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Social Discounting of Large Dams with Climate Change Uncertainty

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ABSTRACT: It has long been known that the economic assessment of large projects is sensitive to assumptions about discounting future costs and benefits. Projects that require high upfront investments and take years to begin producing economic benefits can be difficult to justify with the discount rates typically used for project appraisal. While most economists argue that social discount rates should be below 4%, many international development banks and government planning agencies responsible for project appraisal can be found using rates of 7-12% or more. These agencies justify choosing higher discount rates to account for the opportunity cost of capital. Meanwhile, a new and robust debate has begun in economics over whether social discount rates of even 3-4% are too high in the context of climate change.

This paper reviews the recent discounting controversy and examines its implications for the appraisal of an illustrative hydropower project in Ethiopia. The analysis uses an integrated hydro-economic model that accounts for how the dam's transboundary impacts vary with climate change. The real value of the dam is found to be highly sensitive to assumptions about future economic growth. The argument for investment is weakest under conditions of robust global economic growth, particularly if these coincide with unfavourable hydrological or development factors related to the project. If however long-term growth is reduced, the value of the dam tends to increase. There may also be distributional or local arguments favouring investment, if growth in the investment region lags behind that of the rest of the globe. In such circumstances, a large dam can be seen as a form of insurance that protects future vulnerable generations against the possibility of macroeconomic instability or climate shocks.

KEYWORDS: Social discount rate, climate change, Nile basin, cost-benefit analysis, water resources

INTRODUCTION

The practice of discounting reflects the idea that a given amount of resources available for use today are worth more than the same amount available in the future. There are two sides to this argument. First is the fact that resources today can be put to productive use via investment, such that they yield greater future amounts, whereas future resources can only be put to such productive uses at later times. Alternatively, discounting can be justified on the basis of individual time preferences, since people consistently favour consumption of resources at present over consumption in the future. Indeed, if individuals and firms operated in a world with perfectly efficient markets, discount rates would be set competitively, and individuals could choose to use resources at present or in the future based on the balance of marginal benefits obtained from different inter-temporal choices (i.e. based on their marginal rate of time preference). In the real world, however, social discount rates, or rates that appropriately weight present and future costs and benefits to society as a whole, are not reflected by such market choices. This makes it difficult to settle on which discount rate to use when assessing the economics of long-lived public investment programmes.

   The proper procedure for social discounting of future costs and benefits of large public-sector projects has long been a contentious issue (Boardman et al., 2005). There are two fundamentally

different views in the ongoing discounting debate: the prescriptive view emphasises the norms that should govern the choice of the appropriate social discount rate, while the descriptive one aims to make social discounting consistent with the types of individual decisions and the rates of return on private investment observed in the market place (Portney and Weyant, 1999). In practice, arguments over discounting for public investment appraisal originated in the water resources sector in the United States during the 1950s (Eckstein, 1958; Krutilla and Eckstein, 1958; McKean, 1966), and quickly followed in other sectors of government intervention, most notably transportation in the 1960s (Mohring and Harwitz, 1962) and the energy sector in the late 1970s and early 1980s (Lind et al., 1982). During the Nixon Administration, the Office of Management and Budget (OMB), in an attempt to standardise the widely varying discounting assumptions made by different agencies, issued a directive requiring the use of a 10% rate (US OMB, 1972), which interestingly, did not apply to water projects (Lind et al., 1982).[1] This rate has since been revised downward to about 7%, and is said to "approximate the marginal pre-tax rate of return on an average investment in the private sector in recent years" (US OMB, 1992). This OMB rate is far above the social discount rates preferred by the majority of economists (Weitzman, 2001), many of who fear that rates which reflect private returns on investment might lead to public-investment decisions that are myopic and focused on the short term.

In spite of the general consensus among economists that the social discount rate should be lower than the OMB rate, the practice of discounting remains contentious. The issue featured prominently among those addressed in detail in the background documents on cost-benefit analysis submitted by economists to the World Commission on Dams (WCD) (Nichols et al., 2000; Aylward et al., 2001). The report by Aylward et al., in particular, summarised different approaches to social discounting and explained their importance to the economic analysis of large water infrastructural projects. The report recommended greater use of sensitivity analysis and, when possible, the use of a consumption equivalents approach to adjust for the long-term differences between devoting resources to investment and consumption; in other words, proper accounting for the opportunity cost of capital. The final report of the WCD however did not devote much attention to discounting, and did not take a firm position on how discounting should be conducted in practice (WCD, 2000). It rather emphasised that 1) there are important limitations to using a decision framework based solely on 'balance sheet' considerations (i.e. aggregation of costs and benefits to different parties over time), 2) multilateral development banks tend to employ social discount rates that are too high (i.e. 10% or more according to a review conducted by economic advisers to the Commission; see Lagman and Aylward, 2000), and 3) there is a need for better sensitivity analysis in economic appraisals in general.

A more obvious sign that the discounting debate remains active today is the controversy over the economic implications of climate change, which has attracted the attention of prominent economists (Cline, 1992; Stern, 2006; Weitzman, 2007; Heal, 2007; Nordhaus, 2007; Sterner and Persson, 2008; Dasgupta, 2008). All but Nordhaus argue that society should make substantial, immediate investments to reduce climate change, though even Nordhaus argues for lowering social discount rates relative to those typically used in practice (to about 4%). For Cline and Stern, the need for immediate mitigation follows from their use of very low discount rates. For Sterner and Persson, it results from inclusion of decreasing natural wealth and consumption due to climate-change damages. For Weitzman, the imperative to act follows from the effect of uncertainty and the need to avoid even low risks of catastrophic damages. Finally, for Dasgupta, it comes from a fear that our capacity to mitigate future climate change and avoid the depletion of natural capital in the future may be lower than we hope. In brief, it appears that a wide variety of perspectives and viewpoints other than those based on

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[1] In fact, it was Congress that resisted the move to apply a 10% discount rate to water projects, instead sticking with the formula set forth in Senate Document 97, and later writing into law the formula in Section 80-A of the Water Resources Development Act of 1974 (Public Law 93-251). The Congressional Budget Office (CBO) today uses a 2% discount rate, which is said to approximate the long-term cost of borrowing for the federal government based on a conservative estimate of the long-term real market risk-free interest rate (the Treasury rate).

traditional arguments over the opportunity cost of capital can, and do, legitimately enter into debates concerning discount rates, even among economists, not to mention those of the many others who would comment on the allocation of public resources. Political interests and preferences for or against specific types of projects certainly enter into these arguments as well.

The re-emergence of this debate should thus prompt any person interested in the role of economic and cost-benefit analysis in policy-making to think carefully about the implications their arguments have for public investments besides those destined specifically to avert the negative consequences of climate change. These arguments could alter the very manner in which social discount rates are used. This paper seeks to explore the effect of following some suggestions emanating from the prescriptive approach to discounting, studying their effect on the appraisal of an illustrative hydropower dam on the Blue Nile in Ethiopia. Using a simple Ramsey model of discounting (Ramsey, 1928), the calculations in this paper show the effect that varying growth trends and assumptions about the elasticity of marginal utility of consumption (i.e. how the value of consumption changes with its level) have on the time profile of discount rates for three alternative states of the world. Results obtained using these different time profiles of discount factors are also compared with those using a more standard range of time invariant social discount rates from 2 to 6%.

Though the states of the world explored in this paper are stylised and may seem implausible to some, there are two important points that should be made at the outset. First, it is important to note that the hypothesised growth trends could be considered to apply to smaller national economies of the world, which have in the recent past shown considerable variation in economic growth and variability (particularly sub-Saharan Africa where real per capita growth was negative for much of the 20th century). Indeed, because most large public investment opportunities in the water sector today exist in developing countries with just such a mixed economic record, concerns over the economic context for public investment may hold particular importance, especially if the projects are financed using transfers from richer countries. Second, we could imagine a world in which growth trends change over time, switching from the high growth trends of the recent past to much lower or zero growth over the very long term (perhaps due to climate change). In that case, the economics of long-lived projects will lie somewhere between those predicted for each of the states of the world considered here.

BACKGROUND: DIFFERENT APPROACHES TO SOCIAL DISCOUNTING

Boardman et al. (2005) describe the main methods for social discounting commonly used by economists. The first argues that analysts should use the marginal rate of return on private investment, r (i.e. the economic gains obtained from devoting an additional unit of money to investment), because it most accurately reflects the opportunity cost of resources spent by government (which could alternatively leave those resources in the private sector) (Harberger, 1969). Both corporate and income taxes reduce investment. As a result, r, typically around 8%, exceeds the market interest rate, i. Given this distortion, a new government project, financed by borrowing in the domestic financial market, will shift the demand curve for investment funds outwards, raising the market rate of interest to i'. At this increased rate, private-sector investment falls, and individual savings increase, crowding out both consumption and investment. Harberger argued for the use of r as a good approximation of the true social discount rate on the basis that savings are fairly unresponsive to changes in interest rates.

A second approach is to use the social consumption discount rate, ρ, which is typically estimated to be between 0 and 4% based on the yields from US Treasury Bonds adjusted for taxes and inflation. This rate is much lower than the marginal rate of return on private investment. It is often supported by those who support government projects. It is also similar to the rate used by Congress for the evaluation of water resources projects.

Most economists consider that each of these approaches is applicable only in very special cases, and that public investment more typically simultaneously displaces investment and consumption and yields a time series of future changes in both of these. A third approach is then a hybrid of the two: the

discount rate is obtained by weighting the relative contributions of its sources, which can be domestic private investment, consumption, or borrowing in foreign markets. This method yields rates that are greater than ρ but less than r, and they vary depending on how a project is financed. Unfortunately, this approach ignores the fact that future benefits from the project may also contribute differentially to consumption and investment. The fourth approach to social discounting seeks to address this issue by using the shadow value of capital (Marglin, 1963; Dasgupta et al., 1972). This adjustment converts all present and future investment gains or losses into consumption equivalents, which can then be added to changes in consumption, all of which are then discounted at the social consumption discount rate ρ, previously discussed.

Not surprisingly, given the lack of consensus over the appropriate method for discounting, credible objections can be raised to each of the four methods described above. There are several difficulties with using r. First, it incorporates a risk premium, whereas it can be credibly argued that risks are lower for government projects (Arrow and Lind, 1970). Plus, if public investments are financed using taxes rather than borrowing, it is more likely that consumption will be crowded out than investment, since most taxation revenue comes from income, payroll or consumption taxes. Projects may also be financed with government loans obtained at a lower rate in foreign markets. Third, private-sector returns may be inflated due to distortions arising from negative externalities or imperfect competition. Finally, some economists argue that substantial crowding out of investment is unlikely, given that a) there may be a fixed pool of private investment in the economy, b) the government project may actually create greater investment opportunities, and c) the economy may not be fully using its resources.

On the other hand, using a single social consumption discount rate is troublesome given the heterogeneity in individual preferences and resulting variation in real returns from saving. It can be debated whether it makes sense to consider that individuals have a single marginal rate of time preference, given their complex borrowing and saving behaviours. Use of the weighted social discount rate or the shadow value of capital approaches can help to mitigate these problems, but at the cost of real practical difficulties in determining how much consumption or investment is displaced by the project, and how much future consumption and investment will result from it.

It might at first appear that the higher discount rates applied in the cost-benefit analyses conducted by government agencies such as the US OMB and multilateral development banks are most consistent with an approach based on the private rate of return on capital. However, how project appraisal results are typically presented casts serious doubt on this.[2] Project feasibility studies often apply discount rates without citations or explanations for the rationale behind them (Aylward et al., 2001). Perhaps more importantly, they tend to focus on the economic internal rate of return (EIRR) for a project rather than net present value (NPV), which suggests they are applying a capital rationing approach. The EIRR is the discount rate that yields an NPV of zero, and its use biases project selection towards those with the highest return on investment rather than the greatest overall net benefits.

As different as they are, each of the aforementioned discounting approaches share two characteristics. First, they imply that the weights applied to future costs and benefits decline at a constant rate. Second, they aim to calibrate social discount rates on the basis of other choices made by individuals and governments, whether in investment or in consumption. Using similar reasoning, many economists today argue that government decisions about investment in immediate and costly mitigation actions against climate change should at least account for the long-run rate of return on capital – typically found to be about 4% – to calibrate ρ (Nordhaus, 2007; Weitzman, 2007). These

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[2] In fact, a World Bank operational guide states: "The Bank traditionally has not calculated a discount rate but has used 10-12 percent as a notional figure for evaluating Bank-financed projects. This notional figure is not necessarily the opportunity cost of capital in borrower countries, but is more properly viewed as a rationing device for World Bank funds. Task Managers [sic] may use a different discount rate, as long as departures from the 10-12 percent rate have been justified…" (Operational Core Services Network Learning and Leadership Center, 1998).

economists criticise the lower discount rates used by others active in the debate over climate-change economics, most notably those in Stern (2006). According to Nordhaus, applying low discount rates will lead to over-investment in questionable social policies with very low returns (and too much immediate climate-change mitigation). This is not unlike the argument that low discount rates may "induce a capital intensive pattern of development and promote investments with high upfront costs, such as dams, that could be harmful to the environment" (Birdsall and Steer, 1993).

There are two approaches to discounting that allow for a time-varying profile of discount rates. The first method consists of several proposals (proportional, hyperbolic or gamma discounting) for correcting three well-known problems with using a non-varying rate (Harvey, 1994; Laibson, 1997; Weitzman, 2001): a) the robust empirical finding that people view welfare trade-offs in present and future time periods differently depending on how far in the future they look (Loewenstein and Prelec, 1992), b) the issue that very large benefits and costs (e.g. the value of the whole of world output) occurring far in the future may have very little value because real growth rates of 1-2% are lower than the standard discount rates, and c) the philosophical dilemma that discounting reflects only the preferences of people currently alive, whereas large-scale public investments (such as large dams) may affect future generations (Ramsey, 1928). However, these approaches are difficult to justify on theoretical grounds, which perhaps explains why they are rarely used in practice.

In mulling over the philosophical dilemma of how to discount in the context of inter-generational spillovers, Ramsey himself proposed another approach that allows for non-constant discounting over time. He expressed the consumption discount rate ρ_t, now allowed to vary over time t, as the sum of two components:

$$\rho_t = \delta + \eta(c_t) \cdot R(c_t), \tag{1}$$

where, δ is the pure rate of time preference, $\eta(c_t)$ is the elasticity of the marginal utility of consumption at time t, and $R(c_t)$ is the rate of change of consumption at time t. The theoretical appeal of this expression is that it relies on the real per capita growth rate of the economy rather than on the distorted savings and investment rates that reflect the behaviours of the present generation (Heal, 2007). It also offers the possibility of solving the problems with time-invariant discount rates listed above.

In effect, Dasgupta (2008) shows that the equality between the long-run return on capital and the social consumption discount rate only holds under very special circumstances, what he calls a "fully optimum economy". For the fully optimum economy assumption to hold, markets must be efficient, agents need to have perfect foresight over all future time, and there must be no external effects, and these cannot be argued to exist in the context of climate change (or, for that matter, relative to long-lived investments in the water resources sector).[3] Given the fact investments in climate mitigation and large public-sector projects affect consumption across generations, there are convincing reasons to test what equation 1 and different projections of economic growth would imply about the value of the social rate of discount ρ_t. The task is only to specify expressions for $\eta(c_t)$ and δ, and make projections of economic growth $R(c_t)$. The application presented in this paper explores the use of such an approach.

Before introducing just such an application, though, it is worth considering each of these separate terms in more detail. First, δ is "the rate at which we discount the welfare of future people *just because they are in the future"* [emphasis in the original] (Heal, 2007); it is exogenous and unchanging over time, and arguably the simplest term in equation 1. Philosophers argue that this parameter must be zero since discrimination against future people is unethical. Others suggest the use of a very small number, perhaps 0.1%, to reflect the exogenous probability of extinction of the human race in any given year. Among economists weighing in on the climate-change debate, δ varies from about zero (Cline, 1992; Stern, 2006; Heal, 2007; Dasgupta, 2008), to 2 or 3% (Nordhaus, 2007; Sterner and Persson, 2008).

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[3] In addition, it is plausible that real social rates of return on many investments – perhaps those with high emissions of greenhouse gases – are inflated, as external costs have been ignored.

These higher values however are not ethically based; they are rather adopted to obtain a discount rate that approximates the long-term rate of return on capital.

The second term in equation 1 is endogenous, depends on consumption. Since $\eta(c_t)$ is strictly positive, and $R(c_t)$ has been positive over most of recent history, this term is generally thought to be positive.[4] It therefore follows that future generations' benefits should be discounted relative to those of the present one, particularly in rapidly growing economies, since these are becoming wealthier. Still, projecting $R(c_t)$ far into the future is hard to do with any certainty. Some point out that $R(c_t)$ could become negative if climate change is strongly damaging and reduces aggregate consumption (Stern, 2006; Heal, 2007). Plus, uncertainty about the discount rate itself requires that we adjust it downward (Weitzman, 1998; Newell and Pizer, 2003; Weitzman, 2007). Variability in the growth forecast reduces the risk-free rate (Dasgupta, 2008), reflecting the fact that investment today provides a form of insurance in a less-stable economic future ("saving for a rainy day"), as shown by equation 2:

$$\rho_t = \delta + \eta(c_t) \cdot E[R(c_t)] - [\eta(c_t)]^2 \cdot \mathrm{var}[R(c_t)]/2. \qquad (2)$$

In addition, the consumption of certain goods (e.g. ecosystem services) is likely to decrease in a climate-damaged world, even if aggregate consumption continues to rise (Kellenberg and Daly, 1994; Sterner and Persson, 2008). Sterner and Persson (2008) show that if ecosystem services and general consumption are complements, this decrease could make ρ_t negative.

Finally, $\eta(c_t)$, the elasticity of the marginal utility of consumption at time t, is "the index of the aversion society ought to display toward consumption inequality among people – be they in the same or in different periods" (Dasgupta, 2008). Nearly all existing analyses assume η to be constant (if only for tractability) and low (Cline assumes 1.5, Nordhaus, Stern, and Sterner and Persson 1, and Weitzman 2). If we accept on ethical grounds that $\delta \sim 0$, the implication from reasonable savings rates is that η should be at least 2-3 (Dasgupta, 2008).[5]

IMPLICATIONS FOR COST-BENEFIT ANALYSIS OF LARGE DAMS: A REAL-WORLD EXAMPLE

The current debate on discounting is useful in many ways, but its practical implications for project appraisal are unclear. It remains difficult to appropriately specify equation 1 for two reasons: 1) the lack of consensus on what $\eta(c_t)$ should be, and 2) the fact that uncertainty about future growth in consumption, similar to uncertainty over the consequences of climate change, does not readily lend itself to probability distributions, and hence makes it hard to justify probabilistic treatments of the true social rate of discount. In the remainder of this paper, we compare two approaches for considering these difficulties.

In the first, we apply the 'prescriptive' approach and parameterise equation 1 for three plausible states of the world with different assumptions about economic growth (described further below). We develop an illustrative $\eta(c_t)$ function that seems consistent with the arguments presented by Dasgupta (2008) and others. From this analysis, we see that different growth trajectories and the shape of $\eta(c_t)$ can have a profound influence on how we think about the social welfare implications of large public investments. This is useful because it highlights the importance of differences in assumptions and views towards public investment and climate-change mitigation that arise among people on the various ends of the discounting debate.

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[4] A frequently cited point estimate of consumption growth under business as usual is $R(c_t) = 1.3\%$ (Stern, 2006).

[5] However, some argue that high values of η lead to highly implausible trade-offs. For example, $\eta = 1$ means that a 1% decrease in consumption for a person earning \$1,000 (i.e. a reduction to \$990) leads to an equivalent change in welfare as a 1% decrease in consumption for a person earning \$100,000 (i.e. a reduction to \$99,000). With $\eta = 2$ and $\eta = 3$, the consumption of the second person would have to be reduced 50 or 93%, respectively, to represent an equivalent change in welfare as a 1% decrease in consumption for the first. There is little evidence that the world's societies consider such levels of income redistribution as desirable. But the η that we observe from redistribution choices is contaminated by people's concerns over moral hazard and adverse selection, which are less relevant in an inter-generational context (Dasgupta, 2008).

In the second approach, ρ_t is calibrated based on parameter values that have been proposed by the different authors writing on discounting climate change, using Stern's assumed 1.3%/y growth projection for the business-as-usual scenario (see Stern, 2006). These rates range from 2 to 5%, with several authors' rates falling close to the "calibrated" 4% long-run return on capital (table 1). These are supplemented with the rates used by the US and European governments (US: 2 and 7% for the Congressional Budget Office (CBO) and OMB, respectively; UK: 3.5%; Germany: 3%; France: 4%), to yield a similar range of discount rates of 2-6%. This alternative analysis can be considered to characterise the uncertainty (and/or disagreement) associated with social discounting among typical practitioners of cost-benefit analysis today.

Table 1. Discounting assumptions of different authors in their assessments of climate change, assuming $R(c_t) = 1.3\%/y$.

	Cline	Nordhaus	Stern	Sterner and Persson	Weitzman	Dasgupta
δ = pure rate of time preference	0	3	~0.1	3	2	0
η = elasticity of marginal utility with respect to consumption	1.5	1	1	1	2	3 to 4
ρt = social discount rate	1.95	4.3	1.4	4.3	4.6	3.9 to 5.2

Specifying the states of the world

To begin thinking about possible future economic growth, it is worth briefly considering the historical record. Several economists have worked on obtaining a long-term series of world per capita GDP growth.[6] Angus Maddison (2006) has constructed a detailed series for 1820-2006 using annual data as far as possible, which he supplements with benchmark estimates for 1 A.D.; 1000, 1500, 1600 and 1700 AD. In this series, average annual per capita GDP growth for 1820-2006 is about 1.3% (equivalent to the Stern long-term growth rate); the rate is 2.2% for 1950-2006. Bradford De Long offers an alternative series that attempts to adjust for improved well-being due to the presence of new technologies and goods; this series estimates annual growth to be 1.8% from 1800 to 2000, and 2.8% for 1950-2000 (De Long, 2006).

Since 1950, growth in the Nile basin economies that would be affected by a Blue Nile dam, especially Ethiopia and Sudan, has been slower than the global trend, and Sudan has moved between periods of rapid wealth creation and severe economic contraction over the last half century. The Egyptian economy has performed slightly better than the world average over the same period. Rather than attempting to predict the precise trajectory of economic growth (consumption) over the next century, we explore three illustrative states of the world (table 2).

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[6] We recognise that per capita growth in global GDP is not strictly the same as per capita growth in consumption because the former includes investment, but nonetheless feel that using the historical series of economic growth rates is instructive, especially because Maddison's long-term series is largely based on consumption trends rather than on GDP.

Table 2. Summary of discount rate parameters for the three modelled states of the world.

Parameter	δ	Expected growth (%)	Variance of growth (%)	Description
State of the world 1 (σ_1)	0.1	2.0	0.02	Dependable and steady global growth in consumption
State of the world 2 (σ_2)	0.1	1.3	0.25	Unsteady global growth in consumption
State of the world 3 (σ_3)	0.1	0.0	0.25	Economic stagnation, with large year-to-year fluctuations

State of the world 1. Robust and dependable economic growth (referred to as σ1)

Economic growth continues to be dependable and robust, similar to that observed in modern times (e.g. 2.0% real per capita growth, with relatively low year-to-year fluctuations: variance = 0.02%). This state of the world depends on technological innovation continuing to outpace population growth, such that many economies around the world continue rapid growth. It does not, however, imply that strong growth need occur everywhere. Just as the growth of the past 50 years has not been uniform across all regions of the world, it seems most probable that economic divergence will continue even if world growth remains strong.

State of the world 2. Moderate but variable economic growth (σ2)

Economic growth continues, but is somewhat reduced by the effect of very large inter-annual fluctuations due to climate-change-related shocks (e.g. 1.3% real per capita growth; variance = 0.25%). This lower average growth rate is similar to Maddison's longer-term growth rate for 1820-2006 (and the Stern report's long-term growth rate assumption), though the assumed variance of this state of the world is higher. In this particular situation, technological innovation remains high, as in case 1, but catastrophic events become more frequent and impose large and unpredictable costs on the world economy, which converge to drive down the long-term return on capital.

State of the world 3. Economic stagnation (σ3)

Economic stagnation sets in, and very large inter-annual fluctuations occur due to strong climate shocks (e.g. 0% real per capita growth; variance = 0.25%). This state of the world is similar to conditions prior to the Industrial Revolution, when economic growth was quite low. Technological innovation continues, just as it did in many economies prior to the 1700s, but natural constraints and destructive climate events are such that innovation does not result in an increase in long-term wealth accumulation. This world is highly vulnerable to economic shocks related to climate events and related social disruptions.

Parameterisation of the social consumption discount rate

The social rate of discount ρ_t for the three states of the world is obtained from equation 2. The elasticity of the marginal utility of consumption $\eta(c_t)$ is represented by a functional form that ensures that three conditions hold: a) $\eta(c_t) > 0$ for all $c_t > 0$; b) $\eta(c_t)$ is increasing in c_t, and c) $\eta(c_t) < 1$ for only low levels of consumption; as shown below:

$$\eta(c_t) = \alpha * (c_t/c_0)^\beta \tag{3}$$

where, c_0 = consumption at time 0; $c_t = c_0 * (1+E[R(c_t)])^t$ = consumption at time t; and α and β are parameters that determine the initial level and curvature of η. We use different combinations of α and β to generate three possible $\eta(c_t)$ curves (figure 1) to test the sensitivity of results to these parameters.

In the base case, α = 2 and β = 0.25, yielding η = 2 to 3 for a fivefold increase in average consumption (a high η case increases from 2.5 to 4; low η from 1.5 to 2). Each of the curves used has $\eta > 1$ at base consumption levels, consistent with the assumptions of those economists writing about climate change (shown in table 1).

Figure 1. The three cases of elasticity of marginal utility of consumption $\eta(c_t)$ used in the sensitivity analysis for each modelled state of the world.
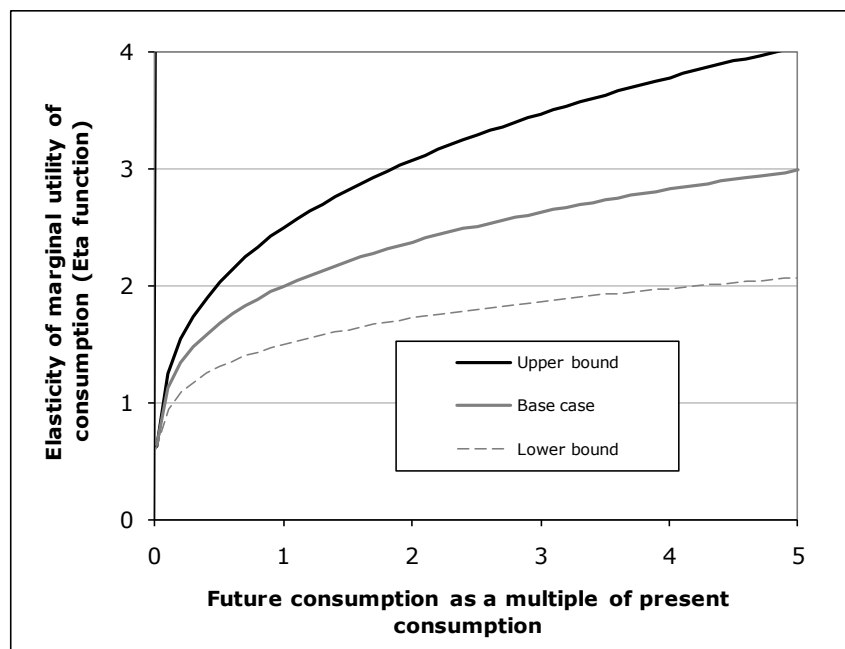
The project

The example project considered in this paper is a potential large hydropower dam on the Blue Nile in Ethiopia. This project is an interesting case study for several reasons. First, there appear to be very attractive sites for large water resources infrastructures at several locations in its upstream reaches (with regard to hydropower potential, surface-to-volume reservoir ratio, low potential for displacement of local populations, and low risk of earthquakes) (BCEOM et al., 1999; USBR, 1964; Whittington et al., 2009). Second, such a project may provide the opportunity for collaborative planning of water resources investments among Nile riparians, which are considering cooperative investment options for inclusion in the Joint Multipurpose Programme (JMP). Blue Nile projects appear to have the potential for generating system-wide benefits (Blackmore et al., 2009). Third, in the context of climate change, research suggests that arid and semi-arid developing countries such as those which make up the set of Nile riparians are particularly vulnerable (Conway et al., 1996; Abou-Hadid, 2006; IPCC, 2007; Strzepek et al., 2007). New or existing infrastructures may play an important role in adaptation to climate change. Finally, there is substantial uncertainty concerning how climate change will impact this region (Gleick, 1991; Conway and Hulme, 1996; Sayed and Nour, 2006; Conway et al., 2007), and there is a need to better understand how that uncertainty compares with other economic and physical aspects of the planning problem.

The economic costs and benefits of this project are considered from a basin-wide perspective, such that impacts at the dam and its downstream are monetised as far as possible given existing data. These costs – mainly capital, power transmission, and operation and maintenance (O&M), plus economic rehabilitation for households that could no longer practise flood recession agriculture in Sudan, and

benefits, mostly hydropower, regulation of irrigation water supply, flood control and carbon offsets – have been discussed in other research (Whittington et al., 2008; Jeuland, 2009). The example in this paper uses similar data, largely obtained from unpublished project studies (summarised in table 3, and presented in additional detail in Jeuland, 2009). We assume that a dam would be added alongside modest irrigation expansion in Sudan and Ethiopia. Egypt is assumed to continue to use the 55.5 billion m^3/y allocation specified in the Egypt-Sudan 1959 Nile Waters Agreement (Sudan has not yet reached her limit). The time horizon for the project is assumed to vary over a wide range from 30 to 100 years; this is a conservative assumption to reflect the fact that siltation may greatly reduce the predicted lifespan of a Blue Nile dam.[7] Moreover, the filling period for the reservoir is included since the potential projects are quite large and would take several years to become fully operational. Risks of catastrophic failure are included as low-probability random events to account for the possibility of dam failure. The Blue Nile gorge in Ethiopia is uninhabitable, and environmental and social costs there are thought to be low (though these require more study; see discussion below). Readers interested in the model used to simulate hydropower production, changes in irrigation water availability, the costs of floods, and project net benefits are referred to Jeuland (2009).

Previous research has shown that assumptions about climate change can have a significant impact on the net benefits of Blue Nile dams (Block, 2006). The simulation model thus incorporates the effect of temperature changes on basin-wide irrigation water use (subject to existing treaty obligations) and evaporation rates – an average increase of 2-3 °C over the next 50 years – from the Intergovernmental Panel on Climate Change's A2 emissions scenario. This scenario is characterised by moderate economic development and slow convergence across the world. Because precipitation projections from General Circulation Models (GCMs), and consequently runoff predictions, are highly uncertain, the modelling includes sensitivity analyses on perturbations in Nile river inflows. Specifically, the project economics in the three different states of the world are assessed assuming that changes in basin-wide runoff could range from a 15% decrease to a similar increase (this is also done for the range of time-invariant discount rates). This spectrum of changes in runoff encompasses most of the predictions from GCMs as well as in the climate-change literature for the Nile basin, which overall suggests that decreases in runoff are probably more likely than increases due to higher evapotranspiration rates (see Jeuland, 2009 for details). Importantly, there is no structural linkage in the model between changes in runoff and the various states of the world; these may, in reality, be connected but cannot be specified given the current state of knowledge.

Before discussing the results of the discounting analysis, we also need to consider two additional and relevant issues for the project appraisal: 1) the real opportunity cost (shadow value) of the capital that would be allocated to this project; and 2) the role of the project (relative to displaced alternatives) in the beneficiary economy.

Even if the relation between the social discount rate and the rate of return on capital is unclear, the opportunity cost of capital is directly influenced by this rate, and should be considered carefully when evaluating public investments. In highly capital-constrained economies such as those of the Nile basin, there are limited resources for large public projects. Investing several billion dollars in dam construction would appear to have a high opportunity cost, as it displaces the best alternative project(s), which may have a very high return.

If we assume that the shadow value of capital is equal to one, conventional procedures used in project appraisal apply, such that costs can be debited directly from the project benefits weighted by the discount factor at the point in time where they occur. This procedure is appropriate if the economy financing the project sacrifices an equivalent amount of consumption in the same year as that in which

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[7] Project studies based on measurements of silt loads in the Blue Nile predict (perhaps optimistically) that siltation of the more attractive dam sites would not impact their live storage for about 100 years, but sedimentation rates are hard to measure and often underestimated by a factor of 3 or more. A recent example from Ethiopia is the Gilgel Gibe hydropower dam (Devi et al., 2008), initially expected to last 70 years but now revised using operational data to 24 years.

the capital outlay occurs. If, instead, the capital expense incurred displaces alternative investment, the consumption sacrificed is deferred in time, such that the shadow value of capital will differ from one (Dasgupta et al., 1972). Indeed, Dasgupta (2008) shows that this shadow value grows as the wedge between the marginal productivity (rate of return) of capital r and the social rate of discount ρ increases in an imperfect economy; this should reassure those who argue that a low value of ρ could lead to over-investment in investments with low pay-offs.

Potential JMP projects are somewhat in the nature of a special case, however. At this time, it appears likely that capital for such projects would come from donor monies devoted specifically to the JMP. Many international sponsors are uniquely interested in supporting cooperation among Nile basin countries, and have in the past raised money from richer countries specifically for this purpose. It is therefore plausible that these resources would come from taxation and most likely displace general world consumption. For this reason, a shadow value of capital of 1 is used in this analysis, but it should be noted that any other potential collaborative JMP project (including non-dam projects such as watershed restoration, enhanced irrigation, or improvements in flood preparedness) that would be similarly financed and directly compared with this one must also be evaluated using this same value. If the investment for these projects instead comes from other sources, this value will not be appropriate. In such cases, one would have to account for the opportunity cost of those alternative capital resources.

The second issue is whether the project in question will itself have an influence on the growth rate of the affected economy. This would be the so-called multiplier effect of water resources projects (Bhatia et al., 2005). This research assumes that the multiplier is 1; in other words, the project neither contributes to nor impedes development of the economy beyond the costs and benefits included in the partial equilibrium analysis.

RESULTS

The time profile of discount factors for the three states of the world

The time profile of discount factors implied by each of the three modelled states of the world varies considerably (figure 2). For the high growth case, σ_1, the rate increases over time, as future generations become much wealthier than the present one. Consumption in this state of the world doubles every 35 years, and sevenfold over a 100-year time horizon. The risk premium is also relatively low, increasing to about 0.25% by the end of 100 years, because the variance of growth is low. The discount rate thus begins at about 4% (range 3-5% for the sensitivity scenarios) and increases to 6.8% (range 4.7-9.0%) by the end of the 100-year time horizon. The higher discount factors applied to future costs and benefits are the result of inter-generational equity considerations. Since future generations will be much wealthier, it is less important for the current generation to bear the social responsibility for investing in furthering the benefits of these future people.

Table 3. Key parameters for economic assessment of the Blue Nile dam.

Parameter	Description	Base-case value	Range for sensitivity analysis
General model parameters			
Target water demand in Egypt (billion m^3/year - Bm^3/y)[a]	Target water demands are specified based on existing irrigation, allowing for modest expansion based on estimates from unpublished country master planning documents, and subject to the allocation limit agreed upon by Sudan and Egypt in the Nile Waters Agreement.	55.5	N/A
Target demand in Sudan (Bm^3/y, baseline temperatures)[a]		16.1	N/A
Target demand in Ethiopia (Bm^3/y, baseline temperatures)[a]		3.4	N/A
Dam construction time (year)	Time from ground-breaking up to project completion	10	N/A
Lifespan of dam (year)	The economic life of the infrastructure, including construction time	75	30 – 100
Cost components			
Capital cost of dam (US$ million)	Cost of land and infrastructures associated with the dam and reservoir	2750	2200 – 3300
Capital cost of power transmission (US$ million)	Cost of power transmission lines from Ethiopia to other eastern Nile countries	800	640 – 960
Shadow value of capital	Adjustment used to account for the opportunity cost of capital (see text for further explanation)	1	1
Construction delay (year)[b]	Delays relative to the inception of filling of the project reservoir	2	0 – 4
Renewal of electrical infrastructures (year)	Economic life of infrastructures for power generation and transmission	20	None
O&M expenditures (as % of annual capital cost)	Annual O&M cost	50	35 – 65
Cost of water deficits (multiple of value of downstream water)	Weight to account for the possibility that irrigation deficits may be more damaging than the net value of water (if inputs are also lost)	2	1 – 3
Number of households displaced [c]	Households requiring resettlement due to area flooded	120	60 – 340
Economic loss per displaced household (US$)	Net economic loss associated with resettlement	3500	1750 – 5250
Area of downstream production lost: grazing + agriculture (ha)	Areas of downstream flood-recession agriculture and herding that would be lost due to flow regulation in the Blue Nile	25,000	12,500-37,500
Economic loss per ha (US$)	Net economic loss associated with lost flood-plain production	20	10 – 100
Risk of catastrophic failure (%)	Risk of dam failure	0.01	0.002 – 0.02
Construction and reservoir emissions (million tons of CO_2)	Carbon emissions due to construction and loss of flooded vegetation	6.4	4.8 – 8.6

Table 3. (Continued)

Benefit components			
Hydropower generated at dam (GW-hr/y)	Hydropower generated at the dam site	From model[d]	N/A
Net gain in hydropower in Sudan and Egypt (GW-hr/y)	Hydropower change due to regulation of downstream river flow	From model[d]	N/A
Value of hydropower (US cents/kW-hr)	Economic value of hydropower produced	6.5	4 – 9
Change in timely irrigation water downstream (Bm^3/y)	Changes in water availability for irrigation at target demand sites	From model[d]	N/A
Net value of timely water downstream (US$/m^3)	Net economic value of added irrigation water delivered downstream	0.075	0.025 – 0.15
Expected flood damage in Sudan (US$ million/y)[e]	Estimated annual flood damages due to Blue Nile floods	8.8	4.4 – 17.6
Decrease in probability of flood (%)	Based on the relative change in peak monthly flows in Sudan	From model[d]	N/A
Value of carbon offsets (US$/ton CO_2)[f]	Economic value of carbon emission offsets	20	10 – 30
Carbon offset factor	Estimate of carbon emissions from alternative power sources	0.52	0.3 – 0.6
Change parameters: climate (in %/y, net of inflation)			
Annual change in value of hydropower	Evolution in the real value of energy over time	0.5	0 – 1.5
Annual change in value of timely water	Evolution in the real value of irrigation water over time	1.0	0.5 – 1.5
Annual change in value of offsets	Evolution in the real value of carbon offsets over time	0.5	0 – 1.5

[a] These demands are further increased 5-10% from pre-climate change levels due to temperature increases. Because Egypt has already reached its allocation specified in the 1959 Nile Waters Agreement, her target demands remain 55.5 Bm^3/y.

[b] Dam projects are notorious for taking longer than expected (WCD, 2000).

[c] Very few people live in the Blue Nile canyon at proposed dam sites, because of its steep topography and inaccessibility.

[e] A hydro-economic simulation model is used to obtain the time series of project impacts on the Nile basin given natural variation and constant changes in mean inflows into the river system (see Jeuland, 2009 for further details).

[e] A conservative estimate of annual damages obtained from one unpublished study; recent models (not yet fully verified) suggest these damages may be much higher.

[f] Acknowledging that the real value of carbon offsets is a matter of some controversy, this range is informed by prices in the European carbon trading market as well as by various economic studies of the economic cost of carbon.

The σ_2 state of the world is different in two respects. First, future generations will be only about 3.5 times wealthier than the present generation 100 years from today. Therefore, the equity argument for increasing the discount rate over time is considerably weaker. In addition, the precautionary principle (due to higher variance in economic growth) lowers the risk-free rate by nearly 1% at the end of the 100-year time horizon.[8] In fact, if the time horizon is extended far enough into the future, the discount rate in this state of the world eventually begins to decrease in time, as the precautionary principle overtakes the equity argument (this happens because the discount rate decreases with the square of the elasticity of marginal utility, which is itself increasing in wealth and time). Current investment in future benefits provides insurance against future shocks to the economic system. The discount rate increases from 2.2% (range 1.8-2.6%) to 2.8% (range 2.2-3.3%) over the 100-year time horizon.

Figure 2. The discount rate for the three states of the world.
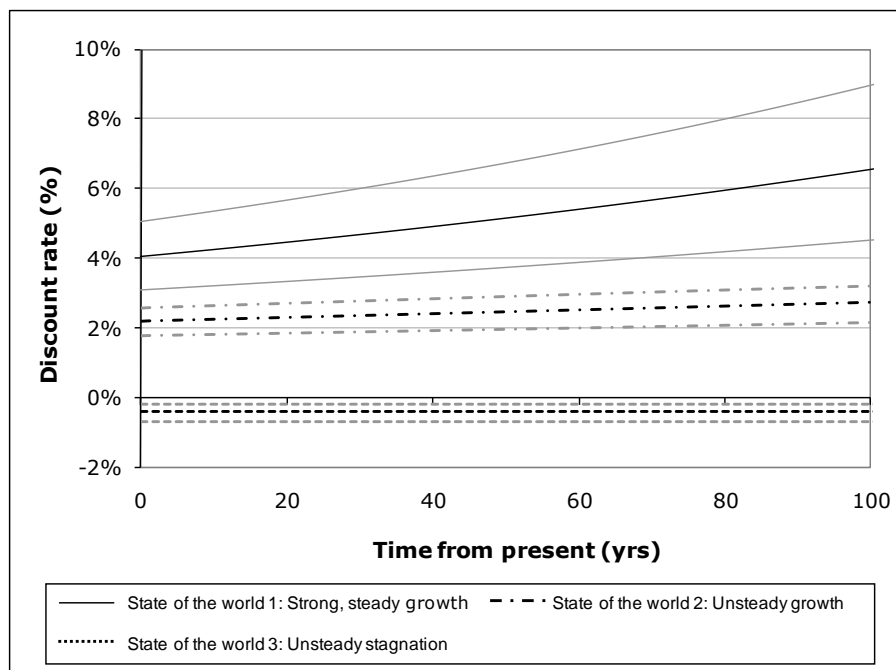
Note: Bounds on the parameterisation of the marginal elasticity of utility are shown by the grey lines around each base estimate.

Finally, for σ_3, the expected growth rate is zero and future generations will be no wealthier than the current one, while the variance of growth is high. Therefore, relatively certain future benefits become more valuable than the current benefits, due to the precautionary principle, just as future costs become costlier than the current ones. The discount rate is thus slightly negative. In fact, because expected growth is zero, the elasticity of utility does not change over time, so that the discount rate remains constant at -0.4% (range -0.2 to -0.7%). In this situation, one dollar of future benefits is worth more than one dollar in present benefits.

If we compare the time-varying discount rates for the three modelled states of the world with the more usual range of constant social discount rates, we note that those for σ_2 and σ_3 lie below or at the

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[8] Note that growth trends over the past decade (~2% real per capita growth; variance = 0.25%) share the average levels of state of the world, σ_1 and the variance of world, σ_2. Thus the risk adjustment to ρ at the end of 100 years in a world like that experienced recently would decrease to that found for σ_1 by more than 1%.

low end of this range over the entire time horizon. For σ_1, however, ρ begins near 4% and rises above the 6% upper bound after 80 years (or after 30 years for the high parameterisation of ρ).

Analysis of the economics of the Blue Nile dam for different discount regimes

Investing capital resources in Blue Nile storage today will result in the delivery of a long stream of economic benefits (primarily hydropower), and the long-term environmental costs of building a dam in this region appear to be low, so costs are concentrated early in the project-planning horizon and benefits extend far into the future. It should thus be clear that the different discounting paths derived in the above section will yield sharply different economic outcomes.[9] The costs for the project are largely incurred in the first 10 years of the project and the benefits begin thereafter, so higher discount rates will tend to put more emphasis on these costs and decrease project NPV.

The economic results vary considerably over the climate conditions and the range of typical discount rates tested here. With a 2% discount rate, the project results in net benefits ranging from 9.5 (for the largest runoff reductions) to US$33 billion (for runoff the largest runoff increases). On the other hand, with a 6% discount rate, net benefits range from US$0.8 to 7.7 billion. The certainty equivalent of the discount rate for this is roughly 3.3% across all flow conditions.[10] The expected EIRR (the break-even value of a time-invariant discount rate) varies from 8.8% to 12.8% over this range of flow conditions.

Based on the analysis in the preceding section, we would expect that investment in the Blue Nile storage in the two lower growth states of the world would be relatively more valuable than an analysis using the certainty equivalent of the discount rate, since ρ_t for these two states of the world is generally below 3%. For σ_1, however, the NPV of the Blue Nile storage will tend to be lower, because the discount rate is generally above 3.3%, reflecting the fact that the imperative for delivering benefits to future, wealthier and more secure generations is decreased. In this state of the world, the expected net benefits for the base case ρ are US$2.1 to 5.7 billion lower (depending on runoff changes) than those obtained using the certainty equivalent of the standard range of discount rates (figure 3; NPV results shown on a log scale because of the wide variation in results). The differences are largest when flows in the system are high. These are conditions under which the future benefits of Blue Nile storage are highest, so that increasing the discount rate decreases project NPV more strongly.

For σ_2, expected net benefits for the base case ρ increase from US$3.3 to 11 billion over the NPV obtained at the certainty equivalent of the standard range. Again, the differences are largest in scenarios with high flows, because the certainty equivalent of the standard range of discount rates reduces future benefits more strongly than that for σ_2, and future benefits are highest under such conditions. For σ_3, the discount rate is slightly negative, so expected net benefits are high across all scenarios. Project NPV in this state of the world is $28 to 79 billion more than what is obtained with the certainty equivalent of the discount rate.

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[9] It is worth emphasising that there have been very limited studies of environmental assets in the Blue Nile canyon other than the project planning documents, which do not highlight them (this may not be surprising). The area is inaccessible, sparsely populated, and malarial, unlike the highlands where most Ethiopians live. There would certainly be some loss of forest cover due to reservoir flooding; this cost has only been included through the land value (which is low) and carbon emissions from loss of vegetation (along with construction emissions). Further research on impacts to biodiversity and erosion of the river channel, including valuation studies, are clearly warranted, as these could affect the economic calculations. Even including such information, it seems likely that project NPV would remain sensitive to the discount rate.

[10] If we apply equal weight to each discount rate value in the 2-6% range, we can plot NPV as a function of the discount rate. The certainty equivalent of the discount rate is the discount rate corresponding to the mid-point of the range of NPV outcomes, or mean NPV. For example, if runoff is reduced by 15%, the project NPV ranges from about US$0.8 billion at a 6% discount rate, to US$9.5 billion at a 2% rate. The average of these NPV values is roughly US$5.1 billion, which roughly corresponds to the result obtained using a 3.3% discount rate. In contrast, using the 4% average discount rate results in lower NPV of US$3.1 billion.

Figure 3. Expected NPV (log scale) for the Blue Nile dam in the three discounting cases, as a function of stream flow.
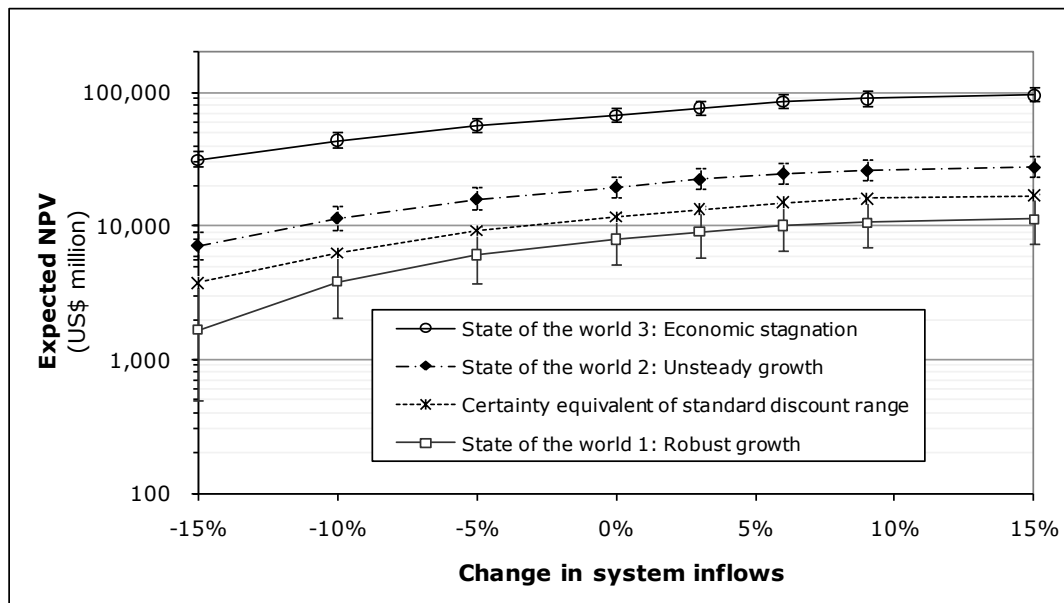
Note: Uncertainty bars show the results for the upper and lower bounds of ρ shown in figure 1 for each case. For the standard range, results are shown for the certainty equivalent of the discount rate.

The sensitivity analysis for other economic parameters of importance shows that the combination of sharply reduced runoff and rapid world growth could diminish the viability of this project (table 4). Although results for the base-case analysis in this situation are slightly positive at $1.7 billion, setting any of three other parameters at the lower bounds shown in table 3 is sufficient to turn project NPV negative. A worst case scenario with several parameters at their lower bounds would be particularly damaging for the project. The effect of changing the parameterisation of ρ is also greatest for σ_1 state of the world. For example, the lower bound ρ is sufficient to drop the NPV to $490 million under these conditions. If runoff remains at historical levels or increases, however, it seems unlikely that this project's NPV would be negative, even in a high-growth world.

When economic growth is slower (e.g. in states of the world σ_2 and σ_3), the sign of project NPV is less sensitive to individual uncertain parameters. The project would probably remain attractive in a more unstable world with low or zero growth even if the magnitude of runoff into the river declines significantly. The parameterisation of ρ in these two cases has a marginal impact on its viability.

The most important parameter for varying outcomes for σ_3 tends to be the life of the project. This is because the discount rates for σ_3 inflate future benefits relative to the present; thus the number of years the project is in operation (and hence the effect of siltation) makes a very large difference for computing NPV. The only exception to this result occurs with the lowest runoff, for which the parameters with the largest influence on outcomes are those which have to do with the value of irrigation water and the relative cost of downstream water deficits. Natural flow variability tends to be more important in the high-growth world when runoff is lower, because a series of particularly low-flow years early in the time horizon has a larger effect on the NPV when the discount rate is high. For the zero-growth state of the world σ_3, a change in the real value of energy over time strongly affects NPV, because the real value of the power produced far in the future is relatively more important when discount rates are low. The possibility of relative price increases for energy may be particularly appropriate to consider for economic assessments in a climate-change world.

Table 4. Hydro-economic model parameters contributing most to changes in NPV outcomes in different "states of the world" (parameters that can individually lead to negative NPV outcomes are shown in italics).

Change in runoff	Standard range (2-6%)	State of the world 1 (σ_1)	State of the world 2 (σ_2)	State of the world 3 (σ_3)
-15%	1. *Value of water*	1. *Value of water*	1. *Value of water*	1. *Value of water*
	2. *Relative cost of deficits*	2. *Value of energy*	2. *Relative cost of deficits*	2. Relative cost of deficits
	3. *Value of energy*	3. *Relative cost of deficits*	3. Value of energy	3. Change in value of energy
	4. Discount rate	4. Natural variability	4. Change in value of energy	4. Value of energy
	5. Change in value of energy	5. Change in value of energy	5. Natural variability	5. Project lifespan
	6. Natural variability	6. High-low parameterisation of ρ	6. Project lifespan	6. Natural variability
+0%	1. Discount rate	1. High-low parameterisation of ρ	1. Value of energy	1. Project lifespan
	2. Value of energy	2. Value of energy	2. Project lifespan	2. Value of energy
	3. Project lifespan	3. Natural variability	3. Change in value of energy	3. Change in value of energy
	4. Change in value of energy	4. Change in value of energy	4. Natural variability	4. Natural variability
	5. Natural variability	5. Project lifespan	5. High-low parameterisation of ρ	5. High-low parameterisation of ρ
	6. Time delay	6. Time delay	6. Relative cost of deficits	6. Relative cost of deficits
+15%	1. Discount rate	1. High-low parameterisation of ρ	1. Value of energy	1. Project lifespan
	2. Value of energy	2. Value of energy	2. Project lifespan	2. Value of energy
	3. Project lifespan	3. Change in value of energy	3. Change in value of energy	3. Change in value of energy
	4. Change in value of energy	4. Project lifespan	4. High-low parameterisation of ρ	4. High-low parameterisation of ρ
	5. Natural variability	5. Natural variability	5. Natural variability	5. Natural variability
	6. Time delay	6. Time delay	6. Value of water	6. Value of water

DISCUSSION

Social discounting of public investment projects consists of assigning weights to future costs and benefits in order to aggregate them into a consistent measure of total welfare gain or loss. Despite decades of debate among economists, there is today little consensus on appropriate discounting procedures. Most economists appear to favour low social discount rates in the range of 0 to 3% (Weitzman, 2001), but government agencies and multilateral development banks continue to use much higher rates in practice. There would therefore appear to be a consistent bias against investments in long-lived infrastructures with high upfront costs, as well as a bias in favour of projects that result in high environmental costs in the distant future. The discounting debate and its implications for inter-generational equity are of particular consequence today as the world contemplates engagement in costly actions to reduce future damages associated with climate change.

This paper explored the implications that recent contributions to the discounting theory – especially with regard to the parameterisation of the social discount rate function – have for the appraisal of capital-intensive water resources investments, using the example of a large potential hydropower dam located in the Blue Nile. We saw that uncertainty about future economic growth and changes in river flow have important implications for how we should think about such investments. For each of three distinct patterns of future economic growth, a time-varying profile of discount factors was obtained. These factors were then applied to the stream of costs and benefits that would result from the implementation of the dam project. NPV was lowest under conditions of robust and dependable economic growth (state of the world σ_1), lower even than those using the certainty equivalent of a range of typical social discount rates. This occurred because the argument for investing for the benefit of wealthier future generations is weaker when growth is high, while the insurance effect against poor future economic conditions is small. In this high growth state of the world, the investment could become unattractive if river runoff also decreased substantially due to climate change (say by 10-15%).

For the other states σ_2 and σ_3, the variability of per capita economic growth around the world was assumed to increase substantially over the present, due to unpredictable climate or population-related shocks. In both these states of the world, the attractiveness of a capital-intensive Blue Nile dam that would deliver a long stream of benefits was shown to improve relative to the standard range. Because future generations are not as wealthy under these conditions as in the σ_1 world, inter-generational equity considerations require the use of lower discount rates. At the same time, the precautionary argument for insuring society against future economic setbacks, which become more frequent, is heightened. The upfront capital investment required for the dam thus appears less costly over the long term.

The relevance of world average per-capita economic growth in consumption to determining which discount rates to apply to Blue Nile dams, rather than the consumption forecast or the rate of return on investment in the affected countries, could be questioned. This analysis assumed that world figures are relevant for two main reasons. First, any large investment upstream in this basin would probably require cooperation among the riparians, and therefore appears likely to receive capital financing from the international donor community and/or multilateral development banks. Second, it seems reasonable to assume that these resources would be raised from taxation and displace general consumption in the rich world. Alternative Joint Multipurpose Programme projects other than dams should also be evaluated in this manner. In addition, if the political economy of the JMP changes, it would be worthwhile to investigate cases that reflect the opportunity costs of the capital resources and economies specifically involved in the investment.

Investments in hydropower dams in the Blue Nile could perhaps also be justified using distributional arguments, even under poor hydrological conditions and continued robust economic growth. The IPCC (2007) considers that poor, developing nations will bear the brunt of the costs of climate change, so the positive effects of continuing technological innovation may not be felt strongly enough in these

countries to compensate for climate-change damages. One could imagine that σ_3-like conditions could occur in the beneficiary economies even as σ_1-type growth persists elsewhere. Since Blue Nile hydropower dams would deliver a variety of benefits – hydropower and carbon offsets, and enhanced dry-season water availability, flood- and sediment-control downstream in Sudan – they may prove especially valuable to the region, possibly for adaptation to climate change.

Nonetheless, there are clear limitations to the illustrative analysis presented in this paper, many of which are related to specific cost-benefit calculations. One obvious shortcoming is that we have little intuition about how the discount rate should be parameterised. This should serve as motivation for additional sensitivity analyses such as those conducted in this paper. There is also little research or information available on the economic costs of decommissioning very large hydropower dams such as these, so these have not been included. Proponents of dams sometimes argue that decommissioning costs will be quite low when standard discount rates are used, and this is usually correct. When lower or decreasing social discount rates are used, however, large costs in the future gain importance, so more research is needed to determine how such costs could alter the net present value of dam projects. Similarly, future environmental costs, which may be increasing in time, should not be neglected when conducting sensitivity analyses on the discount rate. This should motivate valuation research, of which there is relatively little, on the real economic costs to the environment of building large storage reservoirs in different types of locations. In fact, the World Commission on Dams correctly focused attention on the importance of accounting for both decommissioning and environmental impacts from the initiation of project planning. For now, one can interpret the results presented in figure 3 as representing the value of these projects net of decommissioning and perhaps some environmental costs. These additional costs should be included in any complete cost-benefit analysis of dams. One could imagine that unfavourable future hydrology and/or very large environmental costs in the future could significantly reduce the net benefits of this project in each of the three modelled states of the world.

More generally, though, economic analysis only represents one input to the very political and social enterprise of planning large dams. Seen in this light, the calculations presented here show that these projects should not be eliminated from further consideration on economic grounds, but that their overall economic value will be subject to many and varied interpretations, and cannot be firmly captured by any one number or indicator. Some involved in the debate on dams emphasise the inherent limitations of relying on economic analysis to plan contentious projects such as these, but economic analysis nonetheless remains a powerful tool for judging the value of particular projects in improving social welfare. Others selectively choose results from economic analyses to support their respective positions. For example, some opponents of dams argue strategically for both low (when future environmental impacts are large) and high (when they are small) discount rates depending on which approach suits them best for the project at hand. Likewise, their supporters may ignore the possibility of project delays or overestimate the benefits that dams produce by neglecting the time required for, or downstream consequences of, filling reservoirs. In demonstrating the sensitivity of economic calculations for large water projects to factors such as discount rates and climate-perturbed river flows, this paper brings attention to the fact that various stakeholders may appeal to very different economic arguments and assumptions (many of which will be relevant to prudent decision-making) when justifying their positions in the debate on dams.

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REFERENCES

Abou-Hadid, A.F. 2006. *Assessment of impacts, adaptation and vulnerability to climate change in North Africa: Food production and water resources*. AIACC Final Report Project No. AF 90. Washington, DC: The International START Secretariat.

Arrow, K.J. 1995. Inter-generational equity and the rate of discount in long-term social investment. *Proceedings from the IEA World Congress*, pp. 89-102. Tunis, Tunisia: MacMillan Press Ltd.

Arrow, K.J. and Lind, R.C. 1970. Uncertainty and the evaluation of public investment decisions. *The American Economic Review* 60(3): 364-378.

Aylward, B.; Berkoff, J.; Green, C.; Gutman, P.; Lagman, A.; Manion, M.; Markandya, A.; McKenney, B.; Naudascher-Jankowski, K.; Oud, B.; Penman, A.; Porter, S.; Rajapakse, C.; Southgate, D. and Unsworth, R. 2001. *Financial, economic and distributional analysis. Thematic Review III.1*. Prepared as an input to the World Commission on Dams. Cape Town. www.dams.org

BCEOM (Bureau Central d'Etude pour les Equipements d'Outre Mer); BRGM (Bureau de Recherches Géologiques et Minières) and ISL Bureau d'Ingénieurs Conseils. 1999. Main report. Abbay river basin integrated development master plan project. Addis Ababa, Ethiopia: Ministry of Water Resources, Federal Democratic Republic of Ethiopia.

Bhatia, R.; Scatasta, M.; Cestti, R. and Malik, R.P.S. 2005. *Indirect economic impacts of dams – Methodological issues and summary results of case studies in Brazil, India and Egypt*. Washington, DC: World Bank.

Birdsall, N. and Steer, A. 1993. Act now on global warming - but don't cook the books. *Finance and Development* 30(1): 6-8.

Blackmore, D. and Whittington, D. 2009. *Opportunities for cooperative water resources development on the eastern Nile: Risks and rewards.* An independent report of the scoping study team to the Eastern Nile Council of Ministers. Washington, DC: World Bank.

Block, P. 2006. Integrated management of the Blue Nile basin in Ethiopia: Precipitation forecast, hydropower, and irrigation modeling. PhD Thesis. University of Colorado Department of Civil, Environmental and Architectural Engineering, Boulder, CO.

Boardman, A.E.; Greenberg, D.; Vining, A. and Weimer, D. 2006. *Cost-benefit analysis: Concepts and practice*. Third edition. Upper Saddle river, New Jersey: Prentice Hall.

Cline, W.R. 1992. *The economics of global warming*. Washington, DC: Institute for International Economics.

Conway, D. and Hulme, M. 1996. The impacts of climate variability and future climate change in the Nile basin on water resources in Egypt. *International Journal of Water Resources Development* 12(3): 277-296.

Conway, D.; Krol, M.; Alcamo, J. and Hulme, M. 1996. Future availability of water in Egypt: The interaction of global, regional, and basin scale driving forces in the Nile basin. *Ambio* 25(5): 336-342.

Conway, D.; Schipper, L.; Yesuf, M.; Kassie, M.; Persechino, A. and Kebede, B. 2007. Reducing vulnerability in Ethiopia: Addressing the implications of climate change. Integration Report. East Anglia, UK: Overseas Development Group, University of East Anglia.

Dasgupta, P. 2008. Discounting climate change. *Journal of Risk and Uncertainty* 37(2-3): 141-169.

Dasgupta, P.; Sen, A. and Marglin, S. 1972. *Guidelines for project evaluation*. New York: United Nations.

De Long, B. 2006. Estimates of world GDP, one million BC to present. http://econ161.berkeley.edu/TCEH/1998_Draft/World_GDP/Estimating_World_GDP.html

Devi, R.; Tesfahune, E.; Legesse, W.; Deboch, B. and Beyene, A. 2008. Assessment of siltation and nutrient enrichment of Gilgel Gibe dam, Southwest Ethiopia. *Bioresource Technology* 99(5): 975-979.

Eckstein, O. 1958. *Water resource development: The economics of project evaluation*. Cambridge, MA: Harvard University Press.

Gleick, P.H. 1991. The vulnerability of runoff in the Nile basin to climate changes. *The Environmental Professional* 13(1): 66-73.

Harberger, A.C. 1969. The discount rate in public investment evaluation. Conference Proceedings of the Committee on the Economics of Water Resource Development. Denver, CO: Western Agricultural Economics Research Council.

Harvey, C.M. 1994. The reasonableness of non-constant discounting. *Journal of Public Economics* 53(1): 31-51.

Heal, G. 2007. Climate change economics: A meta-review and some suggestions. *Review of Environmental Economics and Policy* 3(1): 4-21.

IPCC (Intergovernmental Panel on Climate Change). 2007. *Climate change 2007: Impacts, adaptations and vulnerability. Scientific-technical analyses: Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

Jeuland, M. 2009. Planning water resources development in an uncertain climate future: A hydro-economic simulation framework applied to the case of the Blue Nile. PhD thesis. University of North Carolina at Chapel Hill, Chapel Hill, USA.

Kellenberg, J. and Daly, H. 1994. *Counting user cost in evaluating projects involving depletion of natural capital: World Bank best practice and beyond*. Environment Working Paper No. 66. Washington, DC: World Bank Environmental Department.

Krutilla, J.V. and Eckstein, O. 1958. *Multiple purpose river development*. Baltimore, MD: Johns Hopkins Press.

Lagman, A. and Aylward, B. 2000. *Survey of multilateral bank practice on financial and economic analysis of large dams*. Contributing paper. Cape Town: World Commission on Dams.

Laibson, D. 1997. Golden eggs and hyperbolic discounting. *Quarterly Journal of Economics* 112(2): 443-477.

Lind, R.; Arrow, K.; Corey, G.; Dasgupta, P.; Sen, A.; Stauffer, T.; Stiglitz, J.; Stockfisch, J.A. and Wilson, R. 1982. *Discounting for time and risk in energy policy*. Washington, DC: Resources for the Future.

Loewenstein, G. and Prelec, D. 1992. Anomalies in intertemporal choice: Evidence and an interpretation. The *Quarterly Journal of Economics* 107(2): 573-597.

Maddison, A. 2006. Historical statistics for the world economy: 1-2006 AD. www.ggdc.net/maddison/

Marglin, S.A. 1963. The social rate of discount and the optimal rate of investment. *Quarterly Journal of Economics* 77(1): 95-111.

McKean, R.N. 1966. *Efficiency in government through systems analysis*. New York: John Wiley and Sons.

Mohring, H. and Harwitz, M. 1962. *Highway benefits: An analytical framework*. Chicago, USA: Northwestern University Press.

Newell, R.G. and Pizer, W.A. 2003. Discounting the distant future: How much do uncertain rates increase valuations? *Journal of Environmental Economics and Management* 46(1): 52-71.

Nichols, D.; Stewart, T. and Von Hippel, D. 2000. *Planning approaches. Thematic Review V.1.* Prepared as an input to the World Commission on Dams. Cape Town. www.dams.org

Nordhaus, W. 2007. The Stern review of the economics of climate change. *Journal of Economic Literature* 45(3): 686-702.

Operational Core Services Network Learning and Leadership Center. 1998. *Handbook on economic analysis of investment operations*. Washington, DC: World Bank.

Portney, P.R. and Weyant, J.P. (Eds). 1999. *Discounting and intergenerational equity*. Washington, DC: Resources for the Future.

Ramsey, F. 1928. A mathematical theory of saving. *Economic Journal* 38(152): 543-559.

Sayed, M.A. and Nour, M. 2006. Impacts of climate change on Nile flows. Paper presented to the Nile Development Forum 2008, Khartoum, Sudan, 17-19 November 2006.

Stern, N. 2006. *The economics of climate change. The Stern review*. London, UK: H. M. Treasury.

Sterner, T. and Persson, U.M. 2008. An even sterner review: Introducing relative prices into the discounting debate. *Review of Environmental Economics and Policy* 2(1): 61-76.

Strzepek, K. and McCluskey, A. 2007. *The impacts of climate change on regional water resources and agriculture in Africa*. Policy Research Working Paper Series. Washington, DC: World Bank.

USBR (US Bureau of Reclamation). 1964. Land and water resources of the Blue Nile basin: Main report and appendices I-V. Washington, DC, USA: United States Department of Interior; US Government Printing Office.

US OMB (US Office of Management and Budget). 1972. Circular N. A-94 (Revised) to the heads of executive department establishments, subject: Discount rates to be used in evaluating time distributed costs and benefits. Washington, DC, USA: Executive Office of the President.

US OMB (US Office of Management and Budget). 1992. Circular N. A-94 (Revised) Memorandum for heads of executive departments and establishments, subject: Guidelines and discount rates for benefit-cost analysis of federal programs. Washington, DC, USA: Executive Office of the President.

Weitzman, M. 2007. The Stern review of the economics of climate change. *Journal of Economic Literature* 45(3): 703-724.

Weitzman, M.L. 1998. Why the far-distant future should be discounted at its lowest possible rate. *Journal of Environmental Economics and Management* 36(3): 201-208.

Weitzman, M.L. 2001. Gamma discounting. *The American Economic Review* 91(1): 260-271.

Whittington, D.; Hanemann, W.M.; Sadoff, C. and Jeuland, M. 2009. The challenge of improving water and sanitation services in less developed countries. *Foundations and Trends in Microeconomics* 4(6-7): 469-609.

WCD (World Commission on Dams). 2000. *Dams and development: A new framework for decision-making*. The report of the World Commission on Dams. London, UK: Earthscan.