as a consequence of the capital market tax wedge, collecting a generation-specific lump sum tax from a generation entails an efficiency cost in the sense that a dollar increase in the lump sum tax would generate a present value increase of less than a dollar in the generation's lifetime tax payments, due to reduced savings, and therefore, reduced capital income tax payments. We use MCF^t (the marginal cost of funds for generation t) to represent the required increase in LT^t for a one-dollar increase in the present value of generation t's lifetime tax payments. Note that MCF^t so defined can be interpreted as the real cost to generation t, in terms of period t consumption, of raising one additional dollar in the present value (as of year t) of generation t's lifetime tax payments, which is generally larger than one as is formally demonstrated in the next section.[10] Then, with the generational benefit B^t from the project, the gain in lifetime tax revenues that can be collected from generation t without making the generation worse off, in terms of present value in year t, is B^t / MCF^t.

Second, as explained earlier, due to the preexisting capital income tax, the relevant inputs for a project's evaluation include $IR_t, t = 0,1,\cdots$, where IR_t is the additional capital income tax revenue in year t caused by the project through its impact on saving behavior. Therefore, the net

On the other hand, if an output – say outputs generated by space exploration projects – does not affect an individual's choices, then the indirect revenue is zero.

[10] A formal definition of MCF^t is given in the next section where a detailed analysis of intragenerational evaluation is provided.

cost of the project in year t is $C_t - IR_t$, $t = 0,1,\cdots$

Now the question becomes whether the additional revenue stream B^t / MCF^t, $t = 0,1,\cdots$, that can be raised without making any generation worse off is sufficient to cover the *net* cost stream $C_t - IR_t$, $t = 0,1,\cdots$, in the sense of keeping the government budget (2) balanced. It is easy to see that a project represented by $(C_t, B^t, IR_t), t = 0,1,\cdots$, is Pareto improving if and only if

$$\sum_{t=0}^{\infty} \frac{B^t / MCF^t}{(1+r_g)^t} > \sum_{t=0}^{\infty} \frac{C_t - IR_t}{(1+r_g)^t}. \tag{3}$$

When a project represented by $(C_t, B^t, IR_t), t = 0,1,\ldots$, satisfies criterion (3), each and every generation can be made better off with the project, along with appropriate intergenerational transfers made through changes in generation-specific lump sum taxes. In words, criterion (3) has the following three features: (i) generational benefits should be first divided by a factor representing the marginal cost of funds (MCF) that is generally larger than one; (ii) both project costs and MCF-adjusted generational benefits should be discounted at the gross rate; (iii) the indirect revenue effects of the project should be accounted for and the indirect revenues in different periods should be treated as negative costs.

Criterion (3) has a critical difference from the SRTP approach to intergenerational discounting, regarding the role of market returns. Reflecting value judgement concerning intergenerational equity, the discount rate for generational benefits in the SRTP approach, with (1) being its most basic form, has no reference to market returns. For the range of values that various economists have assigned to those value-judgement parameters, the resulting discount rates for intergenerational discounting tend to fall between 1% and 3%. In contrast, market returns are back into play in criterion (3). When generation t's benefit from the project B^t is divided by the generation's marginal cost of funds MCF^t, the resulting number B^t / MCF^t has the interpretation as the maximum additional tax revenue (in terms of the present value in year t) that can be collected from generation t without making it worse off. While the consumption of one generation is not comparable to the consumption of another generation using market returns, the tax payments of different generations – i.e., their MCF-adjusted generational benefits – are related by the before-tax gross rate, because the gross rate is the society's rate to transfer resources between two different years.

Note that under the (unrealistic) assumption that there is no tax distortion in the capital market (i.e., $r_g = r_n$), we have $MCF^t = 1$ and $IR_t = 0$ for all t, and criterion (3) simplifies to the well-known

$$\sum_{t=0}^{\infty} \frac{B^t}{(1+r_g)^t} > \sum_{t=0}^{\infty} \frac{C_t}{(1+r_g)^t}. \qquad (3')$$

Main Implications for Intergenerational Discounting

OMB (2003) recommends using 3% and 7% – which are, according to OMB, the net rate and the gross rate, respectively – for short-term (or intragenerational) discounting.[11] At the same time, OMB recommends using "a lower but positive discount rate" for intergenerational discounting.[12] That is, implicit in OMB's recommendations is that the discount rate for benefits to future generations should not exceed the after-tax net rate.

Criterion (3) has three main implications for intergenerational discounting, all of which suggest a project evaluation criterion that is stricter than that recommended in OMB (2003). First, in contrast to the OMB recommendation that the long-term discount rate should be even

[11] OMB is vague about whether these rates should be treated as risk-free or risk-inclusive. In Section 4, we estimate both versions of the gross rate (or the net rate), one risk-free and one risk-inclusive. It seems that OMB's rates are the average of the risk-free version and the risk-inclusive version of the corresponding rate.

lower than the net rate, the basic discount rate in our criterion is the much higher gross rate. The intuition for using the gross rate for intergenerational discounting is that MCF-adjusted generational benefits are simply the tax revenues that can be collected from these generations without making them worse off, and the tax revenues in different periods should be discounted by the gross rate because the gross rate governs the society's tradeoffs between periods.

Second, ignore for the moment the indirect revenues from an environmental protection project.[13] That is, let $IR_t = 0$ for all t in criterion (3). The criterion then becomes

$\sum_{t=0}^{\infty} \frac{B^t / MCF^t}{(1+r_g)^t} > \sum_{t=0}^{\infty} \frac{C_t}{(1+r_g)^t}$, which implies that the *effective* discount rate for a project's environmental benefits to future generations should be even larger than the tax-inclusive gross rate because, before discounting by the gross rate, future generational benefits should be first divided by an MCF factor that is typically larger than one.

Third, our criterion (3) emphasizes the importance of estimating the indirect revenues, $IR_t, t = 0,1,\cdots$, from an environmental project, and incorporating them as offsets to the direct financial costs of the project.[14] An environmental project's outputs may cause changes in private sector behavior (including saving behavior), which in turn cause changes in capital income tax revenues collected over time when there exists a preexisting capital income tax. These indirect revenues from a project are not part of B^t or $C_t, t = 0,1,\cdots$, but have relevance for the project's evaluation. Criterion (3) requires, quite intuitively, that IR_t be treated as the offset to C_t. Given

[12] Citing Portney and Weyant (1999), OMB (2003) places the estimates of SRTP in the range of 1% to 3%.

[13] The indirect revenues from a project are implicitly assumed to be zero in all periods if the tax wedge in the capital market is not explicitly incorporated in the discussion of intergenerational discounting.

[14] Therefore, the "type" of a project's outputs – whether the project outputs are separable from the private goods in the utility function or the project outputs are perfect substitutes for the private goods – becomes an important feature in the discount rate discussion, as pointed out by Liu et al. (2005).

the same B^t and C_t, $t = 0,1,\cdots$, an environmental project with positive (negative) IR_t will have a larger (smaller) chance to pass the efficiency test (3) than when IR_t are assumed to be zero.

Then which is more likely for a typical environmental project, positive IR_t or negative IR_t? As we pointed out earlier, due to the failure to explicitly account for the tax distortions in the economy (in particular, the obviously relevant tax wedge in the capital market), the environmental economics literature on intergenerational discounting has largely overlooked the potential interactions between environmental projects or regulations – especially those aimed at GHG abatement – on the one hand and the tax system on the other. However, the environmental economics literature on the so-called "double dividend" has established the evidence that corrective environmental taxes have negative "tax interaction" effects; that is, environmental taxes tend to cause the revenues from other, preexisting taxes to drop.[15] If – and this is a big if – environmental projects have the same effects on revenues from other taxes as corrective environmental taxes, then the tax interaction effects found in the literature on the double dividend suggest that IR_t from a typical environmental project tend to be negative, causing the net costs of the environmental project to increase.

Both the second and third implications above are the consequences of taking into account the preexisting tax distortion in the capital market: Absent of any preexisting tax distortion, there would be no indirect revenues from a project and the MCF would be one. Indeed, our project evaluation criterion (3) can be reinterpreted as looking at the project's impact on the government's budget holding each generation at their pre-project utility level, and accepting the project if and only if the overall budget impact is positive.

The discussion above suggests that fewer long-term environmental projects would be accepted if criterion (3), instead of the recommendation in OMB (2003), is followed in determining a project's merit. We will discuss other implications of criterion (3) in Section 4, and would like to conclude this section with some comments on what criterion (3) *does not* imply. Our discussions above do not imply that criterion (3), being stricter than that recommended in OMB (2003), is unfriendly to future generations. It is true that fewer long-term environmental projects will be undertaken under criterion (3), but this only means that intergenerational transfers from current to future generations – implemented through debt reductions – would be a more efficient tool in helping future generations than undertaking those projects that would be rejected according to criterion (3). Indeed, our criterion is judgement-free, independent of the social welfare function adopted. We merely emphasize the opportunity costs of long-term projects aimed at helping future generations. An alternative way to help future generations is to simply leave them less debt.[16] For the same reason, undertaking long-term environmental projects under a looser criterion (such as that recommended in government guidelines) does not necessarily mean that future generations will be better off, because future generations may well inherit a larger debt burden along with a better environment.[17]

Related to this, there is often a misunderstanding that implicit in a Pareto-type criterion such as criterion (3) is an assumption that the current distribution of wealth/welfare is optimal or

[15] See Bovenberg and de Mooij (1994), Goulder (1995), Oates (1995) and Parry (1995) for some early discussions of the "double dividend" from corrective environmental taxes.

[16] Currently, the two main governmental generational policies – the debt policy and the (long-term) environmental policy – are at cross purposes. While fighting GHG emissions seems to be gaining steam judged by the recent climate deal reached in Paris, governments all over the world have been growing their debts, hence raising the tax burdens on future generations. See Auerbach et al. (1999) and Kotlikoff (2002) for detailed discussions of the intergenerational inequality in tax burden distribution that is in favor of exiting generations at a cost to future generations.

acceptable. What "Pareto" actually means here is that following criterion (3) to accept or reject a project makes every generation better off than when the decision on the project is inconsistent with criterion (3). If undertaking all the environmental projects that pass our cost-benefit test is not enough to show the care for future generations, then we should consider debt-reducing options, because debt reductions are more efficient in improving future generations' welfare than undertaking environmental projects that do not satisfy criterion (3).

3. A Generation's Intertemporal Decision: Intragenerational Discounting and the MCF

With a simple model of intertemporal consumption decision, we study in this section how an arbitrary generation t would discount the benefits it receives from a project in different years, to form its generational benefit B^t. We will also study how exactly generation t's marginal cost of funds MCF^t is defined.

Without loss of generality, we treat generation t as if it were a single person who is born in year t and dies in year t + N. In each year t + k, k = 0, 1, …, N, the generation consumes a privately purchased consumption good c_{t+k}^t – which is taken to be the numeraire in that year – in addition to the publicly provided environmental quality measured by G_{t+k}. Note that the superscript t in c_{t+k}^t indicates that the private consumption is specific to generation t. The utility function of generation t can be written as

$$U(c_t^t, G_t, \ldots, c_{t+N}^t, G_{t+N}) . \quad (4)$$

[17] This provides a situation that entitlement programs like Social Security and Medicare – which jointly amass a considerable amount of debt as explained in Section 4 – may have helped maintain a better environment for the future (Rangel 2003).

For given G_{t+k}, k = 0, 1, …, N, generation t's problem is to choose c_{t+k}^{t}, k = 0, 1, …, N, to maximize (4), subject to intertemporal budget constraints

$$\begin{cases} a_t^t = w^t + y_t^t - c_t^t - LT^t \\ a_{t+k}^t = a_{t+k-1}^t(1+r_n) + y_{t+k}^t - c_{t+k}^t, \quad k = 1, \cdots, N \\ a_{t+N}^t = 0. \end{cases} \tag{5}$$

where a_{t+k}^{t} is the end-of-year asset or savings in year t + k (consisting of both productive capital and government bonds), y_{t+k}^{t} is income earned in year t + k, w^t is initial wealth, LT^t is the generation-specific one-time lump-sum tax paid in year t, $r_n = (1-\tau)r_g$ is the net (after-tax) rate of return on productive capital and government bonds,[18] r_g is the gross rate of return on productive capital, and τ is the tax rate on capital income. In the present value form, (5) can be rewritten as

$$\sum_{k=0}^{N} \frac{c_{t+k}^t}{(1+r_n)^k} = w^t - LT^t + \sum_{k=0}^{N} \frac{y_{t+k}^t}{(1+r_n)^k}. \tag{6}$$

The first-order conditions of generation t's utility maximization problem are

$$\frac{\partial U / \partial c_{t+k}^t}{\partial U / \partial c_t^t} = \frac{1}{(1+r_n)^k}, \qquad k = 0, \ldots, N. \tag{7}$$

Those outputs of an environmental project that are relevant for generation t's evaluation can be represented by ΔG_{t+k}, k = 0, 1,…, N. Generation t's willingness to pay for ΔG_{t+k}, in terms of consumption in year t + k, is

$$B_{t+k}^t = \frac{\partial U / \partial G_{t+k}}{\partial U / \partial c_{t+k}^t} \Delta G_{t+k}, \qquad k = 0, \ldots, N. \tag{8}$$

On the other hand, generation t's total willingness to pay for the project (i.e., all ΔG_{t+k}, k = 0, 1,

…, N), in terms of consumption in year t, is

$$B^t = \sum_{k=0}^{N} \frac{\partial U / \partial G_{t+k}}{\partial U / \partial c_t^t} \Delta G_{t+k} \ . \tag{9}$$

Substituting (8) into (9) and using the first-order conditions (7), we have

$$B^t = \sum_{k=0}^{N} \frac{B_{t+k}^t}{(1+r_n)^k}. \tag{10}$$

Expression (10) says that intragenerational benefits should be discounted to the first year of a generation's life using the net rate. This is intuitive because it is the net rate that governs the tradeoff between one's consumption in different years. This conclusion to use the net rate for intragenerational discounting is similar to, but at the same time sharper than, OMB's (2003) recommendation to use market-based 3% and 7% – which are respectively the net rate and the gross rate according to OMB – for intragenerational discounting.[19]

Due to the tax rate on capital income τ that drives a wedge between r_g and r_n, generation t also pays a capital income tax $KT_{t+k}^t = a_{t+k-1}^t (r_g - r_n)$ in year t + k, k = 1, …, N, in addition to the initial lump sum tax LT^t. The present value of generation t's lifetime tax payments is

$$LT^t + \sum_{k=1}^{N} \frac{KT_{t+k}^t}{(1+r_g)^k} = LT^t + \sum_{k=1}^{N} \frac{a_{t+k-1}^t (r_g - r_n)}{(1+r_g)^k} \ . \tag{11}$$

In the context here with LT^t as the marginal tax instrument, the marginal cost of funds for generation t is defined as the ratio of the real cost to generation t, in terms of year t consumption, to the increase in the present value of generation t's lifetime tax payments, when

[18]Because there is no uncertainty, the net-of-tax rates of return are the same across different assets.

LT^t is raised at the margin.[20] Formally,

$$MCF^t \,@\, \frac{1}{1+\sum_{k=1}^{N}\frac{(r_g - r_n)\partial a_{t+k-1}^t / \partial(LT^t)}{(1+r_g)^k}} . \qquad (12)$$

Notice that although MCF^t is the marginal cost of funds associated with a lump-sum tax, its value is not necessarily one because of the preexisting tax distortion in the capital market. Indeed, we can prove (see the appendix) that MCF^t given in (12) is unambiguously larger than one under the condition that consumption in every year is a normal good.

For the formal analysis in this paper, the required intergenerational transfers for Pareto efficiency are made through adjustments in the lump sum taxes various generations pay, LT^t, t = 0, 1, … Focusing on lump sum taxation greatly simplifies the notation and, as noted above, helps emphasize the fact that the generation-specific MCF is greater than one even for the lump sum tax as long as there exist tax distortions in the capital market. If, on the other hand, lump sum taxation is not available and some other, distortionary tax must be adjusted to offset a generation's benefits from a project, the only change in criterion (3) is that MCF^t should be understood as being associated with the specific distortionary tax. In other words, the analysis and results in this paper do not depend on intergenerational transfers through *lump sum taxation*.

4. Further Discussions

Three main implications of criterion (3) for long-term environmental project evaluation have been provided in Section 2. We now discuss a few other issues related to criterion (3).

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[19] Note that B^t for generation t is identified using the net rate of return, but when B^t is then discounted as in (3), the gross rate of return is used to establish B^t's present value in the cost-benefit criterion.

[20] This definition of MCF, in a multi-period context, is consistent with the MCF concept traditionally defined for a single-period context (Browning 1987, Mayshar 1991, Ballard and Fullerton 1992, Snow and Warren 1996, Allgood and Snow 1998, Dahlby 1998 and 2008, Sandmo 1998, Browning et al. 2000, and Slemrod and Yitzhaki 2001).

Feasibility of Intergenerational Transfers

Following criterion (3) in project evaluation leads to Pareto improvements only when intergenerational transfers through adjustments in LT^t, t = 0, 1,…, are feasible. In particular, it is assumed that any current environmental inaction that imposes burdens on future generations can be compensated for by transfers from the current to future generations. Then are these intergenerational transfers feasible?

There is considerable skepticism regarding the feasibility of intergenerational transfers from current to future generations. An often-raised question is what would compel the current generation to transfer money to future generations. The question would not be as critical, however, if one recognizes that the same question can be raised about the current generation's motivation for long-term environmental protection.

Another question is how the intergenerational transfers from current to future generations are implemented. One way to implement such transfers is through some kind of "compensation fund" that can be invested in the capital market, but the idea of making a government save and invest draws criticism. Indeed, historical evidence suggests that it is hard for any government to accumulate interest-earning assets. Moreover, giving the government the right to invest in stock markets may politicize investment decisions.

However, there is another way to implement the intergenerational transfers from current to future generations. Government, if it has the political will, can always reduce the size of the debts and therefore the tax burdens on future generations. As far as the intergenerational transfers are concerned, debt reduction serves the same function as government investment.

Government debts include not only the widely publicized publicly-held debt but also other government liabilities. At the federal level, these other government liabilities are mainly comprised of accrued retirement and disability benefits to federal employees and veterans, and accrued benefits in Social Security and Medicare. Elsewhere, we document that the total federal government liabilities were almost $40 trillion as of 2015, and the debt held by the public is but one form of federal liability that places a burden on future generations. Indeed, the $18.5 trillion in accrued Social Security and Medicare benefits were 40% higher than the debt held by the public.[21] Moreover, all the component liabilities have been increasing and all together they have more than doubled in size over the last decade.

Therefore, there is plenty of room for intergenerational transfers through debt reduction, especially in the area of Social Security and Medicare. Long-term environmental projects aimed at helping future generations should be evaluated based on their efficiency relative to reducing the size of the publicly-held debt and the elderly entitlement debts, using criterion (3).

Parameter Values

To use criterion (3) for the evaluation of a long-term environmental project requires that we know the values of "rule parameters" – r_g and MCF^t – in addition to project-specific inputs, $(C_t, B^t, IR_t), t = 0,1,\ldots$. Moreover, we also must know r_n to carry out the intragenerational analysis (i.e., the calculation of each generation's lifetime benefit B^t). We provide estimates here for the value of r_g, r_n and MCF^t.

OMB (2003) sets r_g = 7% and r_n = 3%, but is ambiguous about how much in these numbers is due to risk. In contrast, we provide two sets of estimates of r_g and r_n, one is risk-free and the other is risk-inclusive.

[21] See Liu et al. (2016). The $18.5 trillion in accrued Social Security and Medicare benefits is a very conservative estimate because it only includes the accrued benefits to the program participants who have reached the eligibility

The pre-tax gross rate of return has been variously estimated to be from 8.5% to above 9%. For example, Poterba (1999) estimates the real before-tax rate of return on non-financial corporate capital as 8.5% between 1959 and 1996. However, these relatively high rates of return are risk-inclusive, and the risk-free gross rate of return should be considerably lower. Investment assets that are closest to being risk-free are government bonds. The Trustees of Social Security currently use 2.7% for their long-term estimate of real returns (Social Security Trustees 2016). To arrive at the risk-free gross rate of return, the 2.7% bond rate must be adjusted upward to incorporate the corporate income tax effect. The corporate income tax rate must reflect levies on corporations at the federal, state, and local levels. Feldstein (1998) suggests that the total corporate income tax rate is about 40%, implying a risk-free r_g of 4.5%. Using 9% for the risk-inclusive r_g, it seems that the average of the risk-free r_g (i.e., 4.5%) and the risk-inclusive r_g (i.e., 9%), which is 6.75%, closely corresponds to the choice of $r_g = 7\%$ by OMB.

Using the 40% corporate income tax rate and 20% personal income tax rate, the total levy on capital income is 52%. This, along with various estimates of r_g, leads to corresponding estimates of r_n. The estimates of r_g and r_n are summarized in Table 1 below.

Table 1: Estimates of r_g and r_n

	Risk-free	Risk-inclusive	Average	OMB (2003)
r_g	4.5%	9%	6.75%	7%
r_n	2.2%	4.3%	3.25%	3%

age for the respective program. In addition, those participants of Social Security and Medicare who have not reached the eligibility age have also accrued considerable benefits.

There exist many estimates of MCF, for various tax instruments, in the literature, but most of these estimates are only applicable in a static setting. Providing estimates in a realistic life-cycle setting is beyond the scope of this paper. Using a simplistic two-period life-cycle model, nonetheless, the MCF for a typical generation is, from the general MCF formula (12),

$$MCF = \frac{1}{1 - R_g \tau\gamma / (1 + R_g)}\,, \tag{13}$$

where R_g is the gross rate of return between the first and the second period of life (approximately a 30 year span in a two-period life-cycle model), τ is the capital income tax rate, and γ is the propensity to save (again from the first half to the second half of one's life). With a span of 30 years and a 7% annual gross rate of return (using OMB's value of r_g), $R_g = (1.07)^{30} - 1 = 6.61$. In a two-period Cobb-Douglas utility function with first and second period consumption shares of 2/3 and 1/3 respectively, the propensity to save $\gamma = 0.333$ (Atkinson and Stiglitz 1980). Substituting these parameter values and $\tau = 0.52$ into the above MCF formula yields a marginal cost of funds equal to 1.18.

Consistency between Intergenerational and Intragenerational Discounting

Arrow et al. (2012) point out a potential inconsistency in OMB's (2003) guidelines between the discount rate recommended for intragenerational discounting (3% or 7%) and the discount rate recommended for intergenerational discounting (a rate that is lower than 3%). There may be an inconsistency in the sense that a project's benefit to a specific future generation in a given future year can be viewed both as an intragenerational benefit and as an intergenerational benefit. Then, therefore, which discount rate should be used to convert this future benefit into a present value, if the intragenerational discount rate and the intergenerational discount rate differ?

Our analysis in Section 2 and Section 3 also leads to differential discounting for intergenerational and intragenerational benefits, although, to the opposite of the recommendations in OMB (2003), it is the case that in our approach the intergenerational discount rate (the MCF-adjusted generational benefits should be discounted at the *gross* rate) is larger than the intragenerational discount rate (each generation's benefits should be discounted to the beginning of the generation's life at the *net* rate, to form a single generational benefit).

However, there is no inconsistency in our approach because the situations for using each of these two discount rates are well defined. Within each generation, intragenerational benefits in different periods should be discounted by the net rate, because the net rate governs individuals' intertemporal consumption decision. Between generations, on the other hand, MCF-adjusted (inter) generational benefits are simply the tax revenues that can be collected from these generations without making them worse off, and the tax revenues in different periods should be discounted by the gross rate because the gross rate governs the society's tradeoffs between periods.

Declining Discount Rates

The idea of discounting a more distant future at a lower discount rate – declining discount rates – can be justified with various considerations. Within the SRTP approach, for example, the discount rate given in (1) would be decreasing over time with declining consumption growth rate; incorporating uncertainty in consumption growth, the discount rate would be decreasing over time if shocks to consumption growth are positively correlated.[22]

Our criterion (3) provides another rationale for declining discount rates that is very different from the existing ones. Suppose that the MCF is constant from one generation to another. If we incorporate the MCF factor into discounting in (3), then the *effective* discount rate directly applied to generational benefit B^t – which is $(MCF)^{1/t}(1+r_g)-1$ – becomes smaller as t increases.   Importantly, however, no matter how distant in the future, the effective discount rates for future generational benefits would not go below the gross rate r_g.

5. Conclusion

The evaluation of long-term environmental projects is highly sensitive to the choice of the discount rate. In theory, the SRTP has taken into account the equity concerns in comparing consumption of different generations, but a difficulty with carrying out the SRTP calculation is that there is no objective way to assign a value to the required parameters that represent value judgement regarding intergenerational equity. This is why there is still no consensus among economists regarding the appropriate discount rate for the evaluation of an environmental project's benefits to future generations, as evidenced by the many comments on the acclaimed Stern Review (Stern 2007).[23]

The current generation can help future generations either by leaving them a cleaner environment or by leaving them lower publicly-held debt and/or lower implicit debts in elderly entitlement programs. However, today's environmental policy and elderly entitlement policy are at cross-purposes: New environmental projects and regulations benefit future generations, but the legislations in recent years to expand elderly entitlements increase the tax burdens on future generations. It is now time to consider harmonizing the government's two main generational

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[22] See Groom et al. (2005) and Arrow et al. (2012) for various reasons that the discount rate would decrease over time.

[23] The comments on Stern (2007) in the economics literature focus on the issue of intergenerational discounting. See, for example, Nordhaus (2007), Weitzman (2007), Quiggin (2008), and Sterner and Persson (2008).

policies.

Given the option of helping future generations with a debt policy that reduces the tax burdens on future generations, this paper looks at the evaluation of long-term environmental projects from a perspective of efficiency. It also takes into account the capital income taxes that drive a wedge between the marginal productivity of capital (the gross rate) and the consumer's interest rate (the net rate). It establishes that a project is Pareto improving if and only if it satisfies criterion (3).

In sharp contrast to the OMB's recommendation of using a discount rate that is lower than the net rate for a long-term project's benefits to future generations, criterion (3) suggests that the basic discount rate for the evaluation of an intergenerational project is actually the higher gross rate. Moreover, before applying the gross rate for discounting, both the generational benefits and the financial costs of the project should be adjusted to reflect the effects of tax distortions in the capital market. First, a generation's benefits should be divided by a factor that represents the generation's marginal cost of funds. Second, the indirect revenues should be estimated and be treated as negative costs. As have been explained in the paper, the MCF is likely to be larger than one, and the indirect revenues may be negative on average. So applying our approach would lead to the rejection of more long-term projects, in favor of helping future generations by leaving them with a lighter debt burden. An implication for current policy priority is that we should pay more attention to elderly entitlement reform aimed at reducing the implicit debts embedded in Social Security and Medicare.

References

Ackerman, F., DeCanio S. J., Howarth, R.B., Sheeran, K., 2009. Limitations of integrated assessment models of climate change. Climatic Change 95, 297-315.

Allgood, S., Snow, A., 1998. The marginal cost of raising tax revenue and redistributing income. Journal of Political Economy 106, 1246-1273.

Arrow, K.J., Cropper, M.L., Gollier, C., Groom, B., Heal, G., Newell, R., Nordhaus, W.D., Pindyck, R., Pizer, W., Portney, P., Sterner, T., Tol, R.S.J., Weitzman, M.L., 2012. How should benefits and costs be discounted in an international context? The views of an expert panel. RFF Discussion Paper 12-53, Resources for the Future.

Asheim, G.B., Buchholz, W., 2003. The malleability of undiscounted utilitarianism as a criterion of intergenerational justice. Economica 70, 405-422.

Atkinson, A.B., Stiglitz, J., 1980. Lectures on Public Economics. New York: McGraw-Hill.

Auerbach, A., Kotlikoff, L., Leibfritz, W. (ed.), 1999. Generational Accounting around the World. NBER volume, University of Chicago Press.

Azar, C., and Sterner, T., 1996. Discounting and distributional considerations in the context of global warming. Ecological Economics 19(2), 169-184.

Ballard, C.L., Fullerton, D., 1992. Distortionary taxes and the provision of public goods. Journal of Economic Perspectives 6, 117-131.

Becker, G., Murphy, K.M., Topel, R.H., 2010. On the economics of climate policy. The B.E. Journal of Economic Analysis & Policy, Volume 10, Issue 2, Article 19.

Bovenberg, A.L., de Mooij, R.A., 1994. Environmental levies and distortionary taxation. American Economic Review 84, 1085-1089.

Bradford, D.F., 1975. Constraints on government investment opportunities and the choice of discount rate. American Economic Review 65, 887-899.

Browning, E.K., 1987. On the marginal welfare cost of taxation. American Economic Review 77, 11-23.

Browning, E.K., Gronberg, T., Liu L., 2000. Alternative measures of the marginal cost of funds. Economic Inquiry 38 (4), 591-599.

Burgess, D.F., 2013. Reconciling alternative views about the appropriate social discount rate. Journal of Public Economics 97, 9-17.

Christiansen, V., 2007. Two approaches to determine public good provision under distortionary taxation. National Tax Journal 60, 25-43.

Cline, W.R., 1992. The Economics of Global Warming. Institute for International Economics, Washington, DC.

Coate, S., 2000. An efficiency approach to the evaluation of policy changes. The Economic Journal 110, 437-455.

Cochrane, J. H., 2005. Asset Pricing, revised edition. Princeton University Press, Princeton.

Dahlby, B., 1998. Progressive taxation and the social marginal cost of public funds. Journal of Public Economics 67, 105-122.

Dahlby, B., 2008. The Marginal Cost of Public Funds: Theory and Applications. Cambridge: MIT Press.

Dasgupta, P., 2008. Discounting climate change. Journal of Risk and Uncertainty 37, 141-169.

Feldstein, M., 1964. Net social benefit calculation and the public investment decision. Oxford Economic Papers. 16, 114-131.

Feldstein, M. (ed.), 1998. Privatizing Social Security. NBER. Chicago, IL: The University of Chicago Press.

Gollier, C., 2002. Discounting an uncertain future. Journal of Public Economics 85, 149-66.

Gollier, C., 2010. Ecological discounting. Journal of Economic Theory 145, 812-829.

Goulder, L.H., 1995. Environmental taxation and the “double dividend”: A reader’s guide. International Tax and Public Finance 2, 157-183.

Groom, B., Hepburn C., Koundouri, P., Pearce, D., 2005. Discounting the future: the long and the short of it. Environmental and Resource Economics 31, 445-493.

Gueant, O., Guesnerie, R., Lasry, Jean-Michel, 2012. Ecological intuition versus economic “reason”. Journal of Public Economic Theory 14, 245-272.

Harberger, A.C., 1972. Project Evaluation: Collected Papers. The University of Chicago Press, Chicago.

Hendren, N., 2014. The inequality deflator: interpersonal comparisons without a social welfare function. *NBER* Working Paper 20351.

Hoel, M., Sterner, T., 2007. Discounting and relative prices. Climatic Change 84, 265-280.

Horowitz, J.K., 2002. Preferences in the future. Environmental and Resource Economics 21, 241-259.

Howarth, R.B., 1996. Climate change and overlapping generations. Contemporary Economic Policy 14(4), 100-111.

Howarth, R.B., 2003. Discounting and uncertainty in climate change policy analysis. Land Economics 79, 369-381.

Howarth, R.B., Norgaard, R.B., 1993. Intergenerational transfers and the social discount rate. Environmental and Resource Economics 3, 337-358.

IPCC., 1996. Climate Change 1995 – Economic and Social Dimensions of Climate Change – Contribution of Working Group III to the Second Assessment Report Of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Kotlikoff, L., 2002. Generational policy. in Handbook of Public Economics, Vol. 4, edited by A.J. Auerbach and M. Feldstein, North-Holland: Amsterdam.

Lind, R.C., 1982. A Primer on the major issues relating to the discount rate for evaluating national energy options. in R.C. Lind, ed., Discounting for Time and Risk in Energy Policy, Washington D.C.: Resources for the Future.

Liu, L., 2003. A marginal cost of funds approach to multi-period public project evaluation: Implications for the social discount rate. Journal of Public Economics 87: 1707-1718.

Liu, L., 2011. From the shadow price of capital to the marginal cost of funds: in search of the implementation of a principle. Journal of Public Economic Theory 13: 369-389.

Liu, L., 2012. Inferring the rate of pure time preferences under uncertainty. Ecological Economics 74, 27-33.

Liu, L., Rettenmaier A.J., Saving, T.R., 2004. A generalized approach to multi-generation project evaluation. Southern Economic Journal 71, 377-396.

Liu, L., Rettenmaier A.J., Saving, T.R., 2005. Discounting according to output type. Southern Economic Journal 72, 213-223.

Liu, L., Rettenmaier A.J., Saving, T.R., 2016. Federal Liabilities: 2016 Update. PERC Policy Study No. 1605, August 2016, Private Enterprise Research Center, Texas A&M University. (http://perc.tamu.edu/perc/Publication/policybrief/study_no1605_08_2016.pdf)

Marglin, S.A., 1963. The opportunity costs of public investment. Quarterly Journal of Economics 77, 274-289.

Mayshar, J., 1991. On measuring the marginal cost of funds analytically. American Economic Review 81, 1329-1335.

Nordhaus, W.D., 1994. Managing the global commons: The economics of climate change. The MIT Press, Cambridge, Massachusetts.

Nordhaus, W.D., 2007. A review of the Stern review on the economics of climate change. Journal of Economic Literature. 45, 686-702.

Nordhaus, W.D., 2008. A Question of Balance: Weighing the Options on Global Warming Policies. Yale University Press, New Haven and London.

Oates, W.E., 1995. Green taxes: can we protect the environment and improve the tax system at the same time? Southern Economic Journal 61, 914-922.

Office of Management and Budget (OMB), 2003. Circular A-4: Regulatory Analysis. Washington, DC: Executive office of the President.

Parry, I.W.H., 1995. Pollution taxes and revenue recycling. Journal of Environmental Economics and Management 29, S64-S77.

Pestieau, P. M., 1975. The role of taxation in the determination of the social discount rate. International Economic Review 16, 362-368.

Portney, P.R., Weyant, J.P., eds., 1999. Discounting and Intergenerational Equity. Washington, DC: Resources for the Future.

Poterba, J.M., 1999. The rate of return to corporate capital and factor shares: new estimates using revised national income accounts and capital stock data. *NBER* Working Paper 6263.

Quiggin, J., 2008. Stern and his critics on discounting and climate change: an editorial essay. Climatic Change 89, 195-205.

Ramsey, F., 1928. A mathematical theory of savings. The Economic Journal 38, 543-559.

Rangel, A., 2003. Forward and backward intergenerational goods: why is Social Security good for the environment?. American Economic Review 93, 813-834.

Sandmo, A., 1998. Redistribution and the marginal cost of public funds. Journal of Public Economics 70, 365-382.

Sandmo, A., Dreze, J.H., 1971. Discount rates for public investments in closed and open economies. Economica 38, 395-412.

Slemrod, J., Yitzhaki, S., 2001. Integrating expenditure and tax decision: The marginal cost of funds and the marginal benefit of projects. National Tax Journal 54, 189-201.

Snow, A., Warren Jr., R.S., 1996. The marginal welfare cost of public funds: Theory and estimates. Journal of Public Economics 61, 289-305.

Social Security Trustees, 2016. The Annual Report of the Board of Trustees of the Federal Old-Age and Survivors Insurance and Federal Disability Insurance Trust Funds. Washington, DC.

Stern, N., 2007. The Economics of Climate Change: The Stern Review. Cambridge University Press, Cambridge.

Sterner T., Persson, U., 2008. An even Sterner review: introducing relative prices into the discounting debate. Review of Environmental Economics and Policy. 2, 61-76.

Traeger, C., 2009. Recent developments in the intertemporal modeling of uncertainty. Annual Review of Resource Economics 1, 261-286.

Traeger, C., 2011. Sustainability, limited substitutability, and non-constant social discount rates. Journal of Environmental Economics and Management 62, 215-228.

Weitzman, M., 1998. Why the far-distant future should be discounted at its lowest possible rate. Journal of Environmental Economics and Management 36, 201-208.

Weitzman, M., 2007. A review of the Stern review on the economics of climate change. Journal of Economic Literature 45, 703-724.

Weitzman, M., 2010. Risk-adjusted gamma discounting. Journal of Environmental Economics and Management 60, 1-13.

Zeckhauser, R.J., Viscusi, W.K., 2008. Discounting dilemmas: editors’ introduction. Journal of Risk and Uncertainty 37, 95-106.

Appendix. Proof of MCF^t > 1.

Proposition. If $c_{t+k}^t, k = 0,1,\ldots, N$, *are all normal goods, then*

$$MCF^t \equiv \frac{1}{1+\sum_{k=1}^{N} \frac{(r_g - r_n)\partial a_{t+k-1}^t / \partial(LT^t)}{(1+r_g)^k}} > 1.$$

Proof. To prove MCF^t > 1, it is sufficient to prove $\frac{\partial a_{t+k-1}^t}{\partial(LT^t)} < 0$ for $k = 1, 2, \ldots, N$.

First, differentiating budget constraint (6) with respect to LT^t, we have

$$\sum_{k=0}^{N} \frac{\partial c_{t+k}^t / \partial(LT^t)}{\left(1+r_n\right)^k} = -1. \qquad \text{(A1)}$$

Then, from (5) and by using recursive method, it can be readily checked that

$$\frac{\partial a_{t+k-1}^t / \partial(LT^t)}{\left(1+r_n\right)^{k-1}} = -1 - \sum_{i=0}^{k-1} \frac{\partial c_{t+i}^t / \partial(LT^t)}{\left(1+r_n\right)^i} = \sum_{i=k}^{N} \frac{\partial c_{t+i}^t / \partial(LT^t)}{\left(1+r_n\right)^i} < 0, \qquad k = 1, \ldots, N. \qquad \text{(A2)}$$

In (A2), the second equality is due to (A1) and the inequality is due to the normality of consumption goods in all years.

Therefore, MCF^t >1. Q.E.D.