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Is there room for geoengineering in the optimal climate policy mix?

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ABSTRACT

We investigate geoengineering as a possible substitute for mitigation and adaptation measures to address climate change. Relying on an integrated assessment model, we distinguish between the effects of solar radiation management (SRM) on atmospheric temperature levels and its side-effects on the environment. The optimal climate portfolio is a mix of mitigation, adaptation, and SRM. When accounting for uncertainty in the magnitude of SRM side-effects and their persistency over time, we show that the SRM option lacks robustness. We then analyse the welfare consequences of basing the SRM decision on wrong assumptions about its side-effects, and show that total output losses are considerable and increase with the error horizon. This reinforces the need to balance the policy portfolio in favour of mitigation.

1. Introduction

Climate change due to anthropogenic greenhouse gas (GHG) emissions is viewed as one of the most serious challenges faced by humankind (Stern, 2006). Strategies for dealing with climate change enter three main categories: mitigation, adaptation, and climate geoengineering. International agreements call for reductions in GHG emissions – the mitigation approach. Despite its direct impact on temperature levels, its technical feasibility, and its ethical appeal, several factors limit the implementation of mitigation: (i) the strong inertia in the carbon cycle creates a gap between present abatement costs and future climate benefits (Keller et al., 2007); (ii) the decades-to-millennia-long lifespan of GHG render mitigation ineffective in case of abrupt climate changes; (iii) the atmosphere is a common good and unilateral actions are discouraged by the possibility of free riding (Millard-Ball, 2012).

An alternative for dealing with climate change is adaptation, the development of strategies that effectively reduce climate change impacts (Tol, 2005). Adaptation covers a large array of sectors, and can be 'proactive' or 'reactive' (de Bruin, 2011). While proactive adaptation is directed towards infrastructure and medium-to-long-term economic transformations (Agrawala et al., 2011), reactive adaptation can be deployed almost instantaneously to mitigate unforeseen or underestimated damages. Several features distinguish adaptation from mitigation: (i) adaptation can be implemented unilaterally, giving full control of the benefits to the countries implementing it; (ii) adaptation is expected to exhibit a fast implementation – fast benefits feature, avoiding deadlocks from discounting preferences. However, investments in

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adaptation have been limited so far due, in particular, to difficulties in forecasting its effectiveness.

Given the increasing risk of an unmanageable temperature path, geoengineering has been proposed as an alternative strategy. It corresponds to a deliberate modification of the climate system in order to alleviate climate change impacts (Keith, 2000; Caldeira et al., 2013). One may distinguish between two main techniques: Carbon Dioxide Removal (CDR) and Solar Radiation Management (SRM). In this paper, we focus on an SRM approach that targets the reduction of incoming solar radiation by injection of sulfur in the stratosphere, believed to be one of the most efficient geoengineering strategies to reduce global temperature (Wigley, 2006; Shepherd et al., 2009). Its premise is the ability to keep temperature levels artificially low, instead of reducing GHG emissions. SRM presents several advantages: (i) it involves low implementation costs (Robock et al., 2009); (ii) in case of rapid climate changes (when tipping points are reached), with rare but catastrophic impacts, SRM could act as a quick and effective temperature 'backstop' (Crutzen, 2006); (iii) it can be implemented either unilaterally or cooperatively (Barrett, 2008).

SRM brings along also important risks, as it may produce unintended consequences and harmful side-effects (Victor, 2008). A comprehensive summary is given in Barrett et al. (2014). Injecting sulfur particles into the upper atmosphere is expected to cause polar ozone depletion (Crutzen, 2006; Tilmes et al., 2008; Solomon et al., 2009), acid deposition at the poles (Kravitz et al., 2009), alter ecosystems (Stanhill and Cohen, 2001; Adams et al., 2003; Rasch et al., 2008), and trigger regional imbalances (e.g., in the patterns of surface temperature, radiation, and the hydrological cycle; Trenberth and Dai, 2007; Bala et al., 2008; Brovkin et al., 2009; Kravitz et al., 2013; Niemeier et al., 2013; Schaller et al., 2013; Huneeus and Boucher, 2014). Simulations of sulphate injection predict disruptions in the Asian and African summer monsoons (Robock et al., 2008). Stratospheric aerosol loading impacts the ratio of direct to diffuse light, with consequences for terrestrial and marine photosynthesis and for technologies relying on direct light (Rasch et al., 2008; Vaughan and Lenton, 2011).

Furthermore, SRM achieves only an artificial reduction in temperature levels. With a continued increase in GHG concentrations, the injection of aerosols would need to raise proportionally, and a disruption would lead to a significant jump in temperatures at the corresponding concentration level (Brasseur and Roeckner, 2005; Brovkin et al., 2009; Jones et al., 2013) with probable dire consequences. Additionally, SRM will not be able to counteract other negative consequences coming from high GHG concentrations, such as ocean acidification (Orr et al., 2005; Doney et al., 2009), CO_2 fertilisation of land plants, and other biogeochemical modifications (Ban-Weiss and Caldeira, 2010). Finally, with a lack of assessment of SRM impacts on human societies and on ecosystems, there remains the possibility for unexpected consequences – unknown unknowns (Kravitz et al., 2009). The uncertainty is reinforced by the fact that expected consequences of SRM (both positive and negative) are estimated by comparison with natural volcanic eruptions, which are an imperfect analog to continuous anthropogenic stratospheric forcing (Robock et al., 2013). Finally, there are important societal and political dimensions to geoengineering (Macnaghten and Szerszynski, 2013; Wright et al., 2014).

Given these important caveats, support for geoengineering measures has been inconclusive so far. Crutzen (2006), Wigley (2006), Carlin (2007), and Bickel (2013) advocate additional research on geoengineering before a robust recommendation could be formulated. More recent studies focus on modelling decision-making in the context of multiple sources of risk. Goes et al. (2011) use an integrated assessment model (IAM) where the total damage from climate change is a function of a rate-dependent temperature component, and account for the failure to sustain aerosol forcing and for the subsequent unraveling of drastic climate changes. In such a case, SRM is found to be uneconomical. Bickel and Agrawal (2012) rely on the model of Goes et al. (2011) and show that under modified assumptions some totally different conclusions regarding the use of SRM can be found.

In this paper, we assess the optimal mix of policies to deal effectively with climate change. Our methodology relies on the Ada-BaHaMa model (Bahn et al., 2012), which allows for mitigation and proactive adaptation, and enriches it by explicitly considering reactive adaptation and SRM. We account for different effects of SRM. While the *desired* effects of SRM on radiative forcing can be estimated with a considerable degree of confidence (Crutzen, 2006), the magnitude of *undesired* side-effects of sulfur injection on natural and socio-economic systems remains a significant unknown. We focus on this second uncertainty source, and unlike previous IAMs that consider SRM side-effects to be constant over time (Goes et al., 2011; Bickel and Agrawal, 2012), we model side-effects as a time-varying and persistent process with a stochastic component.

Our original contribution consists in assessing within an integrated assessment framework the optimal policy mix when mitigation, adaptation, and SRM are available. We show that the optimal strategy for dealing with climate change involves the joint use of all three strategies. While mitigation and adaptation are optimally employed in the vast majority of analysed scenarios, SRM passes a cost–benefit test only when its side-effects are low. Moreover, small deviations from expected side-effects can potentially cause large welfare losses, further weakening the case for SRM.

This paper is structured as follows. Section 2 details our dynamic IAM and its calibration. Sections 3 and 4 provide numerical results and analyse specific uncertainties related to SRM. Section 5 concludes.

2. Modelling approach

This section briefly reviews the original Ada-BaHaMa model and details the new modelling features: (i) the introduction of SRM as an instrument to control temperature increase and (ii) a separate accounting of proactive and reactive adaptation.

The model distinguishes between two types of economy: a 'carbon' economy (our present economy), where production generates a high level of GHG emissions, and a 'low-carbon' economy. More precisely, production (Y) occurs in the two economies according to an extended Cobb–Douglas function in three inputs: capital (K), labor (L), and energy (measured through GHG emissions E). Capital stock in each economy