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Are there reasons against open-ended research into solar radiation management? A model of intergenerational decision-making under uncertainty

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ABSTRACT

Solar radiation management (SRM) has been proposed as a means of last resort against dangerous climate change. We propose a stylized model of intergenerational decision making on SRM research, greenhouse-gas abatement and SRM deployment, under uncertainties about (a) the extent of future climate damage and (b) effectiveness and potential harmful side-effects of SRM. Open-ended research may reveal either that SRM effectively reduces climate damage, or that it would cause more harm than benefits. We find that SRM research increases the likelihood of deployment ("slippery slope"), and derive conditions that it decreases abatement effort in expectation ("moral hazard"). Neither of these provides a rationale against SRM research, though. The rational decision is to perform SRM research, unless (i) discounting is hyperbolic and (ii) the absolute prudence of expected climate damage is smaller than absolute risk aversion. These results generalize to the case where SRM research also provides information on climate sensitivity.

Introduction

Anthropogenic climate change is potentially very harmful for humankind and yet, projections of future climate change are still highly uncertain (IPCC, 2013). So far, the global society has been unable to effectively reduce carbon dioxide emissions despite some effort (e.g. UNFCCC, 1992, 1997), and ambitious objectives (UNFCCC, 2015). Solar radiation management (SRM), for example implemented by injecting sulfur into the stratosphere or by marine cloud brightening, has been proposed as an alternative high-leverage climate engineering option to keep global warming within tolerable limits (Latham, 1990; Crutzen, 2006). Indeed, the fact that climate predictions are so uncertain, and that subsequently it might become urgent to combat catastrophic climate change, has been an important argument in favor of SRM research (Crutzen, 2006; Weitzman, 2009, 2011; Keith et al., 2010; Nordhaus, 2011; Long et al., 2011; National Research Council, 2015). SRM, in that view, could be an option of last resort against catastrophic climate change. However, considering known and unknown

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side-effects, it is possible that SRM as a potential "cure" of climate change could be worse than the "disease" (Schneider, 1996; Corner and Pidgeon, 2010; Robock, 2008). Against this background, one may argue that more research is needed to learn about the effectiveness and potential harmful side-effects of the various proposed SRM measures (Royal Society, 2009; Keith et al., 2010; Long et al., 2011; National Research Council, 2015). As a matter of fact, this is the question on climate engineering that requires a societal decision in the near future.

Indeed, a lively debate has emerged whether or not SRM research is desirable (Cicerone, 2006; Victor, 2008; Goodell, 2010; Robock et al., 2013; Klepper and Rickels, 2014). Probably the most prominent argument against SRM research is that the knowledge about its prospects to combat the consequences of climate change may weaken the political will to mitigate greenhouse gas emissions, causing therefore some kind of "moral hazard" behavior (Jamieson, 1996; Keith, 2000; Robock, 2008; Royal Society, 2009; Morrow et al., 2009; Gardiner, 2010; Rayner et al., 2013; Morrow, 2014; Barrett, 2014). As a consequence SRM research might push society onto a "slippery slope", creating an internal dynamic which leads to deployment, irrespective of reasons against deployment (Jamieson, 1996). Against this background, a prominent proposal in the governance debate about climate engineering SRM research is to establish a (temporal) moratorium which prohibits certain research activities, in particular those involving field testing of SRM technologies (Cicerone, 2006; Davis, 2009; Convention on Biological Diversity (CBD), 2010; Hale and Dilling, 2012; Robock, 2012; Parson and Keith, 2013; Züern and Schäfer, 2013; Schäfer et al., 2013).

In this paper, we develop a stylized theory of intergenerational decision making to scrutinize arguments for or against researching into SRM in the near future. In contrast to the literature that often restricts SRM research to the *development* of SRM technologies, we model SRM research as open-ended, that means research may reveal either that SRM is a sufficiently safe technology or that it has harmful side effects. Given that several proposals for SRM technologies are already available, this acknowledges the fact that the main scientific uncertainty is about the effectiveness and potential harmful side effects of such technologies.

We consider three generations, where the first decides on whether or not to do research on the safety or harmfulness of SRM (e.g. by means of field testing). The second generation decides on both abatement efforts and whether or not to do SRM research. The third is exposed to the consequences of climate change and decides on the deployment of the SRM technology. The decisions of both the second and the third generations will depend on the information on SRM. Decisions of the first generation takes place under the two risks of (a) an unknown extent of future climate change and (b) potential harmful side-effects of SRM.[1] The latter uncertainty could be reduced by researching into SRM. In such a situation, the value of information may be negative when the decision-maker's preferences are dynamically inconsistent (Brocas and Carrillo, 2000). This means, the optimal decision by the present generation can actually be against SRM research. In this paper we characterize the conditions for such an outcome, with regard to social time and risk preferences, greenhouse-gas mitigation technology, uncertain dynamics of climate change, and uncertainty about potential harmfulness of SRM technology. In addition, we extend the analysis by allowing for additional learning on the true value of climate sensitivity from SRM field tests.

SRM can be thought of as an insurance against catastrophic climate change because it is expected to achieve a relatively cheap and fast (i.e. within a matter of months) reduction of global temperatures (Matthews and Caldeira, 2007; Keith et al., 2010). However, there are still large uncertainties about the effectiveness of SRM measures (Ferraro et al., 2014; Klepper and Rickels, 2014). Climate models that explicitly include specific SRM measures suggest that the desired reduction in solar forcing might not be achieved that easily (Kuebbeler et al., 2012 study stratospheric sulfur injection, Korhonen et al. (2010), Stuart et al. (2013); and Alterskjaer and Kristjánsson (2013) model marine stratus cloud seeding, and Storelvmo et al. (2013) look at cirrus cloud modification). Furthermore, SRM affects the global climate system differently than reductions in the atmospheric greenhouse gas concentration. SRM can thus change precipitation patterns (Allen and Ingram, 2002; Ricke et al., 2012), and is likely to have quite different welfare effects around the globe (Royal Society, 2009; Klepper and Rickels, 2014; Quaas et al., 2016).

While these considerations and contributions have enriched the debate on the specific research challenge associated with SRM, the underlying trade-offs and implications of the research decision have rarely been investigated in a theoretical decision making framework. As one of the few exceptions, Goeschl et al. (2013) consider a two-generation model where the first generation decides on whether or not to make a SRM technology available to the second generation, which is assumed to be biased either in favor or to the disadvantage of adopting the SRM technology, compared to the benchmark of identical preferences. Because of the different preferences of the two generations, this gives rise to time inconsistent decision-making and thus a strategic game between the two generations, where the first may choose not to "arm the future" with the SRM option if (a) the second is strongly biased in favor of SRM deployment and (b) the costs for research and developing the SRM technology are sufficiently large. Our approach differs from, and extends, Goeschl et al. (2013) in several respects. First, we assume identical preferences for all generations, i.e. the third generation will deploy the SRM technology if and only if the first generation would do this in the same situation. Second, as mentioned above, we model SRM research as open-ended, i.e. the result may also be that SRM is harmful while allowing for the case that the SRM technology is available even without research, but then without information about its potential harmfulness. Goeschl et al. (2013), by contrast, assume that the

[1] Moreno-Cruz and Keith (2013) and Emmerling and Tavoni (2017) do integrated assessment modeling analyses of abatement and SRM deployment under these two uncertainties, but they do not study SRM research.