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Stopping Solar Geoengineering Through Technical Means: A Preliminary Assessment of Counter-Geoengineering

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Key Points:
- Counter-geoengineering is the proposed use of technological means to negate solar geoengineering
- Counter-geoengineering might either generate a radiative forcing counter to solar geoengineering or neutralize the geoengineering agent
- Counter-geoengineering might deter unilateral implementation of solar geoengineering but alternatively could be politically destabilizing

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Abstract Counter-geoengineering is the idea that a country might seek or threaten to counteract the cooling effect of solar geoengineering through technical means. Although this concept has been mentioned with increasing frequency in commentary on geoengineering, it has received little scholarly attention. We offer a preliminary analysis. We begin by distinguishing two kinds of counter-geoengineering: countervailing with a warming agent and neutralizing with a physical disruption. Based on this distinction, we review prior suggestions and describe novel methods by which either method might be accomplished, within the constraints imposed by deep technical uncertainties and substantial technical challenges. We then reflect on the strategic requirements and motivations for developing counter geoengineering and use a simple game-theoretic framework to demonstrate how counter-geoengineering might interact with the free-driver dynamic of solar geoengineering to shape climate geopolitics. We find that any state that could credibly threaten counter-geoengineering would effectively have a veto over the use of solar geoengineering, which could reduce the prospects of unilateral deployment. Alternatively, the development of geoengineering and counter-geoengineering capabilities could lead to dangerous brinkmanship. We conclude that the development of counter-geoengineering would face considerable practical obstacles and would signal continuing political failure to manage climate risks on a cooperative basis.

1. Introduction

Solar geoengineering (also known as solar radiation management or SRM) is a proposal for quickly arresting the rise in global temperatures by blocking out some sunlight (National Academy of Sciences, 2015; The Royal Society, 2009). While many different techniques have been proposed, the leading approach would involve injecting reflective aerosols into the stratosphere. These aerosols would reverse some or all of the additional radiative forcing caused by emissions of greenhouse gases into the atmosphere and would do so at global scale.

Substantial evidence suggests that SRM might be able to reduce many of the physical impacts of climate change. A range of simulations, run on a range of models, consistently indicate that SRM could simultaneously attenuate rising temperatures and disruptions to the hydrological cycle, although it would do so imperfectly and with potentially significant side effects (Irvine et al., 2016). Numerous concerns have been raised about the potential sociopolitical impacts of SRM, however. It has been argued that the geopolitical challenges might prove more intractable than the technical ones, in particular because SRM would have global implications but could theoretically be deployed by a single state, despite objections from other countries (Parker & Keith, 2015).

Concerns about unilateral deployment reflect a judgment that there might be few means available to stop a determined deployer. Small states might be deterred by sanctions or the threat of military action, but if a powerful state (or coalition of states) was determined to geoengineer the climate, the policy options for stopping them might be limited. According to this view, if SRM technology were ever fully developed then the prospect of unilateral (or minilateral) deployment could present a serious threat to global security.

In this context, some observers have suggested that states might either threaten or implement "counter-geoengineering" in response to prospective or actual use of SRM. We define counter-geoengineering as the use of technical means to negate the change in radiative forcing caused by SRM deployment. Although this idea has often been raised in passing during discussions of SRM's geopolitical implications (Barrett et al., 2014; Gertner, 2017; Hamilton, 2013; Morton, 2015; Pasztor, 2017), such considerations have been speculative and lacking in analytical detail; to date, there has been no serious academic exploration of the idea of counter-geoengineering. This paper seeks to remedy that.

We first review the arguments on the potential for unilateral SRM deployment, then outline how counter-geoengineering might be realized technically. Next, we consider how the development of counter-geoengineering could influence the geopolitics of SRM. Finally, we reflect on whether the development and use of counter-geoengineering is a realistic proposal. In time, society would require systematic risk assessments of different counter-geoengineering proposals. But at this stage, unfortunately, the paucity of information currently available about such techniques precludes conducting a meaningful risk assessment.

2. Free Riders and Free Drivers

At the level of the state, the collective action problem presented by SRM is the opposite of that presented by traditional climate mitigation, which is often characterized as a free rider problem (Stavins et al., 2014). As a public good, the benefits of mitigation are nonrival and nonexcludable, meaning that a state incurs present-day economic costs for reducing its greenhouses gas emissions while the environmental benefits arrive in the future and are distributed around the world. This structure creates a strong incentive for states to "free ride" on the mitigation action of others.

In contrast, Weitzman (2015) characterizes SRM as a "free driver" problem. In the absence of international mechanisms to moderate state behavior and if the direct deployment costs of SRM are small compared to the direct benefits a single state receives from deployment, then each capable state would, in principle, seek to deploy SRM to a level of their choosing and would determine the level of cooling experienced by all states. The state wanting the greatest degree of cooling—the free driver—would then be the only one to get its wish. All others would be oversupplied: the exact converse of the undersupply expected (and observed) for mitigation.

Some researchers have challenged the plausibility of this simple form of single-state unilateralism. Parson and Ernst (2013) argue that sustained deployment of SRM would require a minimum of physical and technical capabilities that in practice would be beyond the reach of all but the most advanced states. Barrett (2014) makes a similar point that the potential for single-state unilateral action would likely be restricted to the major world powers. Horton (2011) contends that systemic constraints and interdependencies would frustrate any attempt by a single actor to implement SRM on a unilateral basis.

Expanding the concept of unilateral action, Ricke et al. (2010) suggested that SRM coalitions might develop, where small groups of nations would work together to deploy SRM and maintain control over the global radiative forcing. Such coalitions would not be unilateral in the strict sense, but their aggregate power would make a "minilateral" deployment less vulnerable to the types of pressures that might be brought to bear against individual states acting alone. More importantly, an exclusive SRM coalition might be viewed as no more legitimate than a single actor engaged in unauthorized implementation and would therefore carry the same potential for international tension and conflict that lies at the heart of concerns about one-state unilateralism. Therefore, for the purposes of this paper we treat pure unilateralism and small coalitions as functionally equivalent and use the term *unilateral* to refer to any situation where a minority of states might seek to deploy SRM against the will of the majority.

The basic free driver characteristic of SRM highlights the limitations of a global technology developing in a multipolar international system without an overarching governance framework. Unilateral deployment might be possible, and the perceived benefits of action could tempt a state or small coalition to bypass multilateral agreement. The implication is that if a state was determined to deploy SRM and was unmoved by the softer tools of statecraft such as negotiations, sanctions, and shaming, there might be little that could be done to stop them beyond military action; and military action might be too risky to be a credible threat. How might the ability to counter-geoengineer alter these political dynamics?

3. Possible Counter-Geoengineering Methods

We define counter-geoengineering as action taken through technical means to counter the change in radiative forcing caused by SRM. The idea of counter-geoengineering is not wholly new and has been mentioned in passing in some academic studies (Keith & Dowlatabadi, 1992; Nightingale & Cairns, 2014) and raised repeatedly in prominent popular commentary on SRM (Barrett et al., 2014; Gertner, 2017; Hamilton, 2013; Morton, 2015; Pasztor, 2017), but it has received little scholarly analysis.

At least two distinct versions of counter-geoengineering are conceivable. The first we refer to as countervailing, which would entail the release of warming agents (such as greenhouse gases or aerosols) to balance out the change in radiative forcing caused by the original SRM agent. This is the form of counter-geoengineering suggested in most commentary to date. The second possibility we term neutralizing, which would consist of removing or otherwise rendering inert the original SRM agent. We distinguish counter-geoengineering from the physical destruction of the deployment infrastructure, for example, by shooting down deployment aircraft, since the latter would amount to military action.

The most obvious countervailing warming agents are greenhouse gases that would increase longwave radiative forcing (causing warming) to offset some of the shortwave radiative forcing (causing cooling) that would result from solar geoengineering. Relevant greenhouse gases include sulphur hexafluoride (SF6) and various chlorofluorocarbons and hydrochlorofluorocarbons. These chemicals have very high radiative forcing per unit mass due to their long lifetimes combined with typically strong absorption in those wavelengths where the atmosphere is relatively transparent (e.g., the water vapor window). When investigating options for releasing greenhouse gases to counter the short-term cooling effects of large volcanic eruptions—a situation analogous to countervailing counter-geoengineering—Fuglestvedt et al. (2014) suggested that HFC- 152a might be an effective agent, due to its short atmospheric lifetime and high global warming potential. Difluoromethane, characterized by a limited impact on ozone and a 5-year atmospheric lifetime, is another candidate.

Yet while strong greenhouse gases are obvious countervailing agents, there are a limited number of plausible greenhouse gases, and those with strong global warming potentials typically have long, century-scale lifetimes. As we argue below, a counter-geoengineering agent would be more plausible as a deterrent against SRM if it had a short lifetime—a decade rather than a century.

Alternatively, various solid particles that could have high radiative efficiency were investigated by Teller et al. (1997) and Keith (2010). Such particles could be coated with a thin ($<$10 nm) metal layer making them largely transparent in the solar band and reflective in the thermal infrared, meaning that they would very effectively trap outgoing longwave radiation, while having almost no reflective effect on inbound shortwave solar radiation. This is the same physical principle as is used for making low-emissivity window coatings for cold climates.

These particles can have much higher radiative forcing per unit mass than the fluorinated gases and at the same time have shorter lifetimes. Moreover, the lifetimes of solid particles are less strongly coupled to their radiative properties than is the case for gases, allowing particles to be designed with radiative properties and lifetimes that are (somewhat) independent. Some variants of these particles could be self-lofting (for instance the microballoons proposed by Teller et al. or the photophoretic disks proposed by Keith) making it possible for them to be dispersed from conventional aircraft in the upper troposphere. While the cost of making engineered micron-scale particles might seem prohibitive, current industrial practice provides many examples of low-cost bulk manufacture of particles with similar dimensions, and the technology for bulk gas or liquid phase synthesis of small particles is evolving rapidly. Keith (2010) provides a preliminary analysis suggesting that some relevant particles might be fabricated at small cost compared to other costs considered in climate policy.

While a countervailing method could offset the global radiative forcing from any geoengineering method, a neutralizing method must be more specific to the geoengineering technology that it aims to neutralize. It might, for example, be possible to use high-altitude aircraft to add a base to the stratosphere to counteract the sulphate aerosol that is most commonly considered for geoengineering, though that would only reduce radiative forcing if the resulting salt had a lower radiative forcing or lifetime (Keith et al., 2016). Alternatively, it might be possible to introduce a substance that would accelerate the coalescence or coagulation rate of the geoengineering aerosol and accelerate its removal from the atmosphere by sedimentation. If practicable, such techniques would be more widely applicable in that they could be applied to any stratospheric aerosol. This might be achieved using microstructured aerosols with high aspect-ratio filaments or films that would accelerate coagulation. Alternative mechanisms to increase coagulation rates are theoretically possible, such as electrical polarization or charging of aerosols, or ultraviolet photoionization (in the stratosphere). In some cases, it might be possible to trail the path of SRM deployment aircraft with additional aircraft that release a neutralizing agent into the near-field high-concentration plume. Discounting the operational and security considerations, this might in some cases be more technically effective than attempting to neutralize the aerosol once it was well mixed in the stratosphere.

It may also be possible to neutralize the action of other SRM methods such as marine cloud brightening (for instance by releasing giant cloud condensation nuclei [Feingold et al., 1999]) or cirrus thinning, but this appears less plausible. Finally, for completeness, we note that space-based counter-geoengineering methods are theoretically possible. While space-based geoengineering systems are clearly farther from deployment, many such methods could be adapted for counter-geoengineering by increasing the net downward solar flux (Angel, 2006; Bewick et al., 2013).

4. Strategic Considerations for Counter-Geoengineering

In a world where solar geoengineering is plausible, the capacity to counter-geoengineer could lead to a variety of predictable and unpredictable outcomes. Here we theorize about conditions under which a country capable of counter-geoengineering might have a de facto veto over SRM deployment. To begin with, in order to have any political influence, a threat to counter-geoengineer would need to be credible. Numerous factors would influence this. If the deployment costs were very high, for instance, or if its side effects on human health were severe, then its use would be unrealistic. We suggest that the proposed technique would need to exhibit three characteristics:

1. It would need to be sufficiently cheap to manufacture and release. Specifically, the cost of counter-geoengineering would need to be small compared to the damages the countering state expected to suffer from SRM. Note that this cost might still be large compared to the actual cost to implement SRM, which need not be a factor in the calculations of an actor considering counter-geoengineering.
2. It would need to have acceptably low side effects on health or the environment. A counter-geoengineering technique that risked mass casualties, for example, would probably not constitute a credible deterrent.
3. Its atmospheric lifetime would need to be similar to or lower than the atmospheric lifetime of the geoengineering technique that it was countering. Sulphur hexafluoride (SF_6), for example, is a much more potent greenhouse gas than CO_2 but has an atmospheric lifetime of over 3,000 years. Its large-scale use to counter SRM would make it more like an irreversible “doomsday device” than a credible counter-geoengineering technique.

In addition, for counter-geoengineering to be a credible threat, a country considering SRM must be aware that an opposing state is prepared to use it. This information may or may not be public, but at a minimum those making decisions regarding SRM implementation must believe that a rival intends to counter their deployment; otherwise, the possibility of counter-geoengineering will not affect their decision-making calculus. This would require a potential counter-geoengineer to communicate or otherwise signal their intent.

Although back-of-envelope calculations like this suggest that some candidate agents are more suitable than others, research would be needed to understand whether any greenhouse gases or engineered particles could exhibit all three characteristics required in a credible counter-geoengineering agent.

One of the main reasons to develop counter-geoengineering capability would be that it could provide a novel and uniquely effective policy instrument for any state opposed to SRM. When faced with the prospect of unwanted SRM deployment, in the absence of counter-geoengineering, a state’s options would be limited. The softer policy options would probably be tried first (such as persuasion, shaming, or trade sanctions), and in many cases they might work to face down a threat to geoengineer. Such options might be pursued inside or outside the institutional framework of an SRM governance regime. Harder-edged “gray zone conflict” strategies might also be employed to deter SRM use. These are techniques for imposing state power (such as cyber warfare, espionage, and misinformation campaigns) that go beyond conventional diplomatic or economic measures but that do not involve regular military forces (U.S. International Security Advisory Board, 2017). But if either conventional or unconventional measures failed, the only choice to definitively stop the SRM would be to resort to military action.

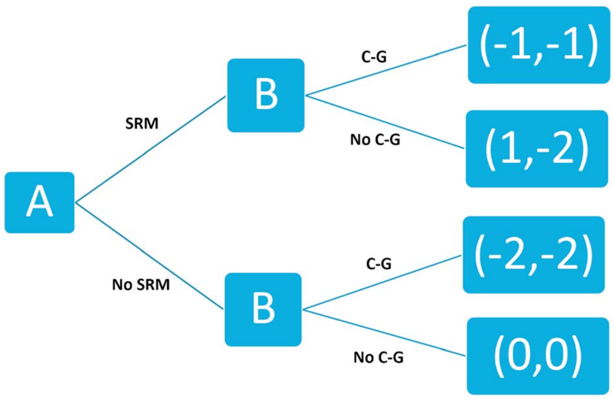

Figure 1. A game tree showing how two states, A and B, might make decisions over use of solar radiation management (SRM) and counter-geoengineering (here labeled as C-G). Preferences are ordinal.

Military intervention, however, would likely be viewed as a highly disproportionate response, especially if the belligerent states were great powers and military action could spark conflict. Indeed, contrary to the common assumption that the ability to engage in solar geoengineering would be widely distributed among states, practical requirements related to delivery infrastructure, technical capacity, and ability to withstand external pressure would likely mean that SRM capabilities would be limited to major powers or coalitions (Parson & Ernst, 2013). (Similar constraints would probably also apply to counter-geoengineering, likewise restricting this response option to relatively powerful states.) Military action to stop SRM deployment by a powerful state would likely only be launched by another powerful state or states, potentially triggering a systemic war (Gilpin, 1981). Yet to the extent that counter-geoengineering were perceived as less confrontational than military attack, counter-geoengineering might provide a more proportionate, less destabilizing, and technically effective means to stop SRM without resort to force. As such, some might see counter-geoengineering as a form of gray zone conflict.

Game theory provides a simple framework illustrating that counter-geoengineering is at least plausible from a strategic point of view. A highly simplified game tree (Figure 1) demonstrates the core logic of why the existence of a credible counter-geoengineering capability could create powerful disincentives against the unilateral deployment of SRM. It reflects a situation where State A perceives that they would gain by implementing SRM and State B perceives that they would lose. (Both states are rational unitary actors.) More specifically, payoffs depend on three assumptions: (a) For State A, SRM alone must be preferable to no SRM; (b) for State B, SRM plus counter-geoengineering must be preferable to SRM alone; and 3) for both states, no SRM must be preferable to SRM plus counter-geoengineering. In this extensive form game, State A has an initial choice of whether to use SRM or not, then State B has a choice of whether or not to counter-geoengineer. Perfect information assures that State A knows of State B's willingness to counter-geoengineer. Neither state can make precommitments.

Outcome (b) of the game tree demonstrates the potential problem of unilateral geoengineering, since the unrestricted use of SRM would reward State A, while State B would lose. Where counter-geoengineering is available, the logic changes. Counter-geoengineering offers State B the option to reduce its losses if State A decides to deploy SRM. Moreover, State A's gains from deploying SRM would not only erode, State A would actually be in a worse position than if it had never deployed at all. Given perfect information about these outcomes, backward induction would therefore lead State A not to deploy geoengineering. That means that the strategy profile (No SRM, No C-G) is the equilibrium outcome (d), and not deploying SRM would be the only rational approach for State A. The threat of counter-geoengineering would have proved a successful deterrent.

Only very modest claims can be derived from such a simplified representation of state interaction around SRM and counter-geoengineering, but the game tree provides prima facie evidence that counter-geoengineering is plausible from a game-theoretic point of view. Real-world political dynamics would be immeasurably more complex than a simple two-stage game, but such a game tree can usefully demonstrate the basic logic for how counter-geoengineering could provide a strategic deterrent.

Altering the assumptions specified above, or changing the conditions of interaction, might lead to different behaviors and results (Schelling, 1960). State B may have no interest in counter-geoengineering yet may threaten to do so if convinced that State A would back down. If preferences remained transparent, State B might choose to precommit to counter-geoengineer in the event State A implemented SRM to ensure credibility. State A might in turn precommit itself to solar geoengineer in anticipation of this, thereby preempting any threat. Imperfect information, impaired communication, and imprecise commitments—these and other characteristics of the game could affect its dynamics and outcome. In the end, developing a capacity to counter-geoengineer could substantially alter the international politics of solar geoengineering, in ways that are both benign and malign.

5. Strategic Implications of Counter-Geoengineering

The prospect of counter-geoengineering could, in theory, change the conditions under which SRM might be deployed. Counter-geoengineering need not actually be deployed to have an influence on policymaking. There is no expectation that any nuclear-armed state would use their weapons except in extremis, and yet their presence still has significant influence on international affairs and over how nuclear and nonnuclear states interact. The same dynamic would probably apply to counter-geoengineering, where states in possession of the capability would not need to use it to be able to project its influence over other parties.

Compared to the conventional tools of statecraft that countries might use to oppose deployment (such as legal action, trade sanctions, or military force), counter-geoengineering would offer more of a proportionate, symmetrical response. In simple terms, any state that could credibly threaten to counter-geoengineer would possess an effective veto over SRM. If a country wanted to conduct geoengineering, it would be forced to negotiate with states capable of counter-geoengineering over whether and how deployment was undertaken. This means, for instance, that any state wanting to use SRM, but dragging their feet on mitigation action, could be prevented from geoengineering until they had made solid commitments to cut their greenhouse gas emissions (Parson, 2014). In this way, threats to counter-geoengineer could be linked to preferred policies pertaining to climate change or other issue areas, promoting broader forms of intergovernmental cooperation. The availability of counter-geoengineering, in other words, conceivably could help foster a “logic of multilateralism” at the core of the international politics of SRM (Horton, 2011).

While analogies to military or nuclear deterrence scenarios are obvious, there are important technical differences that we believe have important consequences for the strategy and plausibility of counter-geoengineering. Based on current understanding, we expect that SRM technologies would likely be deployed by the continuous transport and release of some SRM agent using hardware such as a small fleet of aircraft. This would be an inherently incremental process in which each additional aircraft flight would do nothing detectable to the global climate—only the cumulative impact of (for example) months or years of deployment would have a measurable effect. The same would apply to most of the potential counter-geoengineering technologies discussed here.

Such gradualism, likely characteristic of both SRM and counter-geoengineering deployment (whether countervailing or neutralizing), would make the political decision-making environment, and the role of uncertainty and miscommunication in those decisions, quite dissimilar from the case of nuclear weapons. In nuclear disputes consequences can be virtually instant and potentially catastrophic, and in extreme cases decisions must be made in minutes. In contrast, if one state began to deploy SRM and another state began to deploy counter-geoengineering, both in a gradual fashion, the political negotiations between these states might then play out over months or even years without any strong physical signature climate response to either type of action (MacMynowski et al., 2011).

More fundamentally, the intensity of state preferences regarding solar geoengineering *and* counter-geoengineering would range along a spectrum from weak to strong. In particular, a country’s interest in and possible deployment of counter-geoengineering is likely to vary in relation to the amount and type of solar geoengineering being considered. Just as decisions about solar geoengineering would not be binary, neither would decisions about counter-geoengineering. Further, a threat to counter-geoengineer might not be contingent on stopping SRM altogether, but rather on reconfiguring its deployment, modifying its governance architecture or making some other change short of complete cessation. For all these reasons, real-world bargaining would therefore likely be more conditional and more complex than simple game-theoretic models like the one presented in the previous section.

However, while counter-geoengineering could have the potential to encourage a multilateral approach to SRM deployment, the power to block something that is desired by others could be abused. Even if nearly all countries wanted to implement SRM, counter-geoengineering conceivably could be threatened by a single country to block it or extort concessions. While the concept of counter-geoengineering arose largely in the context of concerns about unilateral deployment of SRM, in principle the technology could be used to counter SRM deployment by any combination of states, including deployments that were widely agreed and thus viewed as legitimate. Given that the motivating factor for deployment of SRM might be desperation in the face of a perceived environmental crisis, a threat to counter-geoengineer might be seen as highly aggressive.

Furthermore, counter-geoengineering could open up the possibility of brinkmanship. One key shortcoming of the game tree in Figure 1 is that in real life neither State A nor B would know the other's preferences regarding different possible outcomes. Both states would probably seek to communicate their intents to geoengineer or counter-geoengineer by signaling, using verbal communications, the buildup of physical infrastructure, or other statements or gestures. But it might be difficult to assess the level of resolve behind the posturing. If tensions rose, threats to geoengineer or counter-geoengineer could lead to brinkmanship and, potentially, increased risks of deployment. Such brinkmanship could continue even after deployment, with both states continuing to escalate their deployment in the hope the other would back down. An "arms race" fought between escalating levels of stratospheric cooling and tropospheric warming could pose large environmental risks to all people on the planet not just the belligerent states.

A final point worth considering is that the strategic implications of a counter-geoengineering response might differ depending on whether it is countervailing or neutralizing in nature. There are at least three reasons for this. First, in principle, a neutralizing response could be perfectly symmetrical to the unilateral intervention, whereas a countervailing response would invariably create new warming effects in the climate system. Second, adopting a purely symmetrical response through neutralizing would minimize room for error or miscalculation compared to a proportional but asymmetric countervailing response. Finally, seeking to undo an act of geoengineering (neutralizing) might be viewed as less hostile than seeking to balance it with equal radiative forcing (countervailing). For these three reasons, we hypothesize that neutralizing would be a strategically preferable approach to counter-geoengineering compared to countervailing.

6. Is Counter-Geoengineering Realistic?

Counter-geoengineering is a theoretical proposal, and there are physical and political reasons why it might never be developed, let alone deployed. On the technical side, research would need to develop a technique that would be both effective at countering the cooling of SRM deployment and sufficiently affordable to realistically be implemented. Side effects on health and the environment would also need to be sufficiently low for the threat of counter-geoengineering to be credible.

But even if it appeared technically possible, it remains unclear whether counter-geoengineering could be a politically feasible proposal. In general, a threat is credible only if the benefits of delivering on the threat outweigh the costs, and at this stage it is unclear whether any decision maker would ever reach this conclusion with respect to counter-geoengineering. If SRM deployment were negotiated diplomatically and multilaterally, then counter-geoengineering would not be relevant. It also seems reasonable to expect that people who objected to SRM on the basis that it involved unacceptable interference with nature would oppose counter-geoengineering.

Yet while there are good technical and political reasons to be skeptical about the practical feasibility of counter-geoengineering, we think that it would be premature to dismiss the idea. Similar grounds for skepticism have not held back serious analysis of SRM as a potential climate policy tool. Further, for anyone who thinks that SRM might be used unilaterally, for instance, or could be contentious enough to lead to interstate conflict, counter-geoengineering should be regarded as plausible, at least in theory.

7. Conclusion

The idea of counter-geoengineering has been emerging in policy conversations about SRM and has been touched upon as a peripheral topic in a few prior publications. Our objective here has been to provide a foundation for thinking about this concept and its potential policy implications.

This preliminary analysis makes several novel contributions. First, we consider how counter-geoengineering might be realized in practice, and we draw an important conceptual distinction between countervailing and neutralizing forms of counter-geoengineering. Second, we specify three strategic requirements for counter-geoengineering and use a highly simplified game theoretic model to demonstrate its prima facie potential to check unilateral SRM. And third, we provide new geopolitical insights based on this more developed technical and strategic basis for theorizing about counter-geoengineering.

It is our hope that these technologies will not be developed or used. The fact that SRM may be needed to counter climate change arises, in part, from a failure of collective action to limit emissions. The development and use of counter-geoengineering would be a further testament to the international system's apparent inability to resolve climate disagreements in a constructive way.

However, some further consideration of counter-geoengineering seems warranted. Like SRM, it has the potential to be helpful or harmful. Like nuclear weapons, it does not need to be used to be influential over state behavior. If it could create an effective deterrent to unilateral deployment of SRM, it might have the potential to nudge decision making towards multilateralism. Alternatively, however, counter-geoengineering could lead to increased international tensions and brinkmanship over the climate and could prove environmentally disastrous if used without sufficient understanding of its impacts or side effects.

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