SOLAR RADIATION MANAGEMENT

AN EVOLVING CLIMATE POLICY OPTION

LEE LANE, HUDSON INSTITUTE

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Executive Summary

Measures to reduce greenhouse gas (GHG) emissions have long dominated public discourse about responses to man-made climate change. However, major institutional and political hurdles dim future prospects for controlling emissions. While adaptation to climate change can accomplish much, flawed institutions are likely to limit its efficacy.

Solar radiation management (SRM) appears to promise at least some capacity to offset the warming caused by the rising atmospheric GHG concentrations. SRM would seek to enhance and manage physical processes that currently reflect sunlight back into space. For example, most researchers have envisioned implementing this concept by adding to the layer of sulfuric acid that is already present in the lower stratosphere. All else remaining equal, global mean temperatures would fall even though GHG levels would not; the Intergovernmental Panel on Climate Change estimates that physical processes such as these already offset about 40 percent of global warming. By lessening the rise in temperature, SRM might lessen some of the risks of global warming.

Recent technical developments have advanced our understanding of important aspects of SRM. First, the regional impacts of SRM will be variable and these differences are likely to become a source of disagreement regarding SRM deployment. Second, given the uncertainties about SRM technologies, there is a pressing need for research and development funding. Third, in contrast to GHG control, SRM may offer a cost-effective way of managing the risk of crossing climate tipping points.

The debate over SRM continues to evolve slowly. Two trends are visible. First, climate change as an issue has lost political salience. Second, SRM's visibility has been rising. The greater focus on SRM has led to a growing debate about its proper governance. So far, only a very narrow range of experts and interests have joined this debate. Even so, no consensus seems to be at hand. Disagreement exists even among environmental advocacy groups.

The economic benefits of a successful SRM program would flow from a reduction in climate damages owing to warming, and a reduction in economic damage caused by GHG controls. Determining the optimal amount of GHG controls to implement in the presence of SRM is an ongoing research effort. Some argue (1) that SRM should be held in reserve and only used in the case of an "emergency," which is never precisely defined, and (2) that no change should be made to plans for emissions reductions such as they are. Others suggest that SRM may augment an emissions reduction program by providing near-term benefits and risk reduction while low-carbon energy sources are developed.

SRM's precise value remains uncertain; however, it seems clear that its potential benefit is very large—on par with the damages brought by climate change itself. In other words, if climate change is a significant problem, then SRM could be part of a significant solution.

The incentives for using SRM appear to be stronger than those for GHG control. Much analysis has used this valid point to conjecture that SRM would be easy to deploy—indeed, that it would be too easy. This fear is largely misguided. Global power politics militate against any state bidding for sole control of an SRM system.

In short, SRM remains a speculative option; nonetheless, a workable SRM system could offer a highly useful backup and supplement to current policy options.

1

The Vexed Political Economy of Climate Policy

Until the quite recent past, measures to reduce greenhouse gas (GHG) emissions dominated public discourse about responses to man-made climate change. However, 20 years of efforts to curb these emissions have achieved little. Today, the prospect of an effective GHG control policy remains far in the future, and actual impacts on climate much more distant still.

Grudgingly, public discourse has begun to accept the need to adapt to climate change. Yet this response also has limits. The costs of adapting to climate change are likely to rise steeply if the change is too rapid or too large. Moreover, in the societies that have the greatest need to adapt, institutions may severely hobble the effort.

Solar radiation management (SRM) is a family of technologies that might be thought of as a tool for lessening the burden of adapting to climate change. Were SRM to prove feasible, it could decrease the change in climate that would result from a given increase in atmospheric GHG levels. It would, therefore, slow the rate of climate change. As a result, both the harm from climate change and the costs of adapting to it would fall. Finally, less risk of harm and less need to adapt would allow for a more gradual move toward low GHG technologies. At present, though, SRM concepts are promising, but unproven.

1.1. GHG Control and Energy Technology Push

Efforts to limit GHG emissions have taken two forms. The more talked-about approach has stressed pricing or regulating emissions. A subsidiary approach uses subsidies and mandates to promote the development and use of technologies that are deemed to lessen emissions. Both approaches face major institutional and political hurdles; neither currently ranks high on the priorities of the world's major powers.

1.1.1. GHG Controls

Halting climate change through GHG control would be a daunting task. Success would require that yearly man-made GHG emissions not exceed the amount of these gases that natural processes remove from the atmosphere. To stabilize GHG concentrations at 550 parts-per-million carbon dioxide (CO_2), by mid- to late-century, global emissions would have to shrink to roughly 20 percent of business-as-usual projections.[1] Moreover, while optimally designed GHG control policies that allow 2.5–3.5 degrees Celsius of warming may produce net benefits, aggressive GHG control targets produce worse results than no policy at all.[2] But if policies are not carefully designed solely to maximize cost-effectiveness, net benefits can easily become net costs.[3] An effort to produce a welfare-enhancing GHG control policy, were it ever attempted in earnest, would constitute a global social-engineering project of matchless scale and daring.

Experience to date is certainly not encouraging about future prospects. The global effort to curb GHG emissions was announced in 1992 with the signing of the United Nations Framework Convention on Climate Change (UNFCCC) and the Rio de Janeiro Earth Summit. Since that year, diplomatic activity has been intense and sustained. Conferences of the parties of the UNFCCC have taken place on at least a yearly basis. The G8, the Asian Pacific Forum, and the Major Economies Forum have also all launched talks on GHG control. A subset of UNFCCC parties has adhered to the Kyoto Protocol, and a minority of those parties has accepted GHG reduction targets. Even among these countries, though, the United States refused to ratify the agreement, and Canada, Japan, New Zealand, and Russia have declined to renew it. For its part, the European Union (EU) has put in place a GHG emission trading scheme.

The impact on emission levels has been marginal at best. Between 1990 and 2009, global emissions of CO_2, the most important man-made GHG emission, grew by more than 38 percent; the growth would have been greater still had it not been for the severe recession at the end of the period.[4]

Most of this emissions growth has taken place in countries that are not members of the Organisation for Economic Co-operation and Development (OECD). The large Asian economies have led the way in this trend. If these countries' economic growth continues, their emission levels also seem destined to continue rising.

Washington has long insisted that US action on GHG control hinges on the acceptance of effective controls in China, India, and other non-OECD countries. All of the most important of these countries have resolutely rejected such demands. The large Asian states refuse to adopt binding GHG control limits. Beijing has not wavered in this stance, nor is it expected to.[5] Delhi's position is much the same.[6]

In both China and India, the government's position conforms to its political imperatives; hence, neither country is likely to reverse its position on this point. The legitimacy of the Chinese Communist Party's rule rests mainly on the rapid rise of gross domestic product (GDP). In India, the same metric strongly influences success and failure in the contest for public office. Furthermore, economic growth builds the capital with which to adapt to climate change and cope with whatever harm it causes. China and India may therefore be wise in preferring GDP growth to GHG control.[7] In any case, through the near- and mid-term, neither government is likely to adopt costly GHG control measures.

Side payments to China and India might break this deadlock, but few if any countries have both the motive and means to make such payments. The countries with the most to gain from GHG controls are those that are poor and have tropical climates. Those countries, though, are so poor that they lack the means to cover the costs of abatement. The United States might be better able to pay, but its motives for doing so are weak. The United States captures only 7 to 10 percent of the total benefits from abating an added tonne of CO_2.[8] In fact, the US capacity to adapt to climate change exceeds China's, and it greatly exceeds India's.[9] By inference, an effective GHG accord can only be implemented if both Beijing and Delhi determine that its benefits to them justify the costs that those countries would incur.

1.1.2. Energy Technology Push

From its start, the Obama administration has sought to subsidize and mandate the use of "green energy." After its cap-and-trade bill failed, that approach became the main thrust of US climate policy. The hope is that as renewable and other green energy technologies are deployed, their costs will fall. As green energy sources become less costly, emission controls may become politically more palatable or even superfluous.

However, achieving the needed cost reductions poses formidable challenges. Existing technologies are too costly to compete broadly with fossil fuels. Existing renewable energy sources are also subject to many constraints that limit their scale. Incremental improvements to them will not suffice to stabilize GHG concentrations. Stabilizing GHG levels at realistic costs seems certain to require breakthrough technologies.[10]

Without a push from public policy, for-profit firms are unlikely to supply the desired innovations. Imitators can often copy a product or process that is based on the discovery of new useful knowledge. Therefore, in competitive markets, anticipated future prices may fall short of levels needed to recoup the costs incurred in discovery; for-profit firms, therefore, tend to invest in innovation at less than socially optimal levels.[11] This investment shortfall becomes larger as innovation moves from basic research to concrete application.[12]

Not even enacting a carbon tax would cure this second kind of market failure. Such a tax might correct markets' failure to account for the potential harm from GHG emissions. It would not, however, correct for their tendency to invest too little in finding innovative ways to curtail emissions.

Economic conventional wisdom has, therefore, favored policies designed to increase the investment in the kinds of innovations that seem likely to lead to technologies that would lower GHG output. The United States and many other countries have adopted policies that purport to foster innovation of this kind. Today, US policy places little stress on directly reducing GHG emissions. Instead, it mainly focuses on rent seeking and energy security.[13] While costly, such policies are unlikely to have much impact on global climate.

The root problem is that US officials' incentives push them to adopt energy research and development (R&D) policies that are likely to produce little useful innovation per dollar spent. Officials seeking reelection tend to back policies that benefit voters and campaign contributors in time to motivate their support in the next election; in contrast, R&D tends to involve long lead times. With the eventual benefits of R&D being politically irrelevant, to office holders, the rewards of backing R&D are the jobs and revenues that it requires.[14]

These perverse incentives push office holders to structure R&D programs inefficiently. For instance, the payoffs to basic research lie far in the future. The payoffs may also be widely diffused; in contrast, demonstration projects and deployment subsidies generate jobs and revenues much sooner and in ways that the beneficiaries can readily identify. Not surprisingly, office holders prefer the latter to the former.[15] The existing pattern of energy spending conforms closely to what one might expect given the political incentives at work. In FY 2010, less than 12 percent of federal energy subsidies were allocated for R&D.[16]

The pork-barrel nature of R&D spending is also clear in the lack of coherence. Indeed, the Obama administration's energy spending, like the Bush-era Energy Independence and Security Act of 2007, could be described as "a dizzying array of tax incentives for specific types of energy, authorizations of funding for energy programs, and establishment of new programs and goals without any unifying objective."[17] All in all, programs of this type display low cost-effectiveness.

Proponents of energy innovation as a solution to climate change may devise institutions that would, were they adopted, cure some, or even all, of the defects of the current programs. As yet, though, proponents have found no way to persuade those in power to sacrifice their interests in the name of future progress in GHG control. As long as the institutions that create these political incentives remain in place, one would not expect future efforts to produce more success than those that have come before.

1.2. Adapting to Climate Change

Throughout history and prehistory, human beings have continuously adapted to changing climates. The dim prospects for GHG control imply that adaptation is likely to be the main strategy for limiting the costs of man-made climate change. That is, as the climate changes, people will seek to exploit new opportunities and avoid potential costs. This process will involve adapting customs, dress, crops, structures, locations, and practices to a changing climate and its effects. Yet adapting to climate change is also subject to limits. While still speculative, SRM shows promise as a means of lightening the task of adapting to climate change.

1.2.1. Strengths of Adaptation

Adaptation offers many potential advantages. In becoming more resilient to climate change, societies are more likely to increase their ability to cope with other sorts of challenges; to a degree, they will also be able to trade off these changes against the need for GHG control.[18] Much adaptation may take place at the individual level. Even adaptation that requires public-sector action can be undertaken by a single country. Some scholars therefore maintain that implementing adaptation policies is less problematic than effective GHG control.[19]

But the efficacy of adaptation is likely to vary from place to place. This variance partly reflects differences in climate and local conditions. For instance, unlike much of the agriculture in temperate climates, for agriculture in tropical countries, low-cost adaptation measures may not be able to offset the potential harm from climate change.[20] The depth of a country's capital stocks also affects its capacity to adapt to climate change. Finally, institutions will be a key to adaptation.

For markets to be efficient, the state must define secure property rights and enforce contracts. Markets, in turn, enable the use of exchange, which can be a potent tool for coping with climate change and climate variability.[21] Other public goods, such as infrastructure, may also be important to adaptation.

Over and above these direct links between institutions and adaptation, there is also a powerful indirect connection. Institutions heavily influence a society's per capita income.[22] This link matters a great deal. All else being equal, richer societies will adapt to climate change more easily than will poorer ones. High-income countries have more human, financial, and physical capital to deploy in efforts to cope with change and variability. They also have more resources on which to fall back.

Viewed in the abstract, adaptation would be able to limit residual climate change impacts to minimal levels. The harmful effects that do persist, though, would be unevenly distributed, and some of them might impose high costs. According to Adger and colleagues: "Large inter- and intra-regional variations were reported. In particular, for many countries located in tropical regions, the potential benefits of low-cost adaptation measures such as changes in planting dates, crop mixes, and cultivars are not expected to be sufficient to offset the significant climate change damages."[23]

1.2.2. Adaptation's Limits

By inference, adaptation's main drawback is that it is likely to perform least well where it is most needed. Namely, poor countries in the tropics are likely to face the greatest challenge in adapting to a warming climate, yet, being poor, they lack the human, financial, and physical capital with which to cope with climate change. Moreover, such countries tend to be poor, in no small measure because their governments often exact more from them in economic rents than they provide in public goods; worse still, to extract rents, their governments often distort key markets.[24] For these countries, therefore, neither their governments nor their major markets are well structured to support cost-effective adaptation.

Increasingly, global climate talks have begun to focus on demands for financial transfers designed to aid these countries in their efforts to adapt to climate change. For over 60 years, Western governments have been providing development aid to the countries facing these challenges. By and large, the aid has failed, largely because, as just noted, governments receiving the aid are inefficient, predatory, or both.[25] Furthermore, aid itself allows those in power to pay even less heed to the productivity of their people.[26]

International donors have responded to this conundrum by trying to use aid as a lever to effect institutional reform. However, such attempts meet stiff resistance. They threaten the power of local elites, and elites often fiercely resist any diminution in their own power. In fact, weakening elite control can also sometimes cause public order to breakdown. As a result, non-elites may also cling to the status quo.[27]

These past failures of development aid are likely to foreshadow the fate of today's plans to aid poor countries seeking to adapt to climate change. As with development, the central problem is the institutions in the countries receiving aid. And the supporters of adaptation aid are already noting the strength of the resistance to reform: "In many parts of the world where democratic traditions are less prevalent and where rigid forms of human interaction have evolved to maintain power differences, changes in governance systems can be neither willed nor mandated."[28] Changing the rhetoric of aid to stress climate change will not improve the outcomes.

Then too, donor countries are gradually becoming more wary. In 2009, at the Fifteenth Conference of Parties of the UNFCCC in Copenhagen, the developed nations promised a large tranche of aid for this purpose. Soon after the promises had been made, though, large shortfalls appeared between the amounts promised and those delivered.[29] The plain fact is that the donor countries' motives are weak. While climate change in poorer countries may cause some spillovers into richer countries, these threats are modest, indirect, and susceptible to other remedies.

1.3. Solar Radiation Management

A family of technologies known as solar radiation management (SRM) represents a possible "force multiplier" for adaptation efforts. SRM appears to promise at least some capacity to offset the warming caused by the rising atmospheric GHG concentrations.

SRM would reduce the amount of solar energy absorbed by the Earth. GHGs in the atmosphere absorb long-wave radiation (heat) and then radiate it in all directions. Some of the heat is radiated back to Earth's surface; as a result, surface temperatures rise. SRM would seek to reflect a small amount of the incoming short-wave radiation (sunlight) back into space. All else remaining equal, global mean temperatures would fall even though GHG levels would not.[30] By preventing some of the rise in temperature that would otherwise occur, SRM might lessen some of the risks of global warming.

At least two current SRM concepts appear to offer promise of significant benefits.[31] One of them contemplates injecting a fine aerosol into the stratosphere. Sulfur is the most studied material, but others are also under consideration. Several delivery methods have been suggested.[32] After perhaps a year or two, particles would fall to the surface. The quantities of sulfur to be injected are small compared to current emission levels.[33] The record of temperature decreases after several past volcanic eruptions suggests that the process could produce cooling on approximately the needed scale.[34]

The second approach involves lofting a fine seawater mist into low-level marine clouds. The added droplets would cause the clouds to "whiten," that is, to reflect more sunlight; it might also lengthen the lives of the clouds.[35] Climate models suggest that this approach might cool the planet enough to offset the warming caused by doubling atmospheric GHG levels.[36] The clouds that form in the wakes of ships at sea offer a natural analogue to the concept; one delivery option is to use a fleet of high-tech, autonomous ships to produce the spray.[37]

Both of these potential SRM technologies may hold great promise as a means of lessening the potential harm otherwise likely to follow from GHG emissions.

2

Technical Developments

Recent technical developments regarding SRM have centered on (1) understanding the effectiveness and safety of differing SRM approaches; (2) refining cost estimates for the research, development, and deployment of SRM; and (3) exploring how SRM may be able to augment emissions reductions measures by insuring against the possibility of significant warming or the crossing of tipping points in the climate system.

2.1. Potential Effectiveness of Solar Radiation Management

Stratospheric aerosol injection is the most discussed SRM method. Most researchers have envisioned implementing this concept by adding to the layer of sulfuric acid that is already present in the lower stratosphere.[38] This may be accomplished via the injection of a sulfuric acid precursor such as sulfur dioxide, or the direct dispersal of sulfuric acid. Scientists are currently exploring the best deployment strategy, while others are exploring the efficacy and safety of other scatters such as titanium dioxide.[39] Differing scatters will have different cost implications, owing to their different masses and dispersal requirements. The environmental impacts are likely to differ as well. For example, some scatters may absorb more heat than others, leading to a warming of the lower stratosphere. This warming could alter stratospheric chemistry and affect the ozone layer.

The effectiveness of SRM is measured by its direct effect on radiative forcing and its indirect effect on temperatures and precipitation. One may expect the direct costs, and possibly the indirect costs (changes in precipitation), to scale linearly with the mass of material injected into the stratosphere.[40] Early estimates based on data from volcanic eruptions have suggested that every million metric tonnes of sulfur (Mt-S) present in the stratosphere would reduce radiative forcing by 0.75 Watts per square meter (W m^{-2}).[41] Other modeling exercises have suggested efficiencies between 0.50 and 0.90 W m^{-2} per Mt-S.[42] More recent modeling work has found reductions in radiative forging of around 0.50 W m^{-2} per Mt-S.[43] Other researchers have found that titanium dioxide may be able to achieve the same efficiency with about one-third less mass than sulfur-based plans.[44]

The mass of sulfur that would have to be injected into the stratosphere depends on the injection strategy, the aerosol's reflectivity, and the aerosol's residence time. Pierce and colleagues found that one would have to inject about one Mt-S per year to create a sulfur burden capable of producing a negative forcing of about one W m^{-2}.[45] Offsetting a doubling of CO_2 would require an annual injection rate of approximately five Mt-S per year. Current anthropogenic emissions of sulfur total about 55 Mt, mostly as a result of coal-fired electricity production.[46]

As another point of comparison, consider the fact that the United Nations Intergovernmental Panel on Climate Change (IPCC) estimates that anthropogenic aerosol emissions (primarily sulfate, organic carbon, black carbon, nitrate, and dust) are *currently* providing a negative radiative forcing of 1.2 W m^{-2}.[47] The current net GHG radiative forcing is 1.6 W m^{-2}, including the negative forcing of aerosols; thus, aerosols currently offset over 40 percent of anthropogenic emissions. This forcing is divided into direct (0.5 W m^{-2}) and indirect (0.7 W m^{-2}) components. The direct component is a result of sunlight being scattered by the aerosol layer. The indirect component represents the aerosols' effect on cloud albedo. The two classes of SRM technologies that have received the most attention parallel this division are stratospheric aerosol injection and marine-cloud whitening.

The physical mechanisms underlying GHG warming and SRM differ. As discussed earlier, GHGs absorb short-wave radiation (sunlight) and reradiate long-wave radiation (heat) in all directions. Conversely, SRM seeks to reflect more short-wave radiation back into space. Because of these different modes of action, one should not expect that SRM could completely offset the effects of increasing GHG concentrations, either in terms of the climate properties affected (for example, temperature or precipitation) or geographically.

Current understanding suggests that SRM cannot, within a single region, simultaneously restore temperature and precipitation to their preindustrial levels. However, when averaged geographically around the globe, Moreno-Cruz and colleagues found that "SRM almost perfectly compensates for the temperature changes from rising [GHGs], but decreases precipitation relative to the [1990s] baseline."[48]

Regionally, just as GHGs cause some regions to warm more than others, SRM will cause some areas (such as high-latitude regions) to cool more than others.[49] These geographical differences are likely to be a source of disagreement regarding any SRM implementation. What is more, SRM could result in some regions being worse off than they would have been under unabated climate change. This issue appears most prominent in Western Africa and Eastern Asia.[50] However, SRM may still be able to deliver a Pareto-optimal improvement in all regions. For example, if one implements SRM only to the point where Western Africa is no worse than it would have been under unabated climate change, SRM may still be able to offset over 50 percent of the damages caused by GHG warming.[51] This finding led Moreno-Cruz to conclude that "contrary to what has been suggested previously in the SRM discourse, a globally optimal level of SRM can compensate for a large proportion of damages at a regional level."[52]

2.2. Estimated Costs of Solar Radiation Management

Researchers continue to refine their estimates of SRM's deployment costs. Early work estimated that stratospheric aerosol injection would cost about $20 billion for each W m^{-2} of negative forcing.[53] This estimate was based on rough assumptions of aerosol forcing efficiency, aerosol residence times, and a 1992 National Academy of Sciences study that nominally assumed the use of naval artillery.[54] More recent estimates have found that it would cost between $5 and $8 billion per year to offset one W m^{-2} of forcing.[55] This estimate implies that for an annual cost of approximately $20 to $32 billion, it would be possible to counter the energy imbalance caused by a doubling of CO_2 emissions (3.8 W m^{-2}), which—as McClellan, Keith, and Apt note—would be less than 1 percent of the cost of CO_2 mitigation measures.[56]

Since SRM technologies have not yet been developed and many significant uncertainties remain, the most immediate need is funding for R&D. Estimates suggest that a 10-year R&D effort would cost roughly $0.5 billion.[57] For comparison, today, the US federal government is spending about $16 billion a year on climate-change science and related technologies.[58] Caldeira and Keith's spending estimates exceed those made by a 2001 George W. Bush administration interagency panel on R&D for climate engineering. That panel devised a plan based on a gradually rising budget with a total five-year cost of $98 million.[59] This program was not funded.

2.3. Solar Radiation Management and Tipping Points

While early discussions of SRM centered on reducing the harm from gradual warming, more recent discussions have centered on the risk-management role that SRM may play. For example, a 2009 workshop explored the use of SRM to respond to climate emergencies, such as the possible irreversible loss of Arctic and Antarctic Sea and land ice.[60]

Given the speed with which aerosols act on the climate system, they may be particularly well suited to serve as an "insurance policy" against rapid or extreme warming scenarios. In fact, it seems likely that only SRM could play this role. As Lenton and Vaughn note:

> It would appear that only rapid, repeated, large-scale deployment of potent shortwave geoengineering options (e.g., stratospheric aerosols) could conceivably cool the climate to near its preindustrial state on the 2050 timescale.[61]

One study investigated the use of SRM to manage the risk of tipping points in the climate system.[62] It demonstrated that emissions reductions are likely to be a very expensive way of addressing this particular dimension of climate-change risk. This is true because emissions reductions seek to reduce the probability of exceeding all temperature levels—moderate-to-extreme warming. However, owing to our great uncertainty regarding the sensitivity of temperatures to CO_2 concentrations, CO_2 emissions may need to be immediately eliminated to lower the probability of exceeding temperature changes that scientists have warned are dangerous to an acceptable level.

Reducing emissions to avoid the risk of large temperature increases is unlikely to be cost-effective.[63] SRM may offer another way of dealing with this particular aspect of climate change. If society had an SRM capability, it may be able to choose an emissions control regime that does not completely eliminate the risk of significant warming and then deploy SRM should this situation arise. Whether SRM could be used in this way is an area for further research.

3

Recent Institutional Developments

The debate over SRM continues to evolve, but it does so slowly. Two trends are visible. First, partly because of global economic woes and partly because of the failure of GHG control efforts, climate change as an issue has lost political salience. Second, as the lack of progress on GHG control has become harder to deny, the visibility of SRM has risen.

The greater focus on SRM has led to a growing debate about its proper governance. So far, only a very narrow range of experts and interests have joined this debate. Even so, no consensus seems to be at hand.

3.1. Climate Policy and the Loss of Agenda Space

Public discourse about SRM is evolving within the larger discussion about global issues in general and climate policy in particular. Amidst the prolonged global economic downturn, climate change has lost much of its salience. In Europe, the climate issue has largely disappeared from the public agenda.[64] In the United States, opinion polls show that worries about the environment have plunged to historic lows, and global warming ranks at the bottom of the list of such concerns.[65]

Factors beyond the impact of the economic downturn may also be at work in the climate issue's loss of salience. The great difficulties that bar the path to adoption of effective GHG control measures imply that, for holders of public office, work on climate policy is not a cost-effective way to curry favor with their selectorates. As political actors learn this lesson, their willingness to invest scarce resources in the issue is likely to wane.[66]

The record certainly confirms the low payoff to most work on climate policy, or at least to most work on GHG control. On the world stage, 2009 saw the Fifteenth Conference of Parties (COP15) of the UNFCCC in Copenhagen. COP15 was the first such summit in the post–George W. Bush era. Many backers of strong GHG control measures in Europe, the United States, and elsewhere expected it to lead to a diplomatic breakthrough. Instead, long-standing conflicts burst into full view. Neither of the two subsequent COPs has produced any sign of consensus. Attendance by world leaders and the news media has fallen off markedly.

In the United States in 2010, the Waxman-Markey cap-and-trade bill died in Congress. Later that same year, the election effectively removed the climate issue from the US public agenda. Since his reelection, President Obama may try to revive the issue. However, the Republicans also maintained control of the House of Representatives in 2012. This result suggests that for the next two years as well, major proposals on climate are unlikely to make their way into law. The one unlikely but not absolutely impossible exception may be a carbon tax, which conceivably might become part of a budget deal.

These results send distinctly mixed signals for the prospects of SRM. On the one hand, the futility of hopes for anything beyond very slow progress on GHG control has become hard to deny. As it has, the need to find a way to live with rising GHG levels has also become more evident. SRM should, as a result, attract more attention. To some degree, it has. On the other hand, economic concerns have thrust the entire climate issue into the background. The larger issue's loss of salience helps keep funding for SRM research at extremely low levels.

3.2. More Focus on Solar Radiation Management

While climate change has lost prominence as an issue, SRM has, to a degree, gained ground within the climate debate. The response is an obvious one. Even putting aside the matter of cost, if GHG controls are not an option and adaptation is an imperfect one, a search for something else is clearly called for.

As events have unfolded, SRM has gained greater attention. In 2010, a committee of the US House of Representatives conducted a series of hearings on the subject, and a committee of the British House of Commons undertook a parallel study.[67] Two research arms of Congress, the Congressional Research Service and the Government Accountability Office, have since released research reports. The latest *Pentagon Quadrennial Defense Review* mentioned the issue.

Within the last three years, major policy research organizations have also conducted studies, convened conferences, and published reports on the subject. Some of the larger efforts of this kind have been those of AEI, the Bipartisan Center, the Climate Institute, the Council on Foreign Relations, the Hudson Institute, the National Academy of Sciences, and the RAND Corporation.

At the international level, interest has increased at the IPCC. In June 2011, all three working groups of the IPCC conducted a joint workshop that covered SRM and other forms of climate engineering. That the next IPCC summary report will cover SRM at greater length than have previous reports seems certain.

The British Royal Society completed a geoengineering study that discussed SRM at some length. The Copenhagen Consensus Center has funded and published studies on SRM. It has also funded studies of other forms of geoengineering.

The British Royal Society, the Environmental Defense Fund (which is a US environmental non-government organization), and the World Academy of Sciences have launched the Solar Radiation Management Governance Initiative (SRMGI). The project released a discussion paper on the principles that might guide SRM governance. This statement paid the obligatory obeisance to the principle that SRM must not be used to replace GHG control. Thereafter, it largely contented itself with listing the pros and cons of various options for research and testing of SRM.[68]

In the United States, the Bipartisan Center created a taskforce that reported on SRM and CO_2 removal (CDR) options. The task force took a clearer and more positive stand. Its report urged the US government to launch SRM research as well as a second R&D effort aimed at exploring CDR options. After the ritual homage to the commandment that SRM must not substitute for GHG control efforts, the report explored a number of options for organizing both domestic SRM research programs and an international SRM research program.[69]

Between 2000 and 2011, media attention to geoengineering technologies grew steadily.[70] It seems likely that SRM drew much of this attention. Furthermore, a recent survey of public opinion in Britain, Canada, and the United States showed that 24 percent of respondents reported having heard of climate engineering; comparison with other survey results suggests that awareness may be growing.[71]

At the same time, public awareness of geoengineering is a fraction of that of most environmental issues. Thus, a recent US opinion poll found that less than 10 percent of the public could not or would not answer a question about the wisdom of policies to promote green energy.[72] By this standard, climate engineering is not really on the public radar screen.

3.3. Environmental Group Positions and Their Implications

Events to date provide only very hazy guidance as to how the future SRM issue might evolve. Nevertheless, some environmental non-governmental organizations (ENGOs) have taken ambivalent positions on SRM. Others have taken virulently negative ones. One inference is that ENGOs are relatively well positioned to again resort to coordinated strategic behavior in which some of the groups play “good cop,” some play "bad cop," and the target is subjected to a series of relentlessly escalating demands.

3.3.1. Good-Cop Environmental Groups

Unlike the situation in Europe, a few US ENGOs have avoided taking a purely negative stance on SRM. In addition to the ambiguous SRMGI report, executives from both the Environmental Defense Fund and the National Resources Defense Council took part as individuals on the report of the Bipartisan Center. Their ambivalence puts them at odds with the groups that candidly oppose all but the most limited forms of R&D into SRM.

This may, though, make tactical sense. Some ENGOs may find categorical rejection of SRM hard to reconcile with their rhetoric on the supposedly calamitous threat of climate change. For such groups, an equivocal position offers advantages. It avoids the appearance of inconsistency. At the same time, the ENGO continues to trumpet demands that SRM must not replace efforts to reduce GHG emissions. It can also insist on the principle that any research on SRM requires formal provisions for ENGO input. This proviso keeps open the option of disrupting progress with further demands about either procedures or substance.

In essence, groups that take this ambiguous stance are positioned to demand concessions for lending provisional support for research. At the same time, they retain the option of opposing the actual eventual use of SRM. Alternatively, they may simply choose to accept such use in principle but to place impossible-to-achieve conditions on it.

3.3.2. Bad-Cop Environmental Groups

Other ENGOs, as suggested, have campaigned actively to block research on all forms of climate engineering, including SRM. These groups include Greenpeace, Friends on the Earth, and the Eco-Systems Climate Alliance. Germany's EcoLogic Institute should probably be placed in this class as well. These groups demand that SRM progress only if it wins acceptance from every government on the globe. The costs for extortion that such a scheme would enable would, of course, throw the entire concept into great doubt, which is clearly the intent.

A small organization called the ETC Group has taken the lead in these efforts. The ETC Group also seeks to hobble genetic engineering and nanotechnology. It is headquartered in Canada; however, it derives much of its funding from left-wing US foundations such as the CS Fund, the HKH Foundation, and the Wallace Global Fund.

In 2010, the Nagoya Convention on Biological Diversity considered a draft resolution that would have condemned all forms of climate engineering. The African Group, the Philippines, Tuvalu, Venezuela, Bolivia, and Grenada supported a ban on research. Left-wing ENGOs such as the ETC Group instigated much of this effort. China, Japan, and Russia opposed the effort to stifle research; China did so forcefully.[73] The Nagoya meeting ended with a nonbinding compromise resolution. The resolution urged parties to ensure that no climate-related geoengineering activity that may affect biodiversity take place "except for small-scale research studies . . . in a confined setting."[74]

In September 2011, the EU Parliament, at the urging of a Greek socialist member, added an anti-geoengineering clause to its instructions to the EU delegates to the Rio+20 Earth Summit. The clause was number 90 of the instruction's 111 points. In the event, geoengineering became one of the very many issues on which the Rio+20 Earth Summit did nothing.

In the United Kingdom, ENGO pressure also played a role in cancelling the so-called Spice experiment. This experiment would have involved a very preliminary test of an SRM delivery technology. The plan had been to inject 150 liters of water into the atmosphere. The water would have been pumped through a one-kilometer pipe. The pipe would have been suspended from a weather balloon and tethered to a ship.

Friends of the Earth protested the experiment. The experiment, by its very nature, could have posed no direct risk to the environment. The ENGO's goal, therefore, could only have been to block the acquisition of knowledge about a technology that it opposes. The scientists who had planned the experiment claimed that issues other than an unwillingness to stand up to criticism were involved in their decision.[75]

3.3.3. Environmental Good-Cop/Bad-Cop Tactics

The events so far remain in the realm of symbolism. No current advocate for SRM research possesses even a modicum of wealth, institutional power, or popular support. Until that situation changes, the politics of SRM will remain embryonic. Future ENGO tactics can, nonetheless, be inferred from the groups' early stances and the patterns of their past behavior.

ENGOs commonly practice good-cop/bad-cop tactics. They do so consciously and with a high degree of tacit or open cooperation.[76] The ENGOs playing good cop support some limited research in exchange for a seat at the table for themselves and a high degree of public disclosure. Meanwhile, the bad-cop groups maintain a stance of opposition root and branch. The bad-cop groups exploit public disclosure of any problems or risks as grounds for all-out opposition. The good-cop groups will, in turn, exploit any signs of rising public opposition as a pretext for demanding added concessions.

ENGO good-cop/bad-cop tactics have typically been used against business firms. Nothing, though, precludes their use against a public-sector research effort. Indeed, the fragmented structure of US governmental institutions facilitates use of such tactics. It may also ensure that bad-cop ENGOs will have wide access to any information that could possibly subject them to a negative spin.

In Europe, state institutions possess more unity. There, however, ENGOs are politically more potent than they are in the United States. They are also more virulently opposed to SRM. It is an interesting question whether democratic forms of government can conduct an R&D program on a concept as polarizing as SRM is at the present time.

3.3.4. Environmental-Group Tactics and Solar Radiation Management Development

Sophisticated and coordinated action by ENGOs is likely to complicate any government R&D program designed to explore the option of SRM. ENGOs may oppose R&D on SRM unless the R&D is preceded by GHG control measures. Governments may respond by adopting new substantive GHG controls, adopting symbolic controls, abandoning the R&D, or defying the ENGO demands. The choice of the response will depend on the government's priorities. Currently, no government appears to place a high enough priority on SRM to pay the costs of researching it, let alone to pay a premium to placate ENGOs.

ENGOs are also likely to demand high levels of disclosure about any SRM R&D program. Granting some or all of these demands may produce some advantages. It may, for instance, provide useful oversight. Added scrutiny may help detect errors or shortcomings in the research program. It may also reassure both the domestic public and foreigners about the program's purpose, status, and safety.

A public oversight process would also entail added costs. ENGOs are masters at throwing up procedural roadblocks to impede the progress of programs with which they disapprove. An R&D program for SRM would already involve many agencies and great amounts of bureaucratic friction.[77] The more outside oversight that the process involves, the higher the transaction costs of managing the program are likely to be.

ENGO involvement entails special risks. The adversarial instincts of such groups may suit them to the role of avid whistleblowers, and this zeal may have some advantages. Yet the experience of ENGO lawsuits also shows that these groups are prone to allowing motives—such as publicity seeking, the quest to recruit new members, and the desire to please large donors—to override pursuit of public welfare.[78]

Moreover, these groups' motives dovetail with the news media's penchant for the sensational. These forces have often worked arm in arm to trigger bandwagon effects on public opinion. Public panics based on little or no evidence have often been the result. Such panics have imposed highly durable constraints on public policy.[79] On the matter's face, SRM seems quite susceptible to this kind of outcome. US political institutions may, however, be poorly suited to the task of resisting such panics.

4

The Economics of Climate Engineering

The economic benefits of a successful SRM program would flow from a reduction in climate damages owing to warming and a reduction in economic damage caused by GHG controls. Determining the optimal amount of GHG controls to implement in the presence of SRM is an ongoing research effort. Some argue (1) that SRM should be held in reserve and only used in the case of an "emergency," which is never precisely defined, and (2) that no change should be made to plans for emissions reductions, such as they are. Others suggest that SRM may augment an emissions reduction program by providing near-term benefits and risk reduction while low-carbon energy sources are developed.

In 2010, we estimated the economic benefit of a continuous SRM program when used in conjunction with varying emissions control regimes, ranging from no controls to a policy designed to limit warming to 2 degrees Celsius. We found that every $W\ m^{-2}$ of SRM accrued between $4 and $10 trillion in benefits. We did not, however, attempt to systematically quantify the damage that might be caused by SRM's use, with lessening precipitation being one prominent example.[80]

Another 2010 study allowed for the possibility of tipping points in the climate system. Crossing a tipping point was assumed to cause significant and permanent economic damage. Quantifying this cost is difficult, but the study assumed that crossing a tipping point caused a reduction of between 2.5 and 5.0 percent in gross world product (GWP). In this case, the study found that SRM could produce a benefit of tens of trillions of dollars.[81]

In 2012, we quantified the benefit of using SRM to hold temperature changes to 2 degrees Celsius at the most, which is a target advocated by many governments.[82] In addition, our study attempted to account for the negative side effects or the damage that might be caused by SRM use. Specifically, we assumed that SRM would cause economic and environmental damages that scale linearly with its use. We assumed that the use of SRM at a level sufficient to offset the forcing caused by a doubling of CO_2 emissions would lower GWP by between 0 and 3 percent.[83] As a point of comparison, a prominent economic model of climate change assumes that unabated climate change will cause damages of about 1.4 percent of GWP in 2065 when CO_2 concentrations are doubled. With these assumptions, we found that SRM may create net benefits between $1 and $10 trillion.[84]

An oft-stated concern regarding SRM use is that once SRM begins, significant costs will result if the program is later aborted. Goes et al. argued that this risk is so severe that the apparent benefits of SRM are an illusion.[85] However, they framed SRM's use in such a way that their conclusion was automatic. Specifically, they assumed that society could either implement very strong emissions controls (that is, a 25 percent reduction in global emissions by 2015 and a 40 percent reduction by 2020) or do nothing and use SRM to offset all energy imbalances.

Further, they assumed that if society does implement SRM and later has to halt the program, that it can take no further action (by implementing emissions controls, for example) and must suffer the consequences. Other authors relaxed these assumptions by assuming that SRM can be added to many different emissions control strategies. In this case, even an aborted SRM program could produce net benefits.[86] For example, using Goes and colleagues' assumptions, another study found that implementing SRM rather than doing nothing could produce net benefits even if SRM results in a 2 percent decrease in GWP (at a level sufficient to offset a doubling of CO_2 concentrations) and that this SRM program would be aborted, after which society could not react.[87] This is clearly an extreme scenario. Thus, while an aborted SRM program could lead to significant damages, it does not appear that this risk alone can negate the potential value of developing this capability.

It remains true, of course, that SRM will not address all costs attributable to CO_2 emissions. For example, SRM will not address ocean acidification, although other geoengineering measures might. The fact that SRM does not address every aspect of climate change is not a *cost* of SRM use, as some claim. Rather, reducing ocean acidification, for example, is a benefit of other approaches such as emissions reductions.

In short, while SRM's precise value is uncertain, it seems clear that its potential benefit is very large—on par with the damages brought by climate change itself. This logic is straightforward: if warming will result in large damages, then lessening warming could result in large benefits. In other words, if climate change is a significant problem, then SRM could be a significant solution.

5

Fears of Unilateral Solar Radiation Management

The incentives for using SRM appear to be stronger than those for GHG control.[88] Much analysis has leapt from this valid point to conjecture that SRM would be easy to deploy—indeed, that it would be too easy. Thus, some reports and articles have adopted a highly moralistic tone in which the supposed ease of SRM becomes a temptation to stray from the path of environmental virtue.

This fear is largely misguided. Concerns that the United States would be tempted into a hasty deployment of SRM are based on false analogies to the Second Gulf War. More broadly, global power politics militates against any state bidding for sole control of an SRM system.

5.1. Alarms over Unilateral Solar Radiation Management

Fears of unilateral action dominate the discussion of SRM governance. Often this action is assumed to be hasty. And the discussion is often tinged with moral censure, such as when the state pursuing SRM is assumed not to have "done enough" to control its own GHG emissions:

> 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 its interests that it should unilaterally engage in geoengineering. Although it is hardly wise to mess with a poorly understood global climate system using instruments whose effects are also unknown, politicians must take geoengineering seriously because it is cheap, easy, and takes only one government with sufficient hubris or desperation to set it in motion.[89]

In this view, yielding to SRM's potent but supposedly false allure will unleash many ills. For instance, the mere existence of an SRM option might weaken incentives for GHG control. As discussed previously, the purportedly especially dangerous case of start-and-stop SRM is a variant of this same worry. Then too, unsanctioned SRM may do harm: "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."[90]

In an even more extreme imagined dystopia, supposedly even a rich capitalist might unleash an SRM scheme: "Although governments are the most likely actors, some geoengineering options are cheap enough to be deployed by wealthy and capable individuals or corporations. Although it may sound like the stuff of a future James Bond movie, private-sector geoengineers might very well attempt to deploy affordable geoengineering schemes on their own."[91]

5.2. The United States, an Implausible Solar Radiation Management Rogue

One may wonder how the fear of "lone ranger" SRM became so prevalent. Much of the concern, at least in Europe, may center on fears that the United States might act alone on SRM. This fear seems to have affected European policy preferences much more than the apparently intractable governance problems that have so far rendered GHG control costly for those states that undertake it and largely ineffectual as a means of lowering global emissions. Despite the seeming sharpness of Europe's concerns about unilateral SRM, grounds exist for doubting its realism.

5.2.1. Fears of Unilateral Solar Radiation Management in Context

In general, Europeans have long fretted about unilateral US action. The end of the Cold War heightened these worries. Even before the Iraq invasion, European analysts distrusted US policy. Gilles Andreani summed up much of the sentiment. The United States, he wrote, "tends to emphasize military, technical and unilateral solutions to international problems, possibly at the expense of co-operative and political ones."[92]

The run-up to the Iraq invasion brought this slow simmering conflict to a rolling boil. No longer checked by the fear of Soviet aggression, then-German chancellor Gerhard Schroeder felt free to voice fierce criticism against the US plans to act against Iraq without UN approval; yet, for the same reason, then-president George W. Bush felt free to flout Schroeder's censures and those of his allies on the Continent.[93]

Iraq, though, was merely an example of a broader US-European conflict. The truth is that, because of its superior power, the United States is able to act without prior European assent in ways that might harm Europe's interests. The United States retains a core interest in a Europe that is secure and peaceful; still, Russia's decline has deprived the European states of much of their bargaining power vis-à-vis the United States. Lacking real leverage, Europe has tended to fall back on appeals to the norms of international law. In contrast, US statesmen feel obliged to defend interests on issues and in parts of the globe from which Europe has long since renounced all pretense of responsibility; thus, in America's eyes, Europe's expansive concept of international law can seem like unhelpful caviling.[94]

The change in control of the White House has muted the conflict. Obama has been as diffident to Europe's feelings as George W. Bush was brash in defying them. But the change in tone does not remove the root cause of the conflict. The United States remains able to take actions that affect European interests, and Europe has no real means of restraining it.

Climate policy is merely another sphere in which this pattern of conflict plays out. Thus, the George W. Bush administration's abrupt exit from the Kyoto Protocol can be viewed in retrospect as a climate policy precursor to the Iraq invasion. The Kyoto decision and the manner in which it was announced caused outrage both in Europe and among the American left.[95] It was clear that the United States could, if it chose, act on its own perceived interests without paying much heed to European sentiments.

Europe's concern over unilateral SRM can, in a sense, be thought of as a delayed response to its shocks over Iraq and Kyoto. With SRM, though, there is an added problem. Not even an expansive reading of the norms of international law offers Europe much of a basis for limiting US or other use of SRM.[96] Hence, Europe is anxious to ensure that rules offering a legal pretext for blocking action on SRM be put in place as soon as possible. Of course, in a real climate-change emergency, such rules would be unlikely to constrain the actions of the United States or any other great power.[97] But to European politicians, weak leverage may be better than none.

5.2.2. US Political Culture and Solar Radiation Management

Ironically, at least as far as the United States is concerned, this fear of unilateral SRM is greatly exaggerated. The point is not that Europe could prevent the United States from launching an SRM system. It is that absent a perceived climate-change crisis, US institutions and political culture make such an effort unlikely.

Certainly, the Iraq invasion is a poor model for predicting US behavior on SRM. In 2003, the 9/11 terrorist attacks galvanized a consensus for forceful action. Without that consensus, the US political system would have been most unlikely to act with such force and celerity. In fact, the 2003 invasion of Iraq displayed a degree of presidential control over policy that would be unlikely in the case of SRM where some domestic interest groups might be harmed. US presidents enjoy much more freedom in foreign affairs than they do in domestic policy. At home, except in times of perceived crisis, the separation of powers, nearly even partisan split, and pervasive power of interest groups tightly constrain presidents. This pattern produces diverse veto points, each of which is able to block action. The result is that US domestic policymaking often lacks strong central direction and coherence.[98]

Over time, the gridlock has grown more pervasive. Presidential freedom of action has narrowed, yet Congress is mired in particularism. Again, with the exception of perceived crises, the scope for large-scale policy change has severely narrowed over time.[99] The current milieu is not one that favors policy innovation as dramatic as SRM would be.

That SRM deals with climate change is a further barrier to action. To be sure, the seemingly high ratio of benefits to costs of SRM creates a potential for far greater support than is the case with GHG controls. Yet the fact remains that the vast preponderance of these costs would accrue abroad, not in the United States.

Thus, the most acute political problem with SRM is not the risk that the United States would deploy it heedless of the harm that it might do to other countries. It is that for the United States, SRM would be, to a large degree, foreign aid. In this role, it might be far more cost-effective than GHG control. It can also bypass the effects of corrupt and ineffective third-world governments; therefore, it would avoid the major defect of adaptation assistance. As such, SRM is likely to face a tough struggle for space on the US public agenda.

Ideology and cultural values compound the difficulty of this contest for approval. A large portion of the environmental movement defines any human interference with nature as morally wrong.[100] To the extent that such views affect the decisions of the major ENGOs, they are largely deaf to the concept of instrumental rationality.

Conversely, many on the right strongly oppose GHG controls. Rather than addressing the poor prospects and low cost-effectiveness of such controls, much of their argument is based on disputing the premise that man-made climate change poses a threat. Not surprisingly, those who hold such beliefs tend to oppose the use of SRM.[101]

In effect, for different reasons, the two politically mobilized ends of the political spectrum on climate change tend to reject use of SRM. The Greens do so because they regard it as morally abhorrent. Conservatives do so because, in rationalizing their opposition to GHG control, they have come to insist that man-made climate change is a hoax. The practical effect is that no organized support exists for research into SRM.

5.3. Constraints on Unilateral Solar Radiation Management

The United States, while not inclined to pursue SRM capability, would be unwilling to concede control of such a system to any other state. One key issue is, therefore, how the development of SRM capability would play out within the context of US-China relations. Other world powers, notably Russia and India, are likely, at least initially, to view SRM development quite skeptically. On principle, many states are likely to be hostile to any single state controlling SRM.

5.3.1. Solar Radiation Management and the US–China Rivalry

In this century, much of world politics is likely to pivot around the relationship between the United States and China. Those who worry greatly about unilateral SRM may fear that, should SRM become a viable option, Beijing or Washington might be tempted to bid for sole control over it. These two states are certainly the least susceptible to pressure from other powers. How real, though, is the threat?

The US-China rivalry is likely to become increasingly tense. China's populace has repeatedly displayed outbursts of anti-American passion.[102] Periods in which a rival overtakes a global hegemon in relative power are historically fraught with intense rivalry and high risks of conflict.[103] The US public shows a growing fear that China has already overtaken the United States as a superpower.[104]

Beijing appears to be pursuing a strategy aimed at replacing the United States as the dominant power in the Western Pacific, but it seeks to do so without provoking open conflict; the United States has sought to engage China economically. At the same time, it has tacitly sought to encircle China with US allies. In doing so, it has, however, also sought to avoid open confrontations.[105]

In light of these tensions, no statesman in either Washington or Beijing could imagine that acquiring a unilateral SRM capacity would not provoke some level of hostile response in the other capital. Both states are aware of the risks that potential conflict between them entails. And both have sought to avoid open confrontations and to dampen their effects when they have occurred.[106]

In this context, then, would having sole control of an SRM system, were that possible, be worth the risks of great power conflict that it would entail? In fact, a state wishing to foil another's plans for unilateral SRM would have a range of options for doing so. It might, for instance, inject short-lived fluorocarbon GHGs into the atmosphere and thereby offset the intended cooling.[107] It might also increase soot emissions to the same end.[108] Such measures, if used covertly, could produce false negatives in tests of the efficacy of another state's SRM project. If used overtly, the same measures could demonstrate a state's resolve to deprive another power of its control over the global climate. The real point is that countermeasures of this kind are known to exist, and the fact that they are known tends to deter any state from seeking such control in the first place.[109]

For the United States or China, the benefits of sole control of SRM, even if it could be asserted and maintained, are unlikely to be worth the vexations and risks that it would entail. Of course, the future damage from climate change is impossible to predict in detail. Either the United States or China might encounter costs that exceed those that now seem likely.

In that case, Washington and Beijing might decide to pursue SRM cooperatively. Such an effort would doubtless entail much hard bargaining. Whether the rewards of such cooperation would justify its high transaction costs would be subject to the relative and absolute risks of climate change, the costs and benefits of SRM, both states' internal politics, and their relative power.

5.3.2. Solar Radiation Management and Other World Powers

Second-tier powers are also likely to actively engage in international bargaining over SRM. Russia and India, for instance, are likely to be wary of SRM. Russia remains a great power, albeit the weakest of these three. India, while perhaps not yet a full-fledged world power, has been on the rise. American strategists, furthermore, regard India as a quasi-ally.[110]

Climate change poses some threat to Russia in the form of melting permafrost, which threatens to damage much of Russia's aging energy infrastructure. Further climate change might also disrupt rainfall patterns and perhaps induce unwanted migration from Central Asia.

At the same time, warming offers new opportunities in Arctic energy development, longer growing seasons, and lower heating costs. Russian leaders remain convinced that further warming is advantageous.[111] While this belief prevails, any SRM scheme would be likely to face Russian opposition.

India is also a complex case. A large share of its agriculture still depends on the Indian Summer Monsoon. Some climate models show greenhouse warming as disrupting the monsoon. However, some models, although not all of them (as previously noted) also suggest that SRM might lessen the monsoon's intensity. Without strong assurance that such an effect will not occur or that it will occur in either case, India would seem very likely to oppose SRM. The tacit US–Indian entente would push much of the US national security elite and its major institutions into support for India.

Worries about SRM should, therefore, be viewed in light of the fact that at least three of the world's four most powerful states would be likely to oppose any near-term deployment of SRM. Of course, no state currently proposes such deployment. These factors are completely at odds with story lines depicting some unnamed state rushing helter-skelter into SRM deployment.

5.3.3. Solar Radiation Management and the Lesser Powers

Until great power opposition abates, a lesser power attempting to deploy SRM would be very likely to encounter coercive sanctions. Options include public and private diplomacy, economic sanctions, SRM countermeasures like those previously discussed, and, perhaps even armed force. Coercion, to be sure, is often costly to the state or states using it. Nonetheless, the greater the differential in relative power between the state wishing to coerce another and that of the target state, the better are the prospects that the coercion will succeed at an acceptable cost.[112]

Conjectures about small- or medium-sized states deciding to change global climate are, therefore, at odds with the nature of global power politics. The mistake is common in economists' analyses of the world political economy. Such analysis often fails to consider the effects of power on states' calculation.[113] The point is not a new one; the Chinese philosopher Mencius made it some 2,400 years ago when he wrote: "It is certain that a small country cannot contend with a great one, that few cannot contend with many, that the weak cannot contend with the strong."[114]

A small state, therefore, might be able to afford the direct cost of deploying SRM. However, deploying SRM would be likely to trigger great power displeasure. What some analysts have ignored is that it probably could not afford the cost of the sanctions that would be imposed on it for defying the preferences of one or more of the great powers.

A fortiori, the notion of a lone individual, however wealthy, pursuing go-it-alone SRM deployment, is preposterous. Individuals are subject to the laws of the states in which they live. And states exist within a hierarchy of power.

6

Inferences for Climate Policy

SRM remains a speculative option; nonetheless, a workable SRM system could offer a highly useful backup and supplement to current policy options. Effective GHG control would require a hefty willingness to pay for it in Beijing, Delhi, Moscow, and Washington. No such consensus is evident and none seems likely to appear soon. Finding low-cost, low-GHG energy sources appears to present daunting challenges of both technology and governance. In theory, adaptation could greatly reduce the costs of climate change. In practice, lack of adaptive capacity seems likely to fall short just where it is most needed.

Recent technological developments have reinforced the sense that SRM may well prove to be feasible and highly cost beneficial. Preliminary models and direct experience suggest that the most damaging effects of climate change can be offset by reflecting, at the most, 1 percent of incoming sunlight back to space. Human activity is already inadvertently engineering the climate to this degree. The technology to undertake this intervention with purpose is believed to be well within our current capabilities.

Institutional and political developments are more mixed. Interest in SRM is clearly on the rise. Furthermore, ENGOs' opposition appears to have somewhat softened. Even so, ENGOs retain the opportunity for a certain amount of strategic behavior of the kind that they often display in their dealings with the private sector. In any case, a core of highly ideological, diehard resistance remains. Whether a US civilian R&D program could make progress in the face of so complex a political landscape remains an open question.

Without doubt, the increasingly evident political bankruptcy of GHG control policies has driven much of the interest in SRM; also important, though, is SRM's economic promise. In this area, too, recent research has tended to confirm earlier analyses. Across a very wide range of scenarios regarding the severity of climate change, the proximity of tipping points, the possibility of emissions controls, and the damage caused by climate engineering, a workable SRM technology would appear to offer very large net benefits.

Of all of the objections to SRM, none has been more persistent than the claim that it poses a troubling risk of unilateral deployment. In Europe and for some US observers, this hypothetical possibility that SRM might someday trigger unilateral action has seemed to outweigh the current and evident fact that the alternatives to SRM all suffer from intractable governance problems of their own. Yet reflection suggests that a US proposal for unilateral SRM would face serious institutional hurdles at home. It is not the cost of SRM that will determine the size of the coalition that will control it. It is the need for a coalition with enough bargaining power to impose its preferences over global climate.

Such questions, however, are premature. Before agreeing to any governance framework, the US needs to ascertain SRM's feasibility and desirability. This understanding will only follow a well-designed R&D effort.

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