How Geoengineering May Encourage Carbon Dioxide Abatement

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Abstract

Once an idea from the realm of science-fiction, geoengineering - the intentional large scale modification of the global climate - may become the method of choice to counteract global warming. However, a lot of controversies surround geoengineering. The main concern is that geoengineering research will reduce incentives for governments to engage in carbon dioxide abatement. Here we show that geoengineering can actually promote worldwide abatement. This result depends on the usefulness of geoengineering as a way to mitigate global warming, discount rates, and risk aversion.

1 Introduction

Global warming is widely expected to become one of the big challenges of the 21st century. Anthropogenic emissions of green-house gases are projected to impose significant costs on current and future generations (Bernstein et al., 2008).

Geoengineering - the intentional large scale modification of global climate - has been proposed to counteract the rise in average global temperatures (Carlin, 2007; Keith, 2001). Most proposed geoengineering methods have considerably lower expected deployment costs than conventional emissions abatement approaches (Nordhaus, 2007). However, the outcome is also less certain and negative side-effects are to be expected (Robock, 2008). [1]

The question we are interested in is how the presence of geoengineering as an alternative to carbon abatement and unrestricted carbon emission is likely to affect international climate negotiations. We analyze a two country or region world in which the countries or regions differ with respect to their first best policy choice towards global warming. Potential reasons for these differences in preferences could be differences in discount rates, risk-aversion or expected cost of global warming. First, we consider the choice between abatement and business as usual: One country prefers to emit unabated amounts of greenhouse gases while the other country favors abatement if the other country also abates. We assume that abatements is successful at mitigating global warming only if both countries abate. In such a setup unconstrained business-as-usual is the equilibrium. Second, we consider the addition of geoengineering to the strategy set. Geoengineering is assumed to be cheap and effective enough to be conducted unilaterally, but comes at the expense of high risks, affecting particularly short-term outcomes. We show in a very simple conceptual model that including geoengineering to the set of feasible options may lead to an equilibrium in which both countries abate. The key insight is that the use of geoengineering by one country can be seen as a threat by the other. For an overview of geoengineering risks see Figure 1. Geoengineering puts higher risks on the near future. We show that if the country initially opposed to abatement has high risk-aversion and/or a high discount rate (it's near-term profits have the highest priority), then geoengineering is likely to be regarded as a threat. Consequently, we find that depending on risk aversion, discount rate and relative cost of global warming, the relationship between abatement and geoengineering is nontrivial.

This paper contributes to the literature on geoengineering and international carbon abatement agreements. The common view in the economic literature about geoengineering is that geoengineering and emission reductions

[1] Keith (2000) estimates the cost of stratospheric SO_2 to increase albedo by direct optical scattering as less than \$1/tc. The Stern Review (2006) estimates that the average global costs of carbon abatement of fossil fuels lie between \$30/tc in 2030 to \$100/tc today (the marginal costs of abatement will rise with the total amount of abatement). The geoengineering cost estimates are to be understood as deployment costs estimates. They are not adjusted for expected cost of negative side-effects of geoengineering. See Figure 1 for some examples of expected side-effects.

GEOENGINEERING	METHODS
- intentional large scale modification of global climate	- aerosols in stratosphere
- a potential solution for the global warming problem	- giant reflectors in orbit
- no long term effect, constant maintenance necessary	- cloud seeding
- relatively low deployment costs	- greening deserts
- cooling effect likely to be heterogeneous	- iron fertilization of sea
- unilateral action possible	- genetically engineered crops
RISKS AND SIDE-EFFECTS	
- geoengineering may fail to stabilize climate	- too much cooling
- unpredictable effects on regional climate	- ozone depletion
- failure to continue geoengineering may cause extreme climate change	- ocean acidification
	- acid rain
- human error	- unknown side-effects

Figure 1: Geoengineering at a glance

are typical substitutes. In his recent article "The incredible economics of geoengineering" Barrett (2008) states that the incentives for countries to reduce their emissions are weaker because geoengineering is an alternative to abatement. Robock (2008) suggests that if humans perceive geoengineering as an easy fix to global warming which allows for unrestricted consumption of fossil fuels, gathering the will to change consumption patterns and energy infrastructure will be even more difficult. We show that it is possible that having geoengineering as an option may encourage worldwide carbon abatement. Our paper suggests that the recent advances in geoengineering may have significant effects on the dynamics of international climate negotiations and on the set of feasible policy architectures.

2 A World Without Geoengineering

Consider a world with two countries or regions. We analyze the countries decisions with respect to carbon dioxide emissions, which cause rising average global temperatures.[2] A key assumption is that one country can single-handedly warm the plant with its greenhouse gas emissions but is not able to significantly mitigate global warming by abating unless the other country also abates.[3] Each country can choose one of the following actions: reduce carbon dioxide emissions which is costly today but has benefits in the future in the form of less global warming (abatement, short notation A) or choose unrestraint greenhouse gas emissions (business-as-usual, short notation B) which has no costs today but has higher eventual expected costs of global warming.

		Country 1	
		A	B
Country 2	A’	a,b	c,d
	B’	e,f	g,h

Figure 2: Payoff matrix of standard pollution game

Consider Figure 2, there are four states of the world: both abate (*AA’*), only country 1 abates (*AB’*), only country 2 abates (*BA’*), both conduct business-as-usual (*BB’*). All states but *AA’* lead to global warming, so unilateral abatement is assumed to be costly but not successful at mitigating global warming.

Suppose country 1’s dominant strategy is to conduct business-as-usual while country 2 prefers the state of the world with mitigated global warming

[2] For simplicity we assume there a no local benefits from local abatement

[3] The carbon dioxide concentration in the atmosphere is predominantely determined by the amount of fossil fuels burned. Since the global capacity of fossil fuels is finite, if one region chooses to not use fossil fuels, this does not imply that these fossil fuels will stay underground. They are likely to end up being consumed by the other region.

(*AA'*). These respective preference orderings can arise from either one of the following three differences between countries: First, the two countries may have different social discount rates. Global warming is expected to predominantly cause cost in the future while abatement is costly now. Hence with a higher discount rate more global warming will be preferred.[4] Second, the two countries may have different expected cost of global warming. These differences can arise from different geographical features such as ocean access, water resources and latitude (Stern e.a. (2006)) For example, the Netherlands as a low-lying country is particularly vulnerable to sea-level rise, floods, and storm surges. Higher expected cost of global warming encourage countries to prefer current actions against global warming. Third, the two countries (or their respective governments) may have different degrees of risk aversion. Global warming is associated with a small risk of catastrophic climate change (Weitzman (2007)). Therefore a more risk averse country prefers more carbon abatement.[5]

Note that in the example above business-as-usual will always be optimal for country 1. Given that country 1 does not abate, country 2's optimal choice is to also conduct business-as-usual. Thus, the equilibrium is *BB'*. We think this is a simplified but accurate description of the real world in which there is currently no significant carbon dioxide abatement effort but several governments have expressed their preference for world wide abatement. While the Kyoto protocoll calls for a 5% (of 1990 emissions) cut in collective emissions by the industrial countries which ratified the protocoll until 2020, so far emissions did not fall as the protocol intended. Other industrialized countries such as the United States (+19% in CO_2 emission from 1990-2005) or

[4]E.g. the results of the Stern review relay heavily on their choice of social discount rate (Nordhaus (2007), Weitzmann (2007)). The Stern review reported a social cost of carbon of $300/tc. Anthoff e.a. (2008) calculate the social cost of carbon to be anywhere between $0 and $120,000/tc, depending on the choice of discount rate and risk aversion. Considering only developed countries, they estimate a discount rate of 1.5% for USA and Australia, while most European countries have an estimated discount rate between 0.8 and 1.1%. We conclude that different discount rates are likely to lead to different climate change strategies.

[5]While there is high uncertainty about global warming and climate sensitivity (the response of global temperatures to changes in carbon emissions) in general, this uncertainty becomes particularly strong, if a climate threshold has been crossed. The outcomes are deeply uncertain at the current point of time, which limits the use of the expected utility framework (Keller e.a. (2008)). Consequently a risk-avers country will try to avoid crossing a climate threshold, choosing a strategy which is robust to manifold climate responses.

highly growing developing countries such as India (+103% in CO_2 emissions from 1990-2005) and China (+137% in CO_2 emissions from 1990-2005) have substantially increased their GHG emissions. Together India, China and the United States produced 44% of global CO_2 emissions in 2005 (Energy Information Administration (2008)). The question we are interested in is what happens if geoengineering becomes an option.

3 A World With Geoengineering

Geoengineering provides either country with an opportunity to unilaterally act against global warming. It is in this respect that geoengineering is fundamentally different from abatement. We think the most interesting case to analyze is when geoengineering is not the most preferred policy for either country but preferred over business-as-usual by country 2, the country which prefers less global warming.[6] For simplicity of the following analysis we assume that for each country geoengineering and abatement are mutually exclusive. In each country, the choice of geoengineering is combined with unabated carbon dioxide emissions. The spirit of the results is not affected. We discuss this further in the conclusion.

A world in which at least one country geoengineers is characterized by the following features: (1) Both countries expect that there is no global warming, (2) if only one country benefits from unilateral geoengineering, for the other country it is optimal to not abate, (3) if both countries benefit from unilateral geoengineering, they may share the costs. Further, we assume that if geoengineering is used it will be used from day one since there is evidence that global warming is already creating cost. For example, the European heatwave of 2003 which caused 35,000 deaths was likely caused by anthropogenic global warming (Stott et al (2004)).[7] Also, usefulness of geoengineering - if one plans to rely solely on it - should be assessed in practice.

[6] One of the motivitations is that unrestrained global warming may be considered to be more risky than geoengineering. The motivation for this is that potential negative side effects of geoengineering are not expected to have a long term impact while global warming may have irrevocable side effects if a climate threshold is breached.

[7] "Likely" is to be interpreted as within a 90% confidence interval. So there is a 90% probability that the heat wave was not a natural phenomenon

	Country 1 A	Country 1 B	Country 1 G
Country 2 A′	a,b	c,d	
Country 2 B′	e,f	g,h	i,j
Country 2 G′		k,l	m,n

Figure 3: Payoff matrix with geoengineering as an option

Consider Figure 3, the countries' strategy set now includes a geoengineering option, G. It is never optimal for one country to abate, if the other country uses geoengineering, hence the corresponding cells in the payoff matrix are shaded. If country 2's payoffs from geoengineering are larger than from the equilibrium outcome without geoengineering (*BB'*), that is $l > h$, and geoengineering is costly, so $k > m$, then *BG'* is the new one-period Nash equilibrium. However in an infinetely repeated game (given a sufficiently high discount rate) - or alternatively under binding contracts - *AA'* can be a Nash equilibrium. This will be the case if $a > k$.

That the availability of geoengineering may encourage abatement, *AA'*, is a rather counter intuitive result. In particular, in the environmental debate geoengineering research has a bad reputation since it is widely regarded as a likely cause for insufficient abatement efforts. The key to our result is that the use of geoengineering by one country can be seen as a threat by the other. Geoengineering puts higher risks on the near future. So, if the non-geoengineering country has high risk-aversion and/or a high discount rate (it's near-term profits have the highest priority), then geoengineering is likely to be regarded as a threat. Note that this threat is credible, since a unilateral action of country 2 directly raises its payoffs. Consequently, we find that depending on risk aversion, discount rate and relative cost of global warming, the relationship between abatement and geoengineering varies.

4 Conclusion

The predominant view in the literature to this point has been to consider geoengineering and abatement as substitutes. Notwithstanding, we show that in a strategic setting geoengineering may actually increase abatement. The relationship depends predominantly on the cost structures of geoengineering and abatement, as well as countries' time preference and risk-aversion.

In our example, we treat abatement and geoengineering as mutually exclusive. In reality, the two approaches may be used simultaneously. In an analogy to the finance literature one can think of abatement as a risk-free investment, with relatively low returns (higher costs). Geoengineering promises higher expected returns (lower costs) but has also considerably higher risks (unknown side effects, human error). In an optimal portfolio an agent will try to combine both investments and the allocation depends on her risk preference. Here, also the time preferences are decisive for the amount of geoengineering used, since geoengineering imposes high near-term risks. The relationship of geoengineering and abatement will also depend on the cost-structures. Clearly, abatement has increasing marginal costs. Some methods of geoengineering have increasing marginal costs as well (e.g. the use of aerosols as sunshields). Other methods such as installing reflectors in the orbit have high fixed costs and near-zero marginal costs. If one considers a geoengineering method with rising marginal costs, a combination of geongineering and abatement is likely to be optimal. Instead, if the technology requires high fixed costs, both options are rather mutually exclusive.[8] We think it is another interesting question for future research to evaluate the potential optimal combination of abatement and geoengineering efforts.

Those countries which prefer abatement over business-as-usual should intensify research in geoengineering. Even if they consider abatement as the globally optimal response to global warming, geoengineering may eventually turn out to be an even better method than abatement or - if it is not - at least enhance the likelihood of global abatement.

[8] If it turns out to be optimal to use both abatement and geoengineering simultaneously, the case that the option of geoengineering increases global abatement effort, may still occur. The results from the example above are robust to such an extension.

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