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Geoengineering and the Myth of Unilateralism: Pressures and Prospects for International Cooperation

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I. INTRODUCTION

In recent years, discussions of geoengineering have intensified among scientists, policymakers, and other interested observers. The possibility that one state might unilaterally deploy geoengineering technology has become a fixture in these debates, and has cast a pall over substantive inquiry into climate intervention research and implementation. Speculation about "rogue" states pursuing geoengineering outside multilateral frameworks has given pause to calls for more robust experiments and field trials, and has contributed to the adoption of moratoria by the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter of 1972 and the Protocol of 1996 (LC/LP) and the Convention on Biological Diversity (CBD).[1] In sum, the fear of unilateralism has become an *idée fixe* in conversations about geoengineering, in effect putting the brakes on more ambitious research efforts and deliberations about governance issues.

In this article, I argue that fear of unilateralism is largely misplaced, grounded more in unexamined policy assumptions than in reasoned analysis of the strategic situation faced by states. I will present this argument in five parts. First, I will document the widespread notion that unilateral geoengineering poses a genuine threat to the international order. Second, I will closely examine the interests and constraints that are likely to confront states contemplating intervention in the climate system. Third, I will demonstrate that international dynamics are more likely to create pressures leading to cooperation than to foster tendencies toward unilateralism. Fourth, I will consider different mechanisms for encouraging collaboration on climate intervention strategies. Finally, I will consider the implications of this argument for future discussions of geoengineering.

The argument developed below is premised on three assumptions: research on geoengineering will demonstrate its efficacy and familiarize states with its uses and limitations; these results will favorably dispose states toward geoengineering through a process of intergovernmental learning; and any state interested in geoengineering desires a successful

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[1] In 2008, parties to the LC/LP agreed to ban ocean fertilization activities except for "legitimate scientific research." *See* U.N.E.S.C.O-I.O.C Res. LC-LP.1 On the Regulation of Ocean Fertilization, LC 30/16/Annex 6 (Oct. 31, 2008). In October 2010, parties to the CBD adopted a moratorium on geoengineering activities. *See* C.B.D. Dec. X/33, UNEP/CBD/COP/DEC/X/33 (Oct. 29, 2010), *available at* http://www.cbd.int/climate/doc/cop-10-dec-33-en.pdf.

intervention. Where these assumptions do not hold, the argument does not follow. For instance, if epistemic and socialization processes do not encourage governments to support geoengineering, the logical outcome of the reasoning presented here would be that any state opposed to geoengineering would wield an effective veto over its deployment.[2] In addition, this article will focus specifically on Stratospheric Aerosol Injections (SAI) as the intervention strategy most likely to be selected to combat the effects of global climate change.[3] Solar Radiation Management (SRM) technologies are broadly regarded as primary candidates for geoengineering deployment due to their relative simplicity, rapid effects, and low cost.[4] The injection of sulfate aerosols is regarded as particularly attractive given current knowledge and familiarity with natural analogs (i.e., volcanic eruptions).[5] As such, the following argument applies strictly to SAI technology. Other geoengineering technologies may fit this pattern to a greater or lesser degree.

II. UNILATERALISM AS CONVENTIONAL WISDOM

Conventional concerns about the threat of unilateral geoengineering typically run as now described. At some point in the decades to come, in a world of accelerating climate change and continuing failure to significantly reduce greenhouse gas (GHG) emissions, Country A decides that its interests would best be served by implementing a climate intervention strategy (in the present case, SAI). This decision may be driven by any number of developments: altered precipitation patterns, rising sea level, shifting disease vectors, disruptions to agriculture, desertification, etc. Unable to gain international support for the deployment of SAI, Country A deploys the technology on a unilateral basis, flouting the consensus among states, materially affecting the global climate system, adversely impacting particular states and regions, offending those who view climate intervention as "unnatural"—in other words, seizing control of the global "thermostat."[6] Put simply, for Country A, the potential costs of defying international opinion are outweighed by the benefits of unilateral geoengineering. Unilateral deployment by Country A subsequently results in global disapprobation and triggers an international response in the form of sanctions, a trade war, or worse.

Variations of this scenario have been advanced most prominently by members of the policy community, especially foreign policy experts.[7] For example, Victor et al. write:

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[2] For more on learning among states, see ERNST B. HAAS, WHEN KNOWLEDGE IS POWER (1990) and Joseph S. Nye, Jr., *Nuclear Learning and U.S.-Soviet Security Regimes*, 41 INT'L ORG. 371 (1987).

[3] *See generally* JASON J. BLACKSTOCK ET AL., NOVIM ORG., CLIMATE ENGINEERING RESPONSES TO CLIMATE EMERGENCIES 4-16 (2009) (providing a comprehensive overview of technical aspects of SAI).

[4] Lee Lane & J. Eric Bickel, *Solar Radiation Management and Rethinking the Goals of COP-15, in* COPENHAGEN CONSENSUS ON CLIMATE: ADVICE FOR POLICYMAKERS (Copenhagen Consensus Center) 15, 16-19 (2009).

[5] THE ROYAL SOC'Y, GEOENGINEERING THE CLIMATE: SCIENCE, GOVERNANCE AND UNCERTAINTY 29-32 (2009).

[6] Alan Robock, *20 Reasons Why Geoengineering May Be a Bad Idea*, 64 BULL. OF THE ATOMIC SCIENTISTS 14, 17 (2008).

[7] *See* BLACKSTOCK ET AL., *supra* note 3, at 44; LANE & BICKEL, *supra* note 4, at 19; Jason J. Blackstock & Jane C.S. Long, *The Politics of Geoengineering*, 327 SCIENCE 527, 527 (2010); John Virgoe, *International Governance of a Possible Geoengineering Intervention to Combat Climate Change*, 95 CLIMATIC CHANGE 103, 115-16 (2009). These concerns were raised in 2009-2010 hearings on geoengineering held by the House Committee on Science and Technology, Subcommittee on Energy and Environment. *See* FRANK RUSCO, CLIMATE CHANGE: PRELIMINARY OBSERVATIONS ON GEOENGINEERING SCIENCE, FEDERAL EFFORTS, AND GOVERNANCE ISSUES 7 (2010); Memorandum from Richard Lattanzio & Emily Barbour, Cong. Res. Serv., to the House Committee on Science & Technology 3 (Mar. 11, 2010) (on file with author) (the subject of the memorandum is the international governance of geoengineering).

> [G]eoengineering is an option at the disposal of any reasonably advanced nation. A single country could deploy geoengineering systems from its own territory without consulting the rest of the planet. Geoengineers keen to alter their own country's climate might not assess or even care about the dangers their actions could create for climates, ecosystems, and economies elsewhere. A unilateral geoengineering project could impose costs on other countries, such as changes in precipitation patterns and river flows or adverse impacts on agriculture, marine, fishing, and tourism . . . . At some point in the near future, it is conceivable that a nation that has not done enough to confront climate change will conclude that global warming has become so harmful to interests that it should unilaterally engage in geoengineering . . . . Unilateral action would create a crisis of legitimacy that could make it especially difficult to manage geoengineering schemes once they are under way.[8]

Policymakers and analysts worry about the effects of unilateral deployment on international peace and stability. Unilateral geoengineering is viewed as a challenge to the international order, in terms of both legitimacy and security, in a way reminiscent of nuclear proliferation.[9]

Climate scientists have also noted concerns about unilateral geoengineering.[10] For instance, Lawrence states:

> [I]t is easy to imagine a future scenario in which certain nations begin to undertake large-scale geoengineering efforts on their own. It is not uncommon for nations to act unilaterally in what they perceive as their own best interests, regardless of any international outcry about the consequences for the rest of the world.[11]

Lawrence continues:

> [W]ithout a good overview of potential geoengineering efforts which might eventually be undertaken, it would be difficult to monitor for the possibility of "covert" geoengineering . . . . a clear line will need to be drawn between allowed scientific experiments which are small-scale yet large enough to have statistically significant signals, and what goes beyond this, so that "science" cannot be used as camouflage for unilateral attempts to undertake large-scale geoengineering efforts.[12]

Not only do members of the scientific community echo fears articulated by policy analysts, they also express concern that unilateral climate interventions might undermine the integrity of the scientific process by parading as experimental in nature. The conduct of

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[8] David G. Victor et al., *The Geoengineering Option: A Last Resort Against Global Warming?*, 88 FOREIGN AFF. 64, 71-72 (2009).

[9] For an explicit comparison, see Clive Hamilton, The Return of Dr. Strangelove: The Politics of Climate Engineering as a Response to Global Warming (June 2010) (unpublished manuscript, *available at* http://www.clivehamilton.net.au/cms/media/documents/articles/dr_strangeloves_return.pdf).

[10] *See* THE ROYAL SOC'Y, *supra* note 5, at 40; Michael C. MacCracken, *Geoengineering: Worthy of Cautious Evaluation?*, 77 CLIMATIC CHANGE 235, 238 (2006).

[11] Mark G. Lawrence, *The Geoengineering Dilemma: To Speak or Not to Speak*, 77 CLIMATIC CHANGE 245, 246 (2006).

[12] *Id.*

nominally "scientific" nuclear research by international pariah states stands as a cautionary tale in this regard.

Opponents of geoengineering have used the unilateral scenario to argue against research and deployment. ETC Group is arguably the most outspoken critic of geoengineering, and has identified "unilateral" as one of the "Best Reasons to Say No to Geoengineering."[13] The organization argues:

> It has been well established in the Stockholm Declaration (1972), the Rio Declaration (1992), the precedent-setting *Trail Smelter* case and in the UNFCCC [United Nations Framework Convention on Climate Change] itself that states are obliged to ensure that "activities within their jurisdiction or control do not cause damage to the environment of other states or of areas beyond the limits of national jurisdiction." The widely acknowledged potential for unilateral geoengineering deployment flies of the face of this principle.[14]

Undoubtedly, many of those scientists, policy analysts, and others who have raised the issue of unilateralism have done so not with the intent to inhibit geoengineering research and possible implementation, but rather to consider unilateralism as one potential complicating factor in any effort to deploy geoengineering technology. Critics of climate engineering raise several other concerns aside from unilateral deployment, such as regional variability, stratospheric ozone depletion, and moral hazard. Nevertheless, speculation about unilateral intervention has injected an element of fear into the climate debate, and been warmly received by those opposed to geoengineering for primarily ideological reasons. Given the present stakes, it is important to show that the specter of unilateral deployment is largely illusory, and that multilateral cooperation is the outcome favored by events.

III. THE MYTH OF UNILATERAL DEPLOYMENT

Unilateral SAI geoengineering is unlikely to occur because the incentives faced by states do not support it. Individual incentives may be insufficient to deter unilateral SAI, but taken together, these impediments to unilateralism form a web of constraints, which acts to steer national behavior firmly toward international consensus and collaboration. The technical attributes of SAI greatly reduce any potential benefits from unilateral deployment, while the costs of retaliation remain unchanged. Costs may include trade sanctions, diplomatic isolation, linked reprisals in other issue areas, and even the use of force. Together, these conditions strongly favor international cooperation in any attempt to successfully intervene in the climate system.

To illustrate, suppose Country B has both an interest in geoengineering deployment and the capacity to carry it out. In the present case, deployment would take the form of a stratospheric aerosol system. Country B would confront a multiplicity of practical constraints that effectively minimizes any gains from unilateral implementation.

[13] ETC GROUP, RETOOLING THE PLANET?—CLIMATE CHAOS IN THE GEOENGINEERING AGE 34 (2009).

[14] *Id.* at 39 (quoting the United Nations Conference on Environment and Development, Rio De Janeiro, Braz., June 2-14, 1992, *Rio Declaration on Environment and Development*, U.N. Doc. A/CONF.151/26 (Vol. I), Ch. I, Annex I (1992)).

First, the relative simplicity and affordability of SAI technology would make it widely available to members of the international community.[15] Other states or international bodies might inject stratospheric aerosols just as easily as Country B does. The likelihood of uncoordinated interventions is low, but the possibility is real, and the effects could be damaging. Indeed, the potential for such deleterious effects helps explain the low probability of multiple, uncoordinated injections in the first place. The prospect of such inexpensive, mutually destructive interference would act as a disincentive to any state contemplating unilateral deployment.

Multiple injections would interact in a variety of ways. Specifically, the results of aerosol injections by Country B would necessarily be mediated by the number of additional injection projects, the volumes of aerosols injected, the types of aerosols injected, the timing and phasing of other injections, and the location of injection sites.[16] The effects of such intervening variables are potentially large and would likely frustrate any deployment plan that failed to take them into account.

For example, one of the most common proposals for SAI involves regional deployment designed to stabilize climate in the Arctic,[17] including the Greenland ice sheet. Preliminary models indicate that isolated, high-latitude aerosol dispersals would combine with increased poleward water vapor transport characteristic of global warming, to produce greater snowfall in the Arctic region.[18] This would result in enhanced regional albedo (reflectivity), reinforced snowpack, and moderated climate change in the north polar region. However, stratospheric injections carried out simultaneously at lower latitudes (by, say, a low-lying island state facing an existential threat from sea level rise) would have the effect of reducing water vapor transport, which in turn would reduce Arctic precipitation, reverse snow pack gains, and leave ice sheets in a deteriorating state. In the absence of international coordination, a regional Arctic rescue plan could come undone as a result of otherwise good intentions.

Aerosol chemistry provides another example. The aerosol most commonly suggested for stratospheric injection is sulfuric acid.[19] Plans call for delivering sulfate aerosols by dispersing gas-phase precursor materials. Precursor oxidation and aerosol formation involve complex processes with the potential to reduce the effectiveness of stratospheric insertion. For instance, coagulation could lead to excessively large sulfuric acid particles that sediment out of the stratosphere, lessening the effect of the initial dispersion.[20] Multiple, independent injections would increase the likelihood of such unintended consequences. Unsynchronized staging, scheduling, and delivery of sulfate aerosol injections would magnify the potential for perverse

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[15] BLACKSTOCK ET AL., *supra* note 3, at 46-51.
[16] *Id.* at 19-20; Ken Caldeira & Lowell Wood, *Global and Arctic Climate Engineering: Numerical Model Studies*, 366 PHIL. TRANSACTIONS OF THE ROYAL SOC'Y A 4039 (2008); Paul J. Crutzen, *Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?*, 77 CLIMATIC CHANGE 211 (2006).
[17] *See* NASA STI PROGRAM OFFICE, NASA/CP-2007-214558, WORKSHOP REPORT ON MANAGING SOLAR RADIATION 5-6 (Lee. Lane et al. eds., 2007), *available at* http://agriculturedefensecoalition.org/sites/default/files/pdfs/16N_2007_33_NASA_April_2007_Workshop_On_Managing_Solar_Radiation.pdf (discussing potential experiments in Arctic cooling using SAI technology).
[18] Caldeira & Wood, *supra* note 16, at 4043-45.
[19] *See* Edward Teller, Roderick Hyde & Lowell Wood, Active Climate Stabilization 4 (Apr. 18, 2002) (manuscript prepared for invited presentation at the National Academy of Engineering Symposium *Complements to Kyoto: Technologies for Controlling CO2 Emissions*, National Academy of Sciences), *available at* http://www.osti.gov/accomplishments/documents/fullText/ACC0233.pdf) (identifying sulfate aerosols as the preferred particle for use in SAI).
[20] BLACKSTOCK ET AL., *supra* note 3, at 22.

particulate interactions, and might jeopardize the success of SAI deployment. Lack of policy coordination may result in separate injection schemes and mutual suboptimality.

As these cases illustrate, aerosols injected by Country B could not be kept separate from injections by other parties, and the consequent interactions could undermine the effectiveness of Country B's deployment. Simultaneous injection schemes carried out by multiple countries may be unlikely, but the possibility is nontrivial, particularly given the technical simplicity and low cost of injection systems. The widespread availability of stratospheric injection technology, combined with its potential to hinder any unilateral deployment, provide strong incentives to coordinate implementation plans at the international level.

Second, other states may choose to pursue other types of geoengineering activities, including alternative SRM strategies and Carbon Dioxide Removal (CDR) techniques. As in the case above, parallel deployments of additional geoengineering technologies would have the potential to interfere with stratospheric injections by Country B. Consequently, Country B would also need to ensure that its stratospheric aerosol deployment was coordinated with any other geoengineering activities conducted by other international actors. The pursuit of strategies such as marine cloud whitening,[21] ocean fertilization,[22] artificial upwelling,[23] etc.,[24] would affect the outcome of stratospheric aerosol deployment by modifying regional albedo, disrupting regional (and potentially global) circulation patterns, altering atmospheric chemistry, affecting nutrient cycles, and in other, less predictable ways.[25] To maximize the chances of success, Country B would need to account for these complicating factors in its aerosol injection plans, monitor concurrent climate interventions carried out by other actors, and adjust stratospheric aerosol deployment schedules and timetables on an ongoing basis.

Third, by undertaking a stratospheric aerosol project, Country B would be faced with the so-called "termination problem": if emissions were not reduced simultaneously, project termination would result in rapid temperature increases and a destabilized climate system, so that in effect Country B would be committed to aerosol injections indefinitely.[26] This dilemma would create pressure for Country B to synchronize national deployment with international emissions mitigation efforts.[27] Unless its government was prepared to shoulder the burden of deployment on an essentially permanent basis, in effect providing a global public good, Country

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[21] *See generally* John Latham et al., *Global Temperature Stabilization via Controlled Albedo Enhancement of Low-Level Maritime Clouds*, 366 PHIL. TRANSACTIONS OF THE ROYAL SOC'Y A – MATHEMATICAL, PHYSICAL, AND ENGINEERING SCI. 3969 (2008).

[22] *See generally* Christine Bertram, *Ocean Iron Fertilization in the Context of the Kyoto Protocol and the Post-Kyoto Process*, 38 ENERGY POL'Y 1130 (2010); Raymond T. Pollard et al., *Southern Ocean Deep-Water Carbon Export Enhanced by Natural Iron Fertilization*, 457 NATURE 577 (2009).

[23] *See generally* A. Oschlies et al., *Climate Engineering by Artificial Ocean Upwelling: Channelling the Sorcerer's Apprentice*, 37 GEOPHYSICAL RES. LETTERS 4701 (2010).

[24] *See, e.g.,* Greg H. Rau, *Electrochemical CO_2 Capture and Storage with Hydrogen Generation*, 1 ENERGY PROCEDIA 823 (2009) (discussing a method of producing hydroxide solutions that can be used to absorb and store carbon dioxide).

[25] *See* Michael C. MacCracken, *On the Possible Use of Geoengineering to Moderate Specific Climate Change Impacts*, 4 *ENVTL. RES. LETTERS* 4-5 (2009) (noting effects of alternative geoengineering strategies on biogeochemical processes affecting weather and climate).

[26] *See* BLACKSTOCK ET AL., *supra* note 3, at 27-29.

[27] *See id.* at 27 (noting that intervention maintenance would require considering greenhouse gas emission scenarios that occur in parallel to any steady-state interventions); Rob Swart & Natasha Marinova, *Policy Options in a Worst Case Climate Change World*, 15 MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE 531, 539 (2010) (noting the necessity of having to maintain an SRM system until other measures have brought down greenhouse gas concentrations).

B would need to link deployment to a robust global emissions reduction policy and a more general decarbonization of the world economy.[28]

For some states, of course, the costs of mitigation would outweigh the costs of continued deployment, so that the termination problem by itself would serve as an ineffective deterrent to unilateral deployment. For example, an Arctic state faced with a rapidly thawing ecosystem may come to believe that undertaking SAI on its own, on an indefinite basis, is a more attractive option than a coordinated policy of global mitigation and temporary geoengineering. However, such states would still be subject to the other disincentives to unilateral action discussed in this section. It is the cumulative force of these constraints, rather than the particular effect of any constraint taken in isolation, that militates against unilateral implementation and instead supports international cooperation.

Fourth, the effects of deployment could be offset with a variety of countermeasures. Though rarely mentioned in the literature, states opposed to geoengineering have a number of tools at their disposal to counteract climate interventions.[29] In the case of SAI, for example, fluorocarbon gases could be deployed to offset cooling effects. Alternatively, the strategic use of black carbon could neutralize artificial albedo enhancement.[30] The availability of effective countermeasures would serve as perhaps the most potent check on unilateral deployment of SAI.

Thus, the incentive structure faced by a state interested in implementing SAI would strongly discourage unilateral postures that dismissed the need for international agreement and coordination. Any country considering unilateral deployment would find itself tangled in a web of technical and political constraints and steered toward reaching some form of global consensus. Individual incentives may be inadequate to deter unilateralism on their own, but their collective weight is likely to tilt the playing field decisively in favor of multilateral cooperation. For instance, Country B may be sufficiently motivated to accept the costs associated with the termination problem and dispense with efforts to synchronize emissions mitigation policies. But once deployed, a large number of international actors would effectively exercise joint control over any injection system, frustrating any attempt by Country B to pursue a coherent SAI policy managed solely by its national government. Furthermore, any actor opposed to the project could easily (and anonymously) counter its effects using relatively simple means such as release of black carbon, thereby neutralizing the entire scheme. For Country B, the costs of unilateral SAI would exceed the benefits, due to the technical limitations inherent in unilateral deployment of such technology, and as a consequence, interest in SAI would require a multilateral approach. The net result is that states are unlikely to view unilateral deployment as a sound, effective policy option.

This situation is ultimately attributable to the highly complex nature of the climate system.[31] Climate dynamics are multivariate and interdependent, determined by a range of

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[28] While climate policy is sometimes presented as a choice between mitigation and intervention, the implications of the termination problem demonstrate that this is a false choice. Geoengineering cannot achieve the goal of climate stabilization without complementary carbon mitigation. Indeed, these two approaches are less mutually exclusive than mutually dependent.

[29] BLACKSTOCK ET AL., *supra* note 3, at 28.

[30] James Hansen & Larissa Nazarenko, *Soot Climate Forcing via Snow and Ice Albedos*, 101 PNAS 423, 424 (2004).

[31] *See generally* INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (I.P.C.C.), CLIMATE CHANGE 2007: SYNTHESIS REPORT, *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf; NICHOLAS STERN, THE ECONOMICS OF CLIMATE CHANGE: THE STERN REVIEW (2007); NATIONAL RES. COUNCIL OF THE NATIONAL ACADEMIES, ADVANCING THE SCIENCE OF CLIMATE CHANGE (2010), available at

factors including atmospheric and ocean chemistry, albedo, atmospheric circulation, the hydrologic cycle, ocean currents, vegetation coverage, biogeochemical cycles (carbon, nitrogen, etc.), and solar effects. Feedback mechanisms and nonlinearities are essential features of the climate system. Because climate complexity renders the outcome of any SAI effort contingent on the interplay of multiple variables and processes, and these phenomena are influenced by the actions of multiple states, success hinges on coordinated international intervention. Even if a unilateral SAI project took the entirety of the climate system into account, and its effects could be predicted with a high level of confidence on paper, the susceptibility of the climate system to the actions of other countries would render the project unpredictable in the absence of multilateral agreement, and would thus strongly favor (though not guarantee) international cooperation.

In other words, SAI geoengineering is ruled not by the threat of unilateral deployment, but rather by a "logic of multilateralism": in a world of multiple, competing nation-states, nature dictates that effective SAI and multilateral cooperation on aerosol injections are identical pursuits. Any country that embarks on unilateral implementation will soon find its efforts frustrated by rivals and friends alike, whose actions across the entire policy spectrum are inextricably linked via the global climate system. The inherent complexity of the climate system makes the success of SAI singularly dependent on the behaviors in which other states do and do not engage.[32] Recognizing the true collective action constraints associated with stratospheric aerosols removes the specter of unilateralism from discussions of SAI. Furthermore, recognizing the multilateral logic that underlies SAI also points to a suite of diplomatic and institutional tools with proven capacity to promote international cooperation.

IV. GETTING PROBLEMS RIGHT

To appreciate the divergent challenges posed by multilateralism, as opposed to unilateralism, the concept of "problem structure" is helpful. Problem structure refers to the essential characteristics of interactive social problems. These characteristics shape attempts at problem resolution and strongly influence the likelihood of success. Arild Underdal provides what is arguably the most sophisticated and useful discussion of problem structure, treating social problems as spanning a continuum from purely benign to purely malign. According to Underdal, "a perfectly benign problem would be one characterized by identical preferences. The further we get from that state of harmony, the more malign the problem becomes."[33] Malign problems are problems of "incongruity" in which "the cost-benefit calculus of individual actors includes a nonproportional or biased sample (representation) of the actual *universe* of costs and benefits produced by his decisions and actions" (emphasis in the original).[34] In other words, for malign problems, costs and benefits do not fall equally on all actors; thus, individual incentives differ from the overall group incentive and suboptimal outcomes result.

In contrast, benign problems are problems of "coordination" in which: "(1) the overall result depends on the compatibility of individual choices, (2) more than one route can lead to the

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http://www.nap.edu/openbook.php?record_id=12782&page=1 (all providing authoritative discussions of climate system complexity and socioeconomic linkages).

[32] For more on structural and behavioral consequences of system complexity, see ROBERT JERVIS, SYSTEM EFFECTS: COMPLEXITY IN POLITICAL AND SOCIAL LIFE (1997).

[33] Arild Underdal, *One Question, Two Answers*, *in* ENVIRONMENTAL REGIME EFFECTIVENESS: CONFRONTING THEORY WITH EVIDENCE 3, 15 (Edward L. Miles et al. eds., 2002).

[34] *Id.* at 17.

collective optimum, and (3) the choice between or among these routes is not a trivial or obvious one, meaning that compatibility cannot be taken for granted even when actor interests are identical."[35] Because benign problems are easier to solve than malign ones, benign problem structures are more likely to result in successful outcomes than are malign structures. Conflicts at any level of analysis, from local to international, may be classified as relatively benign or relatively malign.[36]

SAI geoengineering, governed by a multilateral logic, represents a benign problem structure with relatively few obstacles to cooperation. Indeed, SAI features structural supports that make cooperation advantageous if not essential. Injecting aerosols into the stratosphere requires multi-state coordination if it is to succeed in moderating global temperatures. By contrast, climate mitigation represents a malign problem structure.[37] Emission reductions confront states with the following dilemma: while countries prefer collective carbon mitigation, they more strongly prefer that other countries reduce emissions while they pursue economic growth unburdened by an effective price on carbon.[38] The widespread temptation to "defect" from an emissions mitigation agreement has paralyzing effects. The credible threat of unilateral cheating results in global inaction and accelerating climate change.[39]

The international nuclear arena offers a useful parallel. Like climate mitigation, nuclear nonproliferation presents a malign problem structure in which states face powerful incentives to engage in unilateral violations of agreed nonproliferation rules. Whereas SAI technology is widely available, nuclear technology is not. The nonproliferation regime in effect freezes a given distribution of nuclear weapons, dividing the world into nuclear and non-nuclear states.

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[35] *Id.* at 20.

[36] In the language of game theory, malign problems approximate "mixed-motive games," while benign problems approximate "coordination games." A game is defined by its payoff function or preference ordering, which represents an actor's preferences over possible outcomes. In a standard two-person game, each actor may choose one of two "strategies:" cooperation, conventionally denoted as "C," or defection, "D." This choice situation gives rise to four possible outcomes: mutual cooperation, or "CC"; mutual defection or "DD"; the "sucker's payoff" or "CD," in which the first player cooperates and the second player defects; and the "temptation payoff" or "DC," in which the first player defects and the second player cooperates. Players rank these four outcomes from most to least preferred, depending on the particular characteristics of the situation, and this preference ordering defines the game. An equilibrium (or Nash equilibrium) is an outcome in which neither player has an incentive to change strategy if the other player does not, thereby rendering it stable. A Pareto optimal outcome is one in which it is impossible to improve one player's payoff without reducing the other player's payoff.

Two games are particularly significant. Stag hunt, also known as assurance, is defined by the payoff function CC>DC>DD>CD; while two equilibria, CC and DD, are possible, the fact that only CC is Pareto optimal means that mutual cooperation is the preferred outcome. Stag hunt belongs to a broad category of games called coordination games, which are characterized by the presence of multiple equilibria. In contrast, in a prisoners' dilemma, the payoff function DC>CC>DD>CD leads to the equilibrium DD. Because this is not Pareto optimal, the outcome of mutual defection is referred to as suboptimal. Prisoners' dilemma is the most prominent member of a class of games known as mixed-motive or collaboration games, which are distinguished by the fact that players are motivated both to cooperate and to defect simultaneously. For more on game theory, see MARTIN J. OSBORNE, AN INTRODUCTION TO GAME THEORY (2004) (presenting the main principles of game theory and how they can be used to understand certain phenomena).

[37] Scott Barrett, *The Incredible Economics of Geoengineering*, 39 ENVTL. & RESOURCES ECON. 45, 45-46 (2008).

[38] *See* James K. Sebenius, *Towards a Winning Climate Coalition*, *in* NEGOTIATING CLIMATE CHANGE: THE INSIDE STORY OF THE RIO CONVENTION 277, 286 (Irving Mintzer & J. Amber Leonard eds., 1994).

[39] *Cf.* Lee Lane & W. David Montgomery, *Organized Hypocrisy as a Tool of Climate Diplomacy*, 5 AM. ENTERPRISE INST. FOR PUB. POL'Y RES. ENERGY & ENV'T OUTLOOK, 3-4 (2009), *available at* http://www.aei.org/docLib/05-EEO-Lane-g.pdf (describing emissions mitigation as a tragedy of the commons subject to problematic enforcement).

As power shifts globally, ascendant and revisionist states seek to enter the nuclear club in defiance of rules created for a different, earlier era.[40] These actions result in broken rules and chronic mistrust, as evidenced by the behavior of India, Pakistan, North Korea, Iran, and other noncompliant states. Such noncompliance threatens to undermine the nonproliferation regime.

Arms control, on the other hand, stands as a comparatively benign problem in which bargains are struck with the help of coordination, monitoring, and verification mechanisms. Nuclear arms control agreements are reached between relative equals. Typically, each state is in possession of a secure second-strike capability, so that additional investments in nuclear weapons are irrational from an economic and military perspective.[41] Countries face strong incentives to stabilize the strategic balance of power in order to increase domestic spending and enhance national prosperity. Arms control treaties provide such stability and tend to elicit cooperation. The history of successful arms control pacts, from Strategic Arms Limitation Talks (SALT) I and II to Strategic Arms Reduction Treaties (START) I and II and New START, testifies to the comparative ease of resolving benign problem structures.[42] For both arms control and SAI geoengineering, interests are in relative alignment, outcomes are interdependent, and cooperation is achievable.[43]

Viewed in this way, the conventional tendency to hear nuclear echoes in contemporary debates about geoengineering is turned on its head. The governance challenges associated with SAI resemble the challenges associated with arms control much more than the difficulties plaguing nonproliferation efforts. With SAI and arms control, national interests favor mutual accommodation and coordination. With emissions mitigation and nonproliferation, by contrast, national interests tend to diverge from the collective interest, and hence international agreements are more prone to breakdown. Disputes between nuclear weapons states and non-nuclear weapons states are mirrored by debates between Annex I and Annex II countries. It is not SAI geoengineering, but rather mitigation policy that is subject to the types of malign incentives typical of nuclear nonproliferation. Decades of unsuccessful attempts to reduce global carbon emissions underscore this similarity and explain the need to consider geoengineering in the first place.

V. PROMOTING MULTILATERALISM

The benign problem structure underlying the question of SAI deployment can be addressed through the use of a portfolio of tactics known to political scientists as "international management theory."[44] Employing these instruments facilitates the achievement of multilateral

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[40] *Cf.* ROBERT GILPIN, WAR AND CHANGE IN WORLD POLITICS 48-49 (1981) (summarizing theory of hegemony, distribution of power, and international political change).

[41] *See* Robert Jervis, *The Utility of Nuclear Deterrence, in* THE USE OF FORCE: MILITARY POWER AND INTERNATIONAL POLITICS 108, 108-115 (Robert J. Art & Kenneth J. Waltz eds., 2009) (discussing the restraints imposed by all-out mutual destruction, where nuclear deterrence facilitates mechanisms for maintaining the status quo).

[42] *See generally* THOMAS GRAHAM, JR., DISARMAMENT SKETCHES: THREE DECADES OF ARMS CONTROL AND INTERNATIONAL LAW (2002) (chronicling the U.S. arms control and disarmament policymaking process during the late twentieth century).

[43] There are limits, of course, to this analogy. Arms control and SAI differ with respect to the number of interested parties, the perceived significance of the stakes involved, and other situational characteristics.

[44] For some of the major works in the area, see generally Abram Chayes et al., *Managing Compliance: A Comparative Perspective*, *in* ENGAGING COUNTRIES: STRENGTHENING COMPLIANCE WITH INTERNATIONAL ENVIRONMENTAL ACCORDS 39 (Edith Brown Weiss & Harold K. Jacobson eds., 1998); Abram Chayes & Antonia

coordination and effective international governance. By using these policy levers, interested parties are able to overcome precisely those kinds of obstacles that currently impede global cooperation on SAI. International management theorists cite three strategies as key to solving interdependence problems. Persuasion helps redefine national interests so that states favor international cooperation. Pressure brings national policies into alignment with harmonious interests. Finally, provision of assistance enables states to pursue policies that are compliant. Together, these "three Ps" are the main instruments by which noncompliance is ameliorated and governance regimes are made successful.[45]

In the case of free trade, for example, the international community has systematically dismantled trade barriers through a process of negotiation, pressure, and dispute resolution conducted in successive rounds of the General Agreement on Tariffs and Trade (GATT) and World Trade Organization (WTO).[46] The problem of littoral state territoriality and control has been largely resolved through the Exclusive Economic Zone (EEZ) construct developed and institutionalized under the United Nations Law of the Sea (UNCLOS).[47] As noted above, numerous arms control agreements based on explicit bargains and robust monitoring and verification have mitigated the risk of a nuclear arms race. Stratospheric ozone depletion has been arrested through interstate learning, regulation, and capacity assistance in the context of the Montreal Protocol.[48]

In the case of SAI, the strategy required to achieve cooperative, multilateral implementation of climate intervention technologies is persuasion. Persuasion consists of efforts to alter conceptions of interest so that actors are motivated to behave in ways that support successful outcomes. Learning may be central to the process of redefining interests. The objects of persuasion may include not only governments, but also private firms, which are often the ultimate targets of international regulation, as well as large societal groups whose beliefs and preferences can prove critical to regime performance. Implicit in arguments about the efficacy of persuasion as a problem-solving strategy is a conception of interests as constructed, subjective, and amenable to change.

Handler Chayes, THE NEW SOVEREIGNTY: COMPLIANCE WITH INTERNATIONAL REGULATORY AGREEMENTS (1995); INSTITUTIONS FOR THE EARTH: SOURCES OF EFFECTIVE INTERNATIONAL ENVIRONMENTAL PROTECTION (Peter M. Haas et al. eds., 1993); MANAGING GLOBAL ISSUES: LESSONS LEARNED (P.J. Simmons & Chantal de Jonge Oudraat eds., 2001); RONALD B. MITCHELL, INTENTIONAL OIL POLLUTION AT SEA: ENVIRONMENTAL POLICY AND TREATY COMPLIANCE (1994); Raimo Vayrynen, *Norms, Compliance, and Enforcement in Global Governance*, *in* GLOBALIZATION AND GLOBAL GOVERNANCE 25 (Raimo Vayrynen ed., 1999); Oran R. Young, *The Effectiveness of International Institutions: Hard Cases and Critical Variables*, *in* GOVERNANCE WITHOUT GOVERNMENT: ORDER AND CHANGE IN WORLD POLITICS 160 (James N. Rosenau & Ernst-Otto Czempiel eds., 1992); Oran R. Young & George J. Demko, *Improving the Effectiveness of International Environmental Governance Systems*, *in* GLOBAL ENVIRONMENTAL CHANGE AND INTERNATIONAL GOVERNANCE 229 (Oran R. Young et al. eds., 1996).

[45] Some analysts also cite the importance of clear rules and informational transparency in helping resolve international problems. However, empirical support for these propositions is mixed. *See* Joshua B. Horton, Controlling the Wildlife Trade: CITES, Regime Effectiveness, and the Global Market for Wildlife Products (Aug. 2006) (unpublished Ph.D. dissertation, Johns Hopkins University) (on file with Eisenhower Library, Johns Hopkins University).

[46] *See generally* THOMAS O. BAYARD & KIMBERLY ANN ELLIOTT, RECIPROCITY AND RETALIATION IN U.S. TRADE POLICY (1994) (examining, in part, the effects of various countries' unilateral attempts to open foreign markets).

[47] Scott J. Shackelford, *The Tragedy of the Common Heritage of Mankind*, 27 STAN. ENVTL. L.J. 101 (2008).

[48] *See generally* RICHARD ELLIOT BENEDICK, OZONE DIPLOMACY: NEW DIRECTIONS IN SAFEGUARDING THE PLANET (1991) (analyzing the policymaking and diplomatic process that led to the 1987 Montreal Protocol and its implementation).

In order to move toward deployment, major powers must regard geoengineering as serving their national interest. In the case of stratospheric aerosols, leading states must come to view injections as a necessary complement to carbon reductions. Without consensus on the need for intervention, there is little value in pressing for more robust action. And, capacity does not present any serious obstacles. Indeed, an abundance of capacity in the form of available technologies such as aerosol injections represents a key structural imperative supporting global collective action, as it increases the likelihood of discordant deployments and mutual interference.

Persuading governments to rethink their interests and recast their policies is, of course, a daunting challenge. National interests may be malleable, but they are typically entrenched and taken for granted.[49] Although knowledge of geoengineering remains limited, and international opinion is inchoate, there exists unmistakable latent hostility to climate engineering in most national governments.[50] Opposition may become further entrenched as the variable distributional effects of climate change become clearer.[51] For example, Russia may prefer the improved agricultural productivity and greater accessibility linked to global warming to previously less hospitable conditions across the bulk of its landmass.[52]

However, such positions may be more amenable to change than commonly supposed. At an April 2009 geoengineering workshop in Lisbon held under the auspices of the International Risk Governance Council (IRGC), representatives from the United States (U.S.), Canada, European Union (E.U.) member states, Russia, China, and India all expressed some degree of openness to the goals of climate intervention.[53] Significantly, the world's first aerosol field trial was conducted in Russia in 2009,[54] led by scientists with very close links to Russian government officials including Prime Minister Vladimir Putin.[55] China engaged in weather modification while hosting the 2008 Summer Olympics.[56] Russia, China, and Japan all raised concerns about the wisdom of the recent CBD moratorium.[57]

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[49] *See generally* ALEXANDER WENDT, SOCIAL THEORY OF INTERNATIONAL POLITICS (1999) (applying sociological, "constructivist" theory to international relations).

[50] *Cf.* SCIENCE & TECHNOLOGY COMMITTEE, THE REGULATION OF GEOENGINEERING, 2009-10, H.C. 221-5, at Ev. 4 (U.K.) (Memorandum submitted by Jason Blackstock, entitled *The International Politics of Geoengineering Research*, noting that "preexisting mistrust on global climate issues" warrants taking additional steps "to foster international confidence and cooperation" with regards to the deployment of national SRM programs).

[51] *See* Joshua W. Busby, *Climate Change and National Security: An Agenda for Action*, 32 COUNCIL SPECIAL REP. 1, 4-10 (2007), *available at* http://www.cfr.org/climate-change/climate-change-national-security/p14862 (discussing, in part, the various potential effects of climate change).

[52] *But see* Samuel Charap, *Russia's Lackluster Record on Climate Change*, 79(10) RUSS. ANALYTICAL DIG. 11, 12 (2010) (citing studies showing that global warming will have a net zero effect on Russian agriculture, and that Russian agriculture would be unlikely to take advantage of any gains anyway).

[53] M. GRANGER MORGAN & KATHARINE RICKE, INTERNATIONAL RISK GOVERNANCE COUNCIL (IRGC), OPINION PIECE FOR THE IRGC: *COOLING THE EARTH THROUGH SOLAR RADIATION MANAGEMENT: THE NEED FOR RESEARCH AND AN APPROACH TO ITS GOVERNANCE* 16-17 (2010), *available at* http://www.irgc.org/IMG/pdf/SRM_Opinion_Piece_web.pdf.

[54] *See* Yu A. Izrael et al., *Field Experiment on Studying Solar Radiation Passing Through Aerosol Layers*, 34 RUSS. METEOROLOGY AND HYDROLOGY 265 (2009).

[55] *See* ELI KINTISCH, HACK THE PLANET: SCIENCE'S BEST HOPE—OR WORST NIGHTMARE—FOR AVERTING CLIMATE CATASTROPHE 1 (2010).

[56] Andrew Jacobs, *China Hopes, and Tries, for Rain-Free Festivities*, N.Y. TIMES (Sep. 30, 2009), http://www.nytimes.com/2009/10/01/world/asia/01rain.html.

[57] *See* Masahiro Sugiyama & Taishi Sugiyama, *Interpretation of CBD COP10 Decision on Geoengineering* , SERC DISCUSSION PAPER 10013, 1, 8-9 (2010), *available at* http://criepi.denken.or.jp/en/serc/research_re/10013.html.

In the U.S., John Holdren, chief science advisor to President Barack Obama, famously noted in a 2009 interview on geoengineering: "It's got to be looked at. We don't have the luxury of taking any approach off the table."[58] Holdren broached the subject again at a recent international conference on science and science policy.[59] Several official and semi-official reports on geoengineering, including those issued by the Government Accountability Office (GAO)[60] and the House Committee on Science and Technology (in collaboration with the House of Commons Science and Technology Committee),[61] have been published in recent months, and a report from the National Commission on Energy Policy (NCEP) is set to be released shortly.[62] Small geoengineering research programs have been established in the United Kingdom (UK) and Germany, the latter with EU funding support.[63]

While these and other countries have indicated a willingness to explore the concept of geoengineering, none has called for actual deployment. Such a decision depends on a multiplicity of factors, not the least of which is public opinion. Experience indicates that people are generally unaware of geoengineering and their views on technologies such as SRM remain largely unformed. The UK Natural Environment Research Council (NERC) recently sponsored preliminary research into public attitudes toward geoengineering.[64] Most participants in the study signaled openness to the idea of climate intervention so long as it is linked to ongoing mitigation efforts.[65] A more thorough understanding of public opinions on geoengineering will shed light on the cultural contexts in which national decisions will be made.[66]

VI. IMPLICATIONS FOR GEOENGINEERING

This article has argued that the threat of unilateral deployment so often ascribed to SAI geoengineering is unsubstantiated. Instead, SAI is characterized by a logic of multilateralism,

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[58] Alok Jha, *Obama Climate Adviser Open to Geo-Engineering to Tackle Global Warming*, GUARDIAN (Apr. 8, 2009, 22:42 BST), http://www.guardian.co.uk/environment/2009/apr/08/geo-engineering-john-holdren.

[59] John P. Holdren, Assistant to the President for Sci. & Tech. and Dir., Office of Sci. & Tech. Policy, Climate-Change Science and Policy: What Do We Know? What Should We Do?, Address Before the Kavli Prize Symposium: International Cooperation in Science (Sept. 6, 2010), *available at* http://www.whitehouse.gov/sites/default/files/microsites/ostp/jph-kavli-9-2010.pdf.

[60] *See* U.S. GOV'T ACCOUNTABILITY OFFICE, GAO-10-903, CLIMATE CHANGE: A COORDINATED STRATEGY COULD FOCUS FEDERAL GEOENGINEERING RESEARCH AND INFORM GOVERNANCE EFFORTS (2010).

[61] *See* ENGINEERING THE CLIMATE: RESEARCH NEEDS AND STRATEGIES FOR INTERNATIONAL COORDINATION, H.R. REP. SERIAL NO. 111-A (2010), *available at* http://www.gpo.gov/fdsys/pkg/CHRG-111hhrg62619/pdf/CHRG-111hhrg62619.pdf.

[62] *See* Juliet Eilperin, *Threat of Global Warming Sparks U.S. Interest in Geoengineering*, WASH. POST (Oct. 3, 2010, 6:04 PM), http://www.washingtonpost.com/wp-dyn/content/article/2010/10/03/AR2010100303437.html.

[63] Eli Kintisch, *With Emissions Caps on Ice, Is Geoengineering Next Step in D.C. Climate Debate?*, SCIENCE INSIDER (Sept. 27, 2010, 5:31 PM), http://news.sciencemag.org/scienceinsider/2010/09/with-emissions-caps-on-ice-is.html.

[64] IPSOS MORI, EXPERIMENT EARTH? REPORT ON A PUBLIC DIALOGUE ON GEOENGINEERING 1 (2010), *available at* http://www.nerc.ac.uk/about/consult/geoengineering-dialogue-final-report.pdf.

[65] *Id.* at 53-54.

[66] One effort currently underway is the SRM Governance Initiative (SRMGI), organized by the Royal Society, TWAS (The Academy of Sciences for the Developing World), and the Environmental Defense Fund (EDF). Launched in 2010, the SRMGI project is intended to foster a broad discussion on geoengineering and associated governance issues among stakeholder groups from around the world. The project is focused specifically on governance issues related to SRM research, and its backers intend to release consensus recommendations on research governance arrangements sometime in 2011. For more, see www.srmgi.org.

which renders problems associated with deployment manageable by means of familiar diplomatic tools. Several points follow from this conclusion.

First, the prospects for international cooperation on SAI are brighter than is generally believed. Although conventional wisdom is preoccupied with the notion of states "going rogue," a close examination of the incentive structure facing states interested in SAI reveals that the playing field is tilted in the direction of multilateral collaboration. In the case of SAI, successful deployment depends on close coordination with other countries' climate mitigation and intervention policies. Such deployment exhibits a benign, rather than malign, problem structure, with a corresponding improvement in the likelihood of an effective global partnership to implement climate intervention technologies.

Second, comparisons between SAI deployment and nuclear proliferation are inapt. SAI presents a relatively tractable problem, whereas the issues associated with proliferation are more difficult to resolve given underlying incentives. Emissions reduction shares more in common with nuclear proliferation, as its record makes clear. In turn, SAI shares more in common with arms control, widely regarded as a model of international cooperation and regime performance. Put simply, nuclear proliferation is a poor analogue for SAI, and any attempts to make this connection do not spring from reasoned analysis. If anything, viewing SAI through the lens of nuclear security inspires confidence in our capacity to establish successful governance arrangements.

Third, recognizing SAI as relatively manageable brings into sharper focus a plausible strategy to promote geoengineering. Persuading countries to alter their interests is no simple task, yet the international record is replete with such instances. The principal challenge to successful deployment is not institutional design, but rather convincing interested parties that climate intervention must be an essential complement to emissions reduction strategies. Recent developments suggest that global opinion is beginning to shift in this direction. A short time ago, geoengineering was regarded as a fringe, even taboo subject, yet it has quickly gained attention, exposure, and credibility. If geoengineering attains legitimacy, its prospects as a critical tool in the fight against climate change will further improve, and systemic attributes will favor multilateral SAI deployment.

While there are many risks associated with SAI geoengineering, and it is important that they not be overlooked, it is equally important that research not be obstructed by unfounded fears. Unilateral deployment constitutes one such fear. The perceived threat of unilateral SAI has loomed large over discussions of climate interventions, inhibiting debate and discouraging legitimate scientific inquiry. This article has attempted to expose this threat as myth, and to demonstrate the multilateral bias inherent in SAI. This logic of multilateralism in no way guarantees global collaboration on SAI, but it does suggest strategies for achieving consensus and cooperation. With success contingent on cooperation, it is time to dispense with fears that impede efforts to address climate change on a comprehensive, informed, and timely basis.