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Analysis

Intertemporal Distribution, Sufficiency, and the Social Cost of Carbon☆

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ABSTRACT

We explore how the intertemporal distribution of well-being affects the social cost of carbon. In contrast to the literature that studies parameters of a particular social welfare function, such as the discount rate, we shift the focus and directly assume a parametric form for the intertemporal distribution of well-being. This has the advantage of avoiding explicit discounting choices, which has initiated much debate. Specifically, we consider a set of intertemporal distributions that reach a steady-state at a pre-specified level of "sufficient" well-being, or equivalently after a pre-specified "end-of-growth horizon". We numerically illustrate our results in DICE and find that the social cost of carbon increases over-proportionally with the sufficiency level of well-being. While the social cost of carbon in 2015 is US$ 7 if the sufficiency level is four-fold the present level, it is US$ 30 if the sufficiency level is 15-fold, and US$ 100 if the sufficiency level is 26-fold the present level. This shows in a transparent way how conceptions of intergenerational distributive justice drive the social cost of carbon.

1. Introduction

A major challenge for humankind is avoiding dangerous climate change. Economic studies of optimal climate policy typically use integrated assessment models (IAMs) to determine an optimal path of emission abatement (Golosov et al., 2014; Nordhaus, 2008; Stern, 2007). Many of these studies adopt an intertemporal discounted utilitarian social welfare function (SWF) and arrive at remarkably different estimates for the optimal tax rate on carbon emissions into the atmosphere, i.e. the social cost of carbon (Table 1). These differences are largely attributable to the specific parametrization of the SWF in terms of the so called "ethical parameters", namely the social time preference rate (ρ) and the intertemporal elasticity of substitution ($1/\eta$). The specification of parameter values for ρ and η translates into specific assumptions about how well-being[1] ought to be intertemporally distributed.

Starting with Ramsey (1928), the long lasting economic and philosophical discussion on which intertemporal SWF should be applied mostly focuses on the "correct" parametrization of the SWF within the standard discounted utilitarian framework (Buchholz and Schymura, 2011). Recently there is a growing literature developing alternative social welfare criteria (Asheim, 2010; Fleurbaey and Zuber, 2015; Zuber and Asheim, 2012) although applications of these in well-known IAMs are still relatively rare (Botzen and van den Bergh, 2014).

Instead of studying a particular SWF and restricting the analysis to specific ethical parameter values, one can also take a very different approach, which avoids explicit discounting choices: the intertemporal distribution of well-being can directly be specified in a parametric form. Recently this direct approach has been applied to study sustainable economic development in the light of anthopogenic climate change (Llavador et al., 2010, 2011; Roemer, 2011). However, these studies do not systematically address the question how the intertemporal

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[1] In the studies presented in Table 1 the level of well-being reduces to an index of consumption equivalents (or inclusive consumption), which abstracts from the relative price effects of other components of well-being on the social cost of carbon, like environmental quality (Sterner and Persson, 2008). We acknowledge this shortcoming, but stick to using inclusive consumption as a proxy for well-being as defined in Nordhaus and Sztorc (2013) and Nordhaus (2014) for our analysis.

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Table 1
Selected estimates of the optimal carbon tax, quoted after Golosov et al. (2014).

Study	Parameter	Optimal tax
Nordhaus (2008)	ρ = 1.5%, $\eta = 2$	30 US$/tC
Golosov et al. (2014)	ρ = 1.5%, $\eta = 1$	60 US$/tC
Stern (2007)	ρ = 0.1%, $\eta = 1$	250 US$/tC

distribution of well-being is related to the social cost of carbon.

In this paper we parametrize intertemporal paths of well-being that allow us to study the trade-off between the intertemporal distribution of human-well being and the present social cost of carbon. We choose a specific set of intertemporal distributions that is driven by five underlying assumptions, which mainly reflect a schedule of smoothly decreasing growth rates leading to a steady state with a pre-specified constant, "sufficient" level of well-being, or, equivalently, after a pre-specified "end-of-growth" horizon, resulting in an "s-shaped" intertemporal distribution of well-being. Due to, among others, the last global economic crisis, climate change and biodiversity loss, the debate on limits to economic growth pioneered by Meadows et al. (1972) has recently been intensified (Antal and van den Bergh, 2014; Turner, 2008; Victor, 2010). In a recent questionnaire on public opinions on economic growth and environmental sustainability Drews and van den Bergh (2016) find that two thirds of the respondents believe that growth in rich countries will stop at some future point in time. This is consistent with developing countries typically following an s-shaped course of economic development with high initial growth rates, which decrease in the course of time. Also the DICE model assumes that the growth rate will continuously decline down to zero.

Among the s-shaped set of development paths, we determine the one that minimizes the time until the pre-specified sufficient level of well-being is reached (i.e., the "end-of-growth horizon"). By varying the sufficiency level of well-being we can study how the desire for economic efficiency, growth and the resulting intertemporal distribution affects the social cost of carbon. We quantitatively illustrate our results with the 2013 version of DICE (Nordhaus, 2014; Nordhaus and Sztorc, 2013), which is the most widespread and well-known IAM. The minimization of the end-of-growth horizon requires a full-fledged dynamic optimization, as it affects patterns of investment in human-made capital, as well as carbon emissions into the atmosphere, both of which have long-term consequences that fully have to be taken into account.

We believe that our approach to directly define intertemporal distributions of well-being has clear advantages over making specific discounting choices. For society and policy-makers it might be easier to agree on a certain intertemporal distribution of well-being than to argue on parameter values for a particular SWF. In a recent survey, Drupp et al. (2015) elicit expert opinion on the value of the long-term social discount rate. One of the responses to their open-ended question for comments was the following: "*Instead of imposing a SWF and calculate the corresponding optimum, it is 'better' to depict a set of feasible paths of consumption, production, temperature, income distribution, etc. and let the policy maker make a choice*" (Drupp et al., 2015, p. 17). A similar metaphor has been proposed by Edenhofer and Minx (2014) who suggest economists to construct a feasible "map" of economic development that could be used by policy-makers to "navigate" among different policy options.

Such a "map" requires to parameterize a conceivable set of feasible paths of well-being. As discussed above, the set of s-shaped paths of intertemporal well-being is a particular sensible assumption. This is why we focus on this particular specification in this paper. For each efficient path the policy-maker will be able to obtain the associated social cost of carbon under optimal climate policy. For society our approach could lead to a better informed discussion on normative conceptions of intergenerational distributive justice, which crucially determine the social cost of carbon and are typically hidden in discounting choices within the standard discounted utilitarian model. It becomes very clear, for example, that the desire to attain a high level of well-being in the future, or equivalently to keep the global economy growing for a longer time horizon, substantially increases the social costs of carbon, because in the long-run growth of well-being requires to protect the future generations from adverse consequences of climate change.

The remainder of this paper is organized as follows: Section 2 first formally derives the condition prescribing the optimal intertemporal distribution of well-being when using a (discounted) utilitarian SWF, which is embodied in most IAMs like DICE. Second, we briefly sketch the relevant literature that uses this condition to capture social preferences with respect to intertemporal distributions in IAMs. Section 3 characterizes our approach of directly considering a specific functional form for the intertemporal distribution of well-being. Section 4 presents the numerical results of the dynamic optimization, before Section 5 discusses our results.

2. Intertemporal Distributional Objectives Embodied in a Social Welfare Function

The dominant approach to determine the social costs of carbon is to use a Social Welfare Function in a dynamic Integrated Assessment Model of climate and the economy (IAMs), such as DICE (Nordhaus, 2014). In order to contrast our approach of directly specifying the intertemporal distribution of well-being with a functional form to this standard in the literature, we briefly describe the Social Welfare approach.

Most deterministic dynamic IAMs rank intertemporal paths of per capita consumption c_t, which they refer to as inclusive consumption capturing "well-being", by means of the intertemporal social welfare function (SWF),

$$W_0(c_0, c_1, c_2, \dots) = \sum_{t=0}^{T} \frac{1}{(1+\rho)^t} L_t \frac{c_t^{1-\eta}}{1-\eta}, \tag{1}$$

which can be interpreted as the discounted Utilitarian objective function or as the utility function of a representative, infinitely-lived agent (ILA), weighted by population size L_t. We consider a discrete-time setting with *periods* $t = 0,1,2,\dots T$. The parameters of the welfare function are the time preference rate, ρ, and the preference for consumption smoothing over time, η, with $1/\eta$ being the constant intertemporal elasticity of substitution of consumption.

Maximizing Eq. (1) subject to the economic and climate constraints of the DICE model (Nordhaus, 2014) leads to the following condition (see Appendix 1 for a derivation),

$$(1+\rho)\left(1+\frac{c_t - c_{t-1}}{c_{t-1}}\right)^{\eta} = 1 + Y_{K_t} - \delta^K, \tag{2}$$

where Y_{K_t} denotes the marginal productivity of capital and δ^K the proportional rate of capital depreciation. Eq. (2) is the discrete-time version of the well-known Ramsey rule (Dasgupta, 2008) and characterizes the intertemporal distribution of well-being that is optimal according to Eq. (1).

Much of the recent economic debate on the social costs of carbon focuses on how a society should choose the values for the discounting parameters of a SWF, i.e. ρ and η. Interpreting the SWF (1) as the utility function of a representative ILA, these parameters can be derived from observed behavior on markets reflecting opportunity costs of capital (Arrow et al., 1996; Buchholz and Schymura, 2011). In this vein, Nordhaus (2008) argues that short-term time preferences should be in line with historical consumption choices. He thus uses the Ramsey (Eq. (2)) to determine ρ and η from inferred values of real market interest rates and the consumption growth rate.

Other studies interpret the intertemporal SWF (1) as the (discounted) Utilitarian objective. According to this point of view, ethical