Sustainable development: from discounting to simulation

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ABSTRACT

Management of global natural resources is important for sustainability. Two questions are central: what are the welfare effects of different resource policies, and how should one choose between different welfare developments over time? There are methodological challenges related to both macroeconomic analysis of policy effects and choice involving distribution over time, i.e. discounting. There is also a democratic challenge related to the complexity of macroeconomic analysis and discounting. To overcome or reduce these challenges a simulation approach is proposed and discussed. Its potential for democratic choice is tested on a subset of the UK population.

Key words: discounting, macroeconomics, simulation, climate change, energy, Stern Review

Introduction

Recent economic literature on climate policy reveals great disagreement about the strength of policy measures. This is illustrated by the widely differing taxes on greenhouse gases (GHGs) recommended by the Stern Review (*1*) (Stern for short) and by Nordhaus (*2*). Their tax rates differ by a factor of ten, mainly because of diverging arguments behind their choices of discount rates. This disagreement is problematic. While both studies do recommend positive GHG taxes, great disagreement is likely to reduce policy maker confidence in this type of analysis. The arguments and analyses are complex and policy makers are not likely to solve the controversies by themselves.

This paper is about five challenges for the analysis of sustainable development or intergenerational welfare. For each challenge, the traditional economic approach with its maximization of discounted utility is contrasted to a simulation approach.

The first challenge is macroeconomic modeling of the effects of policy on welfare development. This calls for models that capture mechanisms that could lead to non-sustainable development. Non-sustainable development should not be ruled out by simplifications motivated by limitations of modeling approaches. In case analysis shows that there is a real risk of non-sustainable development, only models that can produce non-sustainable development can be used to test policies to avoid such undesired outcomes. This favors simulation models over optimization models.

Second, welfare criteria should reflect concerns about sustainable development. Optimization requires aggregation over time and space such that a unique criterion can be maximized. Such criteria may not discriminate against cyclical or overshooting behavior. In comparison, by using simulation, decision-makers are invited to judge simulated time developments.

Third, as already mentioned, there is great disagreement over the choice of utility discount rates as well as consumption elasticities in optimization criteria. One suggestion has been to test out different parameter sets until optimization produces resource policies with desired welfare consequences. Simulation is more direct in that resource policies are adjusted until desirable outcomes result.

Fourth, economic analysis of global resource management should acknowledge considerable uncertainty. Hence, policies should be seen as contributing to insurance. This complicates both optimization and simulation. Regarding simulation, Monte Carlo simulations represent a viable option.

Fifth, complexity of analysis creates a democratic problem. Recent literature on bounded rationality suggests that reliance on poorly developed intuition leads to biased decisions in complex dynamic systems (*3*). Therefore simple models and methods, that help counter biases should be developed and used. As a first step, a survey among UK residents shows that ordinary people can relate to and make policy choices based on outputs from simulation models.

1. Welfare effects of policies for sustainable development

Currently the International Panel on Climate Change (IPCC) coordinates large-scale research efforts to better understand climate change. Models have been built to study changes taking place in the atmosphere, on land, and in oceans. Data have been sought to understand and quantify cause-and-effect relationships and to produce long-ranging historical time-series.

In comparison, the research efforts to understand how the global economy will react to climate change, scarcity of cheap fossil energy, acidification of oceans, loss of biodiversity etc. seem almost negligible. Typically, individuals or small research groups have carried out the few studies that exist. There is no international panel to coordinate research efforts and to foster competition and productive debate.

Lack of research cannot be explained by the existence of near-perfect models that everybody agrees to. There are greater differences between models than what the studies by Nordhaus and Stern exemplifies. Trust in trend extrapolation of historical economic growth may explain some lack of interest in this type of research. However, people have been overconfident in trend extrapolation before. Examples are the great depression, repeated crashes in financial markets, overshoots in utilization of natural resources, national and governmental debt escalations, and overshoots in private business and private affairs (*3*). Typically early warnings, which may not be based on transparent analyses, get widespread attention only after problems have manifested themselves. Failures to produce reliable forecasts may have discredited economic models and reduced people's belief in their usefulness. However, what is discussed here is use of models to analyze policies (under uncertainty), not the far more ambitions task of producing forecasts.[1]

Economic policy analysis typically relies on optimization. This is often computationally demanding. Therefore complexities such as delays, frictions, non-linearities, and feedback are often left out of welfare economic models. However, these are the mechanisms that could potentially cause overshoots and non-sustainable development in combination with scarcity of natural resources. Such omissions and a bias towards relying on extrapolations of historical trends in exogenous variables may explain why: "…it has become a habit among economists to confine attention to forecasts in which consumption increases indefinitely." Dasgupta (*4*). To test the appropriateness of various model simplifications, more complete models are needed.

Simulation models allow for a rich description of dynamics and non-linearities. Compared to optimization models that is a blessing. Mechanisms that could cause, and policies that could prevent non-sustainable development can be tested. Assessments of how costs increase as remaining resources are depleted provide an alternative to trend extrapolation. But flexibility is also a curse as it allows models to become overly complex and hard to test, understand and communicate. Three principles seem important to limit this problem. First, model variables and coefficients should have real life interpretations allowing for use of prior information about both model structure and parameters[2], and allowing for a variety of tests beyond time-series fitting[3] (*6, 7*). Second, models should be simplified when analysis finds a mechanism to be of little importance. Third, competition between teams with different backgrounds should be organized and encouraged. No single team will ever produce unbiased models. A constructive debate between teams should be facilitated.

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1 For instance, while it is very difficult to forecast commodity prices, a simple supply and demand diagram demonstrates the problems with a policy of price control.

2 Resource constraints are described in physics, chemistry, and biology. Economic constraints are described in economics. Elicitation techniques, laboratory experiments, and past experiences provide information about likely human behavior in different circumstances.

3 According to Solow (*5 p.311*): "…we are not so well off for evidence that we can afford to ignore everything but time-series of prices and quantities.".

To illustrate, consider a simulation model of the world economy. The model has a differential equation for a vector of stocks *s* and explicit equations for marginal return on capital *r* and per capita consumption *c* as functions of *s*.

$$ds / dt = f(s, r, c, T) \qquad (1)$$

$$r = f(s) \qquad (2)$$

$$c = f(s) \qquad (3)$$

Stocks include natural capital, manmade capital, technology, population, health, prices and preferences. *T* denotes public policies for sustainable development and may include taxes, quotas, standards, and R&D subsidies. Policy *T* resembles "the more direct approach of guaranteeing sustainability by means of quantitative limits and safe minimum standards" suggested by Daly (*8*). Simulations allow for explicit testing of the long-term macroeconomic consequences of such policies.

2. Criterion to judge welfare over time

The standard method of welfare economics is to maximize infinite horizon discounted utility

$$\max_T \sum_{t=0}^{\infty} U\{c_t(T)\} / (1+\delta)^t \qquad (4)$$

where $U\{c_t(T)\}$ denotes utility derived from per capita consumption c_t in year *t* for policy *T*.[4] The optimal policy T^* determines the optimal time path of consumption c_t^*. Both T^* and c_t^* will be functions of the *utility* discount rate δ and the parameter η in the typical utility function

$$U(c_t) = c_t^{1-\eta} / (1-\eta) \qquad (5)$$

4 Ideally, consumption should not be defined to be exclusively man-made goods and services; services provided by nature should also be included.

The concavity is determined by the elasticity of the marginal utility of consumption η, "consumption elasticity" for short. For positive values of η, utility increases more and more slowly as per capita consumption increases. Hence, optimization will tend to favor policies that increase the allocation to the poorest generation.

According to Heal (*9*): "Discounting has always been a source of controversy between economists and those from other disciplines interested in the environment.... Perhaps less well-known is the fact that discounting has also been a source of controversy within the economics profession." These controversies point to hard to solve problems with the method itself.

Positive utility discount rates mean less and less weight on future utility and favors policies that yield high consumption for the current generation. This seems of little concern if all policy options imply steadily increasing consumption paths. Then a positive value of η will also help favor the current generation. To illustrate, it seems desireable if optimization recommends the solid path in Figure 1.

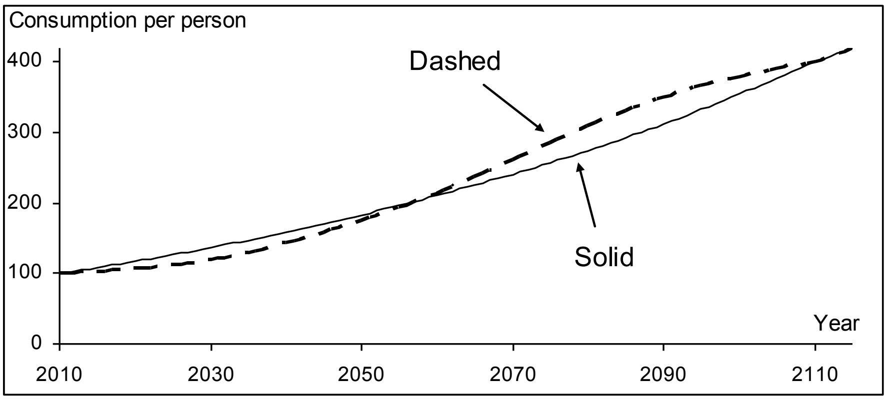

Figure 1: Two steadily growing consumption paths (paths coincide after 2010)

The criterion is problematic if some policy options are such that high consumption in the short run compromises "the ability of future generations to meet their own needs" Brundtland (*10*). In Figure 2 the solid path represents a non-sustainable development. A positive value of η will tend to favor the poor future generations. However, this effect could be overruled by a high utility discount rate.

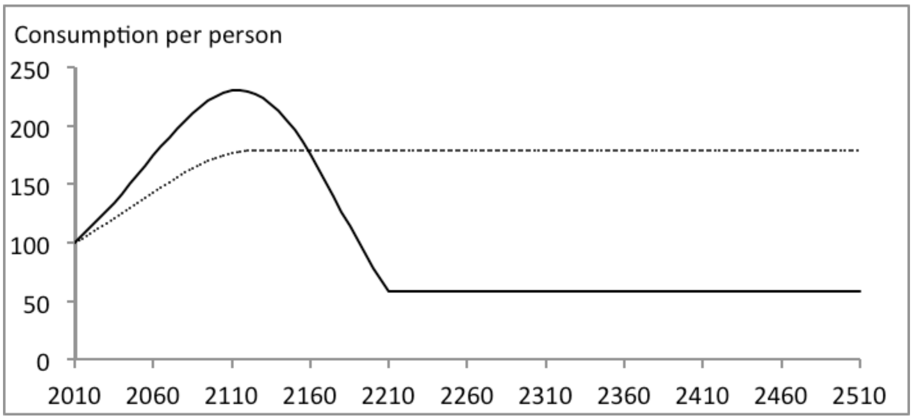

Figure 2: Sustainable versus non-sustainable development

The criterion is also problematic if it favors policies that create temporary overshoots and contractions in an otherwise growing economy. This is exemplified by the solid curve in Figure 3. To see this, assume that η equals zero such that utility is proportional to consumption. In this case, discounted utility could be the same for a smooth consumption path and one that fluctuates widely around the smooth path. A positive value of η implies that consumption paths that lead to a wider spread in consumption rates will reduce discounted utility. However, this reduction tends to be of minor importance for policy recommendations.

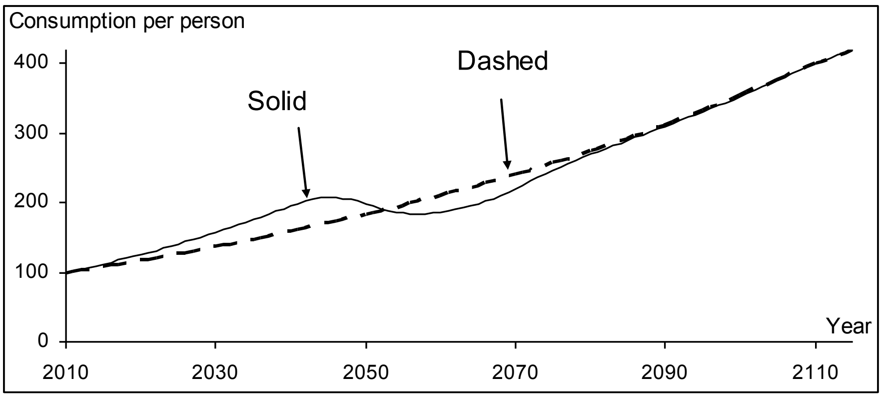

Figure 3: Steadily growing and overshooting consumption path (paths coincide after 2010)

A near zero utility discount rate could help prevent non-sustainable development, but not necessarily prevent overshoots along growth paths. More advanced criteria may help prevent this problems. However, alternatives do not come easy. One interesting alternative is the rank-discounted utilitarian approach (*11*). While this criterion discounts most heavily the richer generations, it does not discriminate against the overshoot in Figure 3.[5]

The Ramsey equation

$$\rho_t \approx \delta + \eta g(c_t) \qquad (6)$$

provides another way to illustrate the importance of future growth in consumption for the different policy options. The *consumption* discount rate ρ_t is related to the *utility* discount rate δ as well as the consumption elasticity η times growth in consumption $g(c_t)$. This means that discounting of consumption from one point in time to the next must consider growth in consumption in the same time interval. Because consumption growth will be sensitive to all meaningful policies, consumption cannot be discounted with a constant *consumption* discount rate, the full criterion in Equation 4 must be used. Nor is it correct to assign a declining *consumption* discount rate independent of variations in consumption growth.

Much of the above problems arise because optimization must take place with respect to one single criterion value. This requires aggregation in space and time. This is different from simulation, where policy-makers can see and judge time paths of consumption and where they may also consider other variables of interest than consumption.

3. Choice of utility discount rate and consumption elasticity

There is great uncertainty and disagreement about what utility discount rates and consumption elasticities to use as exemplified by the Stern and Nordhaus studies. The "baseline" assumptions made by Nordhaus were δ =1.5% and η =2.0 while Stern assumed δ =0.1% and η =1.0; i.e. Nordhaus put less weight on future generations and more weight on the poorest (and present) generation than Stern. As documented by Nordhaus, these assumptions explain almost the entire ten-fold difference between their recommended GHG taxes. Hence the choice of δ and η is very important.

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5 A negative rank utility rate is needed to favor steady growth in Figure 3.

To explore the consequences of Nordhaus' and Stern's assumptions, consider how they would choose between the consumption paths in Figures 1 to 3. Figure 4 shows indifference curves[6] for each of the figures together with the δ and η values used by Nordhaus and Stern. In Figure 1, Nordhaus is in favor of the path where consumption is highest in the short run while Stern is indifferent to letting the first and poorest generation pay for higher consumption for future richer generations. In Figure 2, Nordhaus is indifferent to letting numerous future generations pay for a short-term bonanza while Stern favors sustainable development. In Figure 3, both Nordhaus and Stern prefer the overshooting path. For the given criterion, negative utility discount rates are needed to avoid the overshoot for all values of η.

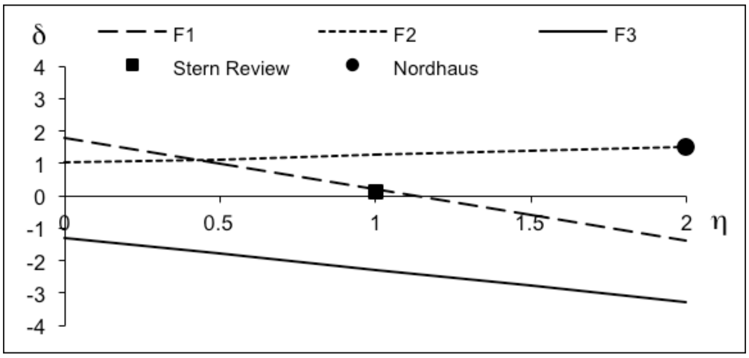

Figure 4: Indifference curves for consumption paths in Figures 1 to 3 together with assumptions made by Nordhaus and Stern

A reasonable hypothesis, that will be tested, is that most people will prefer high early consumption in Figure 1 and low early consumption in Figure 3. However, Figure 4 shows that there is no set of δ and η values that is consistent with both these choices: in Figure 1, δ values should be above the dashed indifference curve F1; in Figure 3, δ values should be below the solid indifference curve F3. If the hypothesis holds, as will be seen, there is no parameter set for which the criterion in Equations 4 and 5 can be made fully consistent with people's preferences.

What are the arguments for the different choices of parameters? Nordhaus' argues for a consumption discount rate equal to the market rate of return. The main argument is that the market reflects people's preferences more accurately than any philosopher's subjective preferences. Doing this he admits that his "approach does not make a case for the social

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6 The indifference curves are found using Equations 4 and 5.

desirability of the distribution of incomes over space or time…" Hence the GHG taxes he recommends are not intended to reflect what people may consider as desirable. Rather they reflect what seems feasible given how self-interested governments and investors behave. This said, his results still reflect the philosophy underlying the welfare criterion as well as his subjective choice of parameter values. When determining δ and η from the Ramsey equation $\rho_t = r_t \approx \delta + \eta g(c_t)$ there is one degree of freedom. His paper (*2*) gives no justification for choosing η=2 and δ=1.5% p.a. to obtain a consumption discount rate equal to market returns of 5.5% p.a. Equality in the Ramsey equation could also have been obtained for e.g. η=3 and δ=0% p.a. This would have led to different recommendations when sustainability is threatened, as illustrated in Figure 4 for the case of Figure 2.

Stern does not insist on consistency between the current market rate of return and the consumption discount rate. When using a utility discount rate close to zero he agrees with Ramsey (*12*) who philosophied that discounting is "ethically indefensible and arises merely from the weakness of the imagination." Nordhaus' main argument against Stern's assumptions is that his low consumption discount rate to a first approximation would "lead to a doubling of the optimal global net savings rate". In a steadily growing economy that seems a large sacrifice for the present and poorest generation. Assuming that Stern chose his assumptions in order to solve the climate change problem, it seems an undesired consequence that global savings and investments have to double.

The above discussions suggest that the present form of intergenerational welfare economics is a problematic and complicated tool to guide policy making for global sustainability. Long ago, Koopmans (*13*) suggested the following approach: "… the problem of optimal growth is too complicated, or at least too unfamiliar, for one to feel comfortable in making an *entirely* a priori choice of an optimality criterion before one knows the implications of alternative choices. One may wish to choose between principles on the basis of the results of their application." In other words, Koopmans suggests making changes in the *criterion* (including the utility discount rate and consumption elasticity) until an acceptable optimal growth path results.

Using simulation, changes are made in *policies T* until an acceptable development results. Thus, simulation is a more direct approach to analyze policies to reduce the risks of non-sustainable development. While economists have discussed different criteria at length, it may seem surprising that optimization itself has not been seen as a cause of complexity, inconsistency, and disagreement.

If proper policies *T* are put in place to correct for externalities and to prevent non-sustainable development, markets will operate as before but with higher prices on scarce resources. Businesses, governments, and consumers can use the same reasoning when discount the future as they do now; however new values of stocks *s* will give different market rates of return *r*. The role of policies *T* is to bring the economy closer to optimality judged by a normative criterion. Within the framework of a relatively simple model, Dasgupta (*4*) reaches the related conclusion that in a fully optimizing economy is it appropriate to discount future consumption at market rates of return. It is of little concern that realized rates of return *r* will be different from the *implicit* consumption discount rates derived from choices between simulated consumption paths when choosing policies *T*.

If simulations find that future sustainability is not threatened, also simulations will recommend that one should burden richer future generations with some unsolved pollution problems. Before doing so, however, one should check whether consumption growth represents Pareto improvements or whether unsolved pollution problems systematically make some groups worse off. Simulation models that allow for more detail than optimization models could make it easier to judge Pareto improvement.

A natural next question is how businesses, governments, and individuals should choose resource policies and discount rates in a second best world where proper policies to ensure global sustainable development are not in place. A first task seems to be to analyze the risks and nature of global non-sustainable developments. Next, local policies must be adapted not only to deal with natural resources but also to deal with uncertainties in global economic development. Once these policies are in place, it again seems reasonable to rely on the traditional way of reasoning regarding discount rates.

4. Uncertainty

The risk of major catastrophes complicates welfare analysis further. In addition to the question about distribution of welfare among generations, the precautionary principle requires an answer to the question: how much insurance to buy? The answer depends on the probability of non-sustainable development. Accoring to Weitzmann (*14*) "…standard approaches to climate change (even those that purport to treat uncertainty) fail to account fully for the implications of large consequences with small probabilities…".

Dasgupta (*4*) writes in a concluding section: "… if the uncertainties associated with climate change losses are large, the formulation of intergenerational well-being we economists have grown used to could lead to ethical paradoxes even when the uncertainties are thin-tailed: an optimum policy may not exist (Proposition 4). Various modelling avenues that offer a way out of the dilemma were discussed. It was shown that none of them is entirely satisfactory…. Intergenerational welfare economics raises more questions than it is able to answer satisfactorily."

Hence, uncertainty complicates welfare economics further. It also complicates simulations studies, however, methods exist. Sensitivity tests and repeated Monte Carlo simulations help explore effects of policies in light of parameter values chosen within conceivable ranges. Policies can be changed until probabilities of non-sustainable development are brought to acceptable low levels.

In cases such as ozone depletion, analysis could be simplified to find sufficient tax levels, or equivalent policies, for markets to bring forth needed new technologies to alleviate the problem completely. Historically, solving the ozone problem did not require massive investments and did not have much of an impact on global consumption. This may also represent a proper way to approach climate change. At what price levels will photovoltaics, wind power, geothermal, solar thermal as well as new energy saving technologies start growing quickly? Recent data suggest that this may require less than a doubling of e.g. electricity prices. Assuming that energy costs make up 6 percent of world GDP, a doubling of energy prices would represent the loss of only a few years of growth in consumption.

Macroeconomic simulation models with learning curves can then be used to design policies for a smooth and acceptable transition, e.g. using subsidies of R&D and green certificates.

5. Democracy and public choice

According to Nordhaus: "The [Stern] Review takes the lofty vantage point of the world social planner" implying that Stern makes up assumptions to his own liking, assumptions that do not reflect a democratic process. Of course, every analyst has to make assumptions; that is not the main problem. The main problem is concealed subjectivity. Ideally, in a democracy everybody should be able to understand all analyses with implications for own wellbeing. In a more realistic setting, everybody should have access to interpretations of analyses by trustworthy sources. The current complexity of welfare economics complicates this process. Simulation models can also be complex, however, the problems caused by the complexity of the criterion is largely removed. People are invited to judge policy effects by their own criteria.

As a last step, a questionnaire was used to see if people are willing and able to choose between simulated consumption paths emanating from different policies T. To test this, a sample of the UK adult population (N=2305) was asked to choose between the consumption paths shown in Figures 1 (Q1) and 2 (Q2), see Supplementary Material for details. For both questions, 78% of the respondents did not choose the option "I cannot answer the question", similar to a good turnout at elections.

Of particular interest here is how people react to overshoots. In question Q1 the choice was between two paths of steady growth in consumption; in Q2 the choice was between steady growth and overshoot. Consumption paths were announced to be equal after 2110. In Q1 indifference between the two developments occurred for a constant *consumption* discount rate of 1.78% p.a., in Q2 for a rate of -1.3% p.a.

Figure 4 shows that in Q1 84% chose consistent with a consumption discount rate equal to or higher than 1.78% p.a., similar to previous findings (*15*). In Q2, 79% chose consistent with a consumption discount rate equal to or lower than -1.3% p.a. Sign tests show that the median is significantly higher than 1.78% in Q1 and significantly lower than -1.3% in Q2.

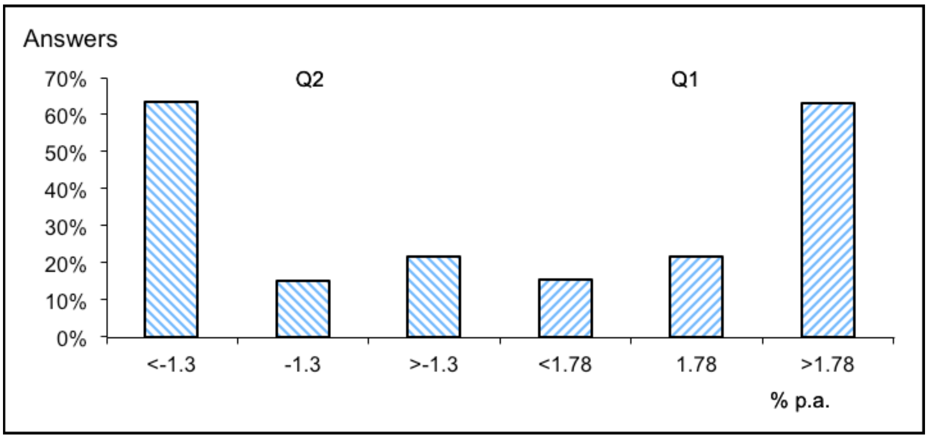

Figure 4: Histogram of choices in Q1 and Q2 as function of implicit constant consumption discount rates

The results show a clear aversion to overshoots. Further research is needed to explore how public choice is influenced by considerable uncertainty. People's willingness to buy house, health, and car insurance suggests that risk matters.

In Q1 a clear majority of respondents chose as if they had a δ higher than the upper indifference curve in Figure 3, in agreement with Nordhaus. In Q2 the majority chose as if their δ was lower than the lower curve, different from both Nordhaus and Stern.

Conclusion

Management of global natural resources such as climate change, scarcity of cheap fossil resources, and ocean acidification requires analysis to counter misperceptions and to ensure sustainable development. This paper has argued that the current practice of intergenerational welfare economics is complicated, fails to incorporate mechanisms that may cause non-sustainable development, the standard criterion is not capable of capturing observed preferences, and the method has difficulties dealing with uncertainty. Many of these problems are acknowledged by leading economists and much effort has gone into improving the method. However, the likely main cause of complications, optimization, has not been questioned. This paper argues that simulation is a more direct and flexible method where decision-makers are free to judge a variety of policy consequences over time and under uncertainty. A questionnaire shows that people are willing to judge policies by their resulting consumption developments and that people are averse to overshoots that discounted utility is not sensitive to. There seems to be a need for a coordinated effort to develop and debate better simulation models of pressing global resource problems, as well as local adaptations to uncertain global developments.

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SUPPLEMENTARY MATERIAL

Questionnaire

The two questions were part of a larger survey performed by YouGov in the U.K. from 22 to 24 March 2011. The two questions were as follows:

Imagine that you are going to participate in a referendum about governmental policies that will influence consumption development over the next one hundred years. Think of consumption as the sum of private consumption and public services. You get no information about what the policies are. However, you will see the exact consequences of the policies on national consumption development per person.

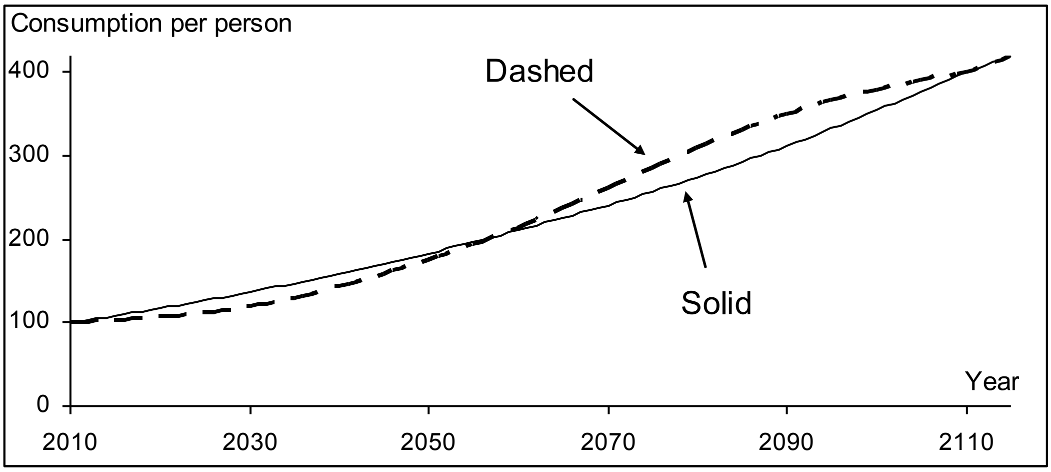
Your personal consumption will develop in pace with national consumption. When choosing between consumption developments, pay close attention to how consumption develops over your expected lifetime. You may also consider the future consumption of your own and friends' children and grandchildren. Be honest about how much of your own consumption you are willing to give up for children and grandchildren that will enjoy higher consumption than you.

The effects of two different consumption development policies are shown as *Solid* and *Dashed* lines on the below graph.

Solid shows steady growth and in the last year consumption is 4 times higher than in 2010. *Dashed* also shows steady growth, however, it has lower consumption than *Solid* until 2057, after that *Dashed* gives the higher consumption. After year 2110, the two consumption developments are equal.

Q1: Which of the developments, *Solid* or *Dashed*, do you prefer?

I prefer *Solid* development
I prefer *Dashed* development
I find both developments equally good
I cannot answer the question



Like in the previous question, the effects of two different consumption development policies are shown as *Solid* and *Dashed* lines on the below graph.

Dashed shows steady growth such that in the last year consumption is 4 times higher than in 2010. *Solid* does not show steady growth, and shows a decline in consumption for a 12 year long period after 2045. However, *Solid* does give higher consumption than *Dashed* until 2052, after that *Dashed* has the higher consumption. After year 2110, the two consumption developments are equal.

Q2: Which of the developments, *Solid* or *Dashed,* do you prefer?

I prefer *Solid* development
I prefer *Dashed* development
I find both developments equally good
I cannot answer the question