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A critical examination of the climate engineering moral hazard and risk compensation concern

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Abstract

The widespread concern that research into and potential implementation of climate engineering would reduce mitigation and adaptation is critically examined. First, empirical evidence of such moral hazard or risk compensation in general is inconclusive, and the empirical evidence to date in the case of climate engineering indicates that the reverse may occur. Second, basic economics of substitutes shows that reducing mitigation in response to climate engineering implementation could provide net benefits to humans and the environment, and that climate engineering might theoretically increase mitigation through strong income effects. Third, existing policies strive to promote other technologies and measures, including climate adaptation, which induce analogous risk-compensating behaviours. If the goal of climate policy is to minimize climate risks, this concern should not be grounds for restricting or prohibiting climate engineering research. Three potential means for this concern to manifest in genuinely deleterious ways, as well as policy options to reduce these effects, are identified.

Keywords

climate change, climate economics, climate engineering, geoengineering, global warming, mitigation, moral hazard, risk compensation

Introduction

Anthropogenic climate change poses major threats to humans and the environment. The dominant approach thus far to reducing climate risks has been efforts toward reducing annual greenhouse gas emissions (‘mitigation’). However, given the slow rate of the natural removal of additional carbon dioxide (CO_2), this can be only a long-term strategy. There is also a significant chance that this mitigation will be suboptimal. In the meantime, emissions continue to accumulate in the atmosphere and the climatic effects of today’s emissions will not be felt for decades. As a consequence, we are already committed to an uncertain amount of climate change (Allen et al., 2009) which may

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already surpass the internationally agreed-upon 2°C threshold for ‘dangerous climate change’ (Peters et al., 2013). Therefore, even though mitigation remains vital, society faces an unpleasant future of managing climate change. Adaptation of society and ecosystems to a changed climate has become the second set of responses to climate risks. Significant steps toward adaption may now be evident, as countries are pledging billions of dollars for it. The promised cash is not yet fully in hand, though, and like mitigation, adaptation also easily gets mired in the morass of international politics and divergent perceptions of justice.

In the context of the seriousness of climate risks and the limits of likely mitigation and adaptation, some observers are increasingly considering intentional, large-scale interventions in natural systems in order to reduce climate change risks. These ‘climate engineering’ or ‘geoengineering’ proposals are diverse, and fall into two general categories. ‘Carbon dioxide removal’ (CDR) or ‘negative emission technologies’ would capture the leading greenhouse gas from the atmosphere and sequester it. Proposals include CO_2 capture from ambient air and ocean fertilization. ‘Solar radiation management’ (SRM) would slightly increase the reflective albedo of the Earth in order to compensate for the warming effect of climate change. These techniques could include stratospheric aerosol injection and marine cloud brightening.

Climate engineering proposals have been controversial for a variety of reasons. Perhaps the most widespread concern is that they would undermine mitigation efforts. Indeed, nearly any discussion of climate engineering outside of a few scientific journals devotes significant attention to this. Taken to an extreme, this concern – typically called ‘moral hazard’ but more accurately ‘risk compensation’ – justifies a taboo, which was essentially the case (Lawrence, 2006) prior to an essay by a Nobel laureate atmospheric scientist (Crutzen, 2006), whose bona fides were beyond doubt and whose career and legacy were secure. Yet this concern has gone mostly unscrutinized (for an exceptional examination, see Hale, 2012). Although attention to climate engineering has increased in recent years, relative to mitigation and adaptation it remains on a distant tier of consideration.

This article challenges the concern that the consideration, research, development, potential for implementation and actual implementation of climate engineering would lessen mitigation and – to a lesser extent – adaptation, leading to undesirable outcomes such as greater climate change damage.[1] This will be called the climate engineering moral hazard-risk compensation (CE MH-RC) concern and, if it manifests, the CE MH-RC effect. Note that, although the CE MH-RC concern could apply to all forms of climate engineering, it is much more pronounced in those forms – particularly within SRM – which may be effective, rapid and inexpensive. It is these proposals which are the primary, but not sole, subject of this paper. The intention in this paper is to be somewhat provocative in order to encourage critical examination of widespread assumptions and assertions. It uses three approaches – empirical evidence, basic microeconomics of substitutes and existing and potential policies – to demonstrate that this concern may be overstated and hindering the development of effective climate policy. Specifically, from these approaches, I assert that

(a) there may be either no CE MH-RC effect or a reverse one;
(b) independent of (a), some substitution of climate engineering implementation for mitigation could provide net reduction of climate risks; and
(c) independent of (a) and (b), if policy-makers wished to reduce any potential CE MH-RC effect, there would be little that they could effectively, realistically and ethically do.

In the process, I highlight three potential mechanisms of a genuinely deleterious CE MH-RC effect. However, these mechanisms are often present in the formation of a wide range of public policies, and their problematic consequences for climate change are much broader than potentially lessening mitigation. Importantly, examination of the CE MH-RC concern raises the question of what precisely are the goal and the means of climate policy. Assuming that the goal is the reduction of climate risks and subsequent damage, and that the means to this include but are not limited to mitigation and adaptation, the CE MH-RC concern should not be grounds for restricting or prohibiting climate engineering research, and responsible climate engineering research should be encouraged. However, there are some policy options to address and reduce the potential deleterious CE MH-RC effects.

Moral hazard, risk compensation and their empirical evidence

The first approach is to examine existing empirical data in order to see whether they imply a probable CE MH-RC effect. Moral hazard and risk compensation, which are the two existing categories of analogous human behaviour, will be examined in general. The former is the term that has most often been used to describe the CE MH-RC concern, although the latter is a closer fit. In each case, existing empirical evidence will be briefly reviewed. This is drawn from the disciplines which developed the terms: for moral hazard, behavioural economics of insurance; for risk compensation, behavioural psychology of risk and safety. Then the existing but limited empirical evidence for the potential CE MH-RC effect will be summarized. Note that this section describes responses of individuals whereas climate engineering is a matter of collective decision-making. Consequently, its actual consideration, research and development could yield distinct results. Collective decision-making will be explored to some extent in the subsequent section.

Moral hazard

Moral hazard is a socially inefficient increase in risk-taking by one party once another party absorbs some of the potential negative consequences of the first party's actions, typically through an insurance-like agreement between the parties and typically without the latter party's full knowledge of this increase. The term's negative connotation is a vestige of its original meaning, which was limited to intentional actions by 'unscrupulous' insurees (Black, 1910: 563). With the rise of more theoretically rigorous economic studies in the mid-20th century, the concept was broadened to include any increase in risk-taking by insurees (Pauly, 1968). This was then seen as a rational but possibly subconscious response to altered incentives. Now, moral hazard has been further generalized to the principal–agent problem in which the agent who creates risk has greater information regarding her actions than the principal who bears the risk (Stiglitz, 1983).

Although moral hazard seems logical and has been supported by modelling, there is no agreement as to its actual magnitude because of several challenges in empirical work (for a review, see Cohen and Siegelman, 2010). Most importantly, the problem is one of information asymmetry, which makes research inherently difficult: if the principal cannot obtain certain information regarding the agent's behaviour, then often researchers cannot as well. Another challenge is how to distinguish among three different behaviours by insurees which each lead those with greater insurance to file more claims, which is typically the actual observable event. The first of these behaviours is the increase in risk-taking after obtaining or increasing insurance. This is more specifically called ex ante moral hazard and is the one most relevant to the CE MH-RC concern. Second, ex post moral hazard is when an insuree, after increasing his coverage, files more or greater insurance claims while his risk-taking remains constant. Third, adverse selection is when those who know beforehand that they present more risk will choose to obtain more insurance. A further challenge to obtaining empirical evidence of ex ante moral hazard is that insurers undertake steps to reduce it, such as monitoring insurees and sharing risk with them through deductibles, co-payments and coverage limits. Finally, there are other behaviours, some of which may remain unknown, which further confound evidence of ex ante moral hazard. For example, obtaining medical insurance may expose insurees to information regarding the benefits of eating healthy, resulting in them *reducing* their risky behaviour.

Therefore, while numerous studies find that individuals with more insurance file more and larger claims, the majority of these studies do not (and generally cannot) distinguish ex ante moral hazard from adverse selection and especially from ex post moral hazard.[2] One review of several forms of insurance concluded that ‘This literature identifies a moral hazard effect in some contexts but not in others’ (Cohen and Siegelman, 2010: 72). In the best-examined field, that of medical insurance, ‘there are theoretical reasons to believe that health insurance coverage may cause a reduction in prevention activities, but empirical studies have yet to provide sufficient evidence to support this prediction’ (Dave and Kaestner, 2009: 369). Research into automobile insurance is just now beginning to try to tease apart ex ante moral hazard; initial data indeed supports at least its existence (Abbring et al., 2008). As a final example, the case of workers’ compensation is muddled, in part because three parties are involved: the insurer, the employer and the employee. A recent study found some support of ex ante moral hazard among workers, but this seemed to be more than compensated by greater safety measures taken by the employer in order to reduce their costs (Guo and Burton, 2010). Outside of insurance, other manifestations of ex ante moral hazard – such as mutual defence treaties (Benson, 2012), foreign aid (Bräutigam and Knack, 2004), humanitarian intervention (Kuperman, 2008) and financial investments (Stiglitz, 1983) – can be theorized and perhaps modelled but are even more difficult to confirm empirically.

Risk compensation

Risk compensation is an increase or decrease in risk-taking once an individual perceives that risk to be lower or higher, respectively. The actual risk may or may not have changed in a manner consistent with the change in perception. It relies on a model of human behaviour in which people balance the advantages and disadvantages of risk-taking. If some exogenous change such as a new regulation or technology alters the perceived risk of an activity, then individuals will compensate. It differs from ex ante moral hazard in that the increase in risky behaviour is not due to its negative consequences being transferred onto another party, and there is consequently no information asymmetry. However, like ex ante moral hazard, it can be considered to be a rational, although perhaps subconscious, response to changed incentives.

Empirical evidence of risk compensation is mixed, with studies producing a wide range of rates of offsetting behaviours. The best-studied field is automobile safety, such as seat belts, road lighting and vehicle safety inspection. Early work found that although seat belt laws reduced driver and occupant fatalities, they led to more dangerous driving as evidenced by increases in accidents with pedestrians and bicyclists (Peltzman, 1975). More recent research has shown much smaller effects, with one study concluding that ‘If anything, these laws and the accompanying increase in belt use result in safer driving behaviour … Overall, seatbelt laws and the higher belt use these laws induce do not increase nonoccupant risk exposure’ (Houston and Richardson, 2007: 933). Similarly divergent results have been observed in the cases of children’s and sports protective equipment (McIntosh, 2005; Pless et al., 2006; Scott et al., 2007), bicycle helmets (Fyhri et al., 2012), vaccines and condoms to prevent AIDS/HIV and other sexually transmitted diseases (Brewer et al., 2007; Eaton and Kalichman, 2007) and hypertension drugs (Steptoe and McMunn, 2009). Another notable area of debate is harm reduction efforts in use of alcohol, tobacco and illicit drugs (Ritter and Cameron, 2006). Importantly, the risk compensation literature does not indicate a net increase in harm resulting from the offsetting behaviour, but instead only a smaller net reduction of harm than would be expected from the initial change alone.

In another similarity with moral hazard, these data are uncertain because reliable empirical studies of risk compensation are difficult. In an experimental setting, manipulating research subjects' risk perceptions is challenging, and may raise ethical constraints (Underhill, 2013). Outside of the laboratory or clinic, the offsetting behaviour can be difficult to measure and/or may be confounded by other variables. For example, bicycle helmet laws may lead to a selection effect wherein those who bike more slowly yet helmetless are deterred from biking, leaving behind those who bike for speed while helmeted (Fyhri et al., 2012). There could also be counteracting information effects, in which the perception of safety equipment serves as a reminder of a risk's seriousness, leading to *more* cautious behaviour.

Debates over certain policies which may have risk compensation effects are sometimes muddled by commentators' normative commitments. This is particularly the case with behaviours which are condemned by some as immoral, such as non-marital sex and illicit drugs. Some observers assert that even though policies such as human papillomavirus (HPV) vaccinations, prostitution decriminalization and clean intravenous needle exchanges may reduce harm, such steps would 'send a wrong message' and lead to an increase in the condemned behaviour. These situations are typically disagreements as to the policy goal. To some, the goal is to reduce certain tangible harms, while to others it is to reduce the occurrence of the morally condemned behaviour. This disagreement will be revisited below.

Empirical evidence for climate engineering moral hazard and risk compensation

The case of a potential CE MH-RC effect is even more uncertain than the investigated examples of moral hazard and risk compensation, because climate engineering is not actually being used yet and because the 'actor' in question is global society, behaving collectively with intergenerational impacts. Although the term 'moral hazard' is used more often for climate engineering, risk compensation fits better, although is still imperfect (Keith, 2013; Lin, 2013). In order for climate engineering and its research to present a moral hazard, then risks would need to be consensually transferred to another party who has inferior information as to the behaviour of the risk-taking party.[3] If climate engineering research and development were to reduce mitigation, then this may transfer some risks to future generations, but future generations would also be the ones to benefit by having greater knowledge about climate engineering and perhaps the additional option to implement it. It remains unclear whether these together would result in a net increase in their climate risks. Furthermore, future generations have not (and cannot) consent, and the crux of the CE MH-RC concern is not that the present generation has greater information about its behaviour than future ones do. In contrast, with risk compensation, risks to the actor are exogenously reduced, often through a technological intervention, which in turn impacts risk perception and behaviour. Models thus far do indicate that climate engineering could provide a reduction of risks from climate change,[4] although some risks may be transformed in type (for example, from changes primarily in temperature to changes primarily in precipitation) and to different populations.

There are only a handful of opinion studies of climate engineering, and just five of these have implications for the CE MH-RC concern.[5] Although each has limitations, all point toward a nonexistent or even reverse CE MH-RC effect, perhaps resulting from an information effect analogous to seeing a seat belt. First, the Royal Society of London convened focus groups, which indicated that

> rather than presenting a 'moral hazard' issue, the prospect of geoengineering could galvanise people to act, and demand action, on greenhouse gas emission reductions. Although participants were generally cautious,

> or even hostile, towards geoengineering proposals, several agreed that they would actually be more motivated to undertake mitigation actions themselves (such as reducing energy consumption) if they saw government and industry investing in geoengineering research or deployment. (Shepherd et al., 2009: 43)

Second, a public dialogue organized by the UK's Natural Environment Research Council found evidence 'contrary to the "moral hazard" argument that geoengineering would undermine popular support for mitigation or adaptation' (IPSOS Mori, 2010: 2). Third, an opinion survey of residents of Canada, the UK and the USA produced a moderate degree of opposition (a mean of 2.07 on a scale of 1 to 4, where 2 is 'somewhat disagree') to the statement 'Solar Radiation Management should be used so we can continue to use oil, coal and natural gas' (Mercer et al., 2011: 5). Fourth, in an experimental survey, some respondents were exposed to information about climate engineering, while others were not. 'Contrary to the "moral hazard" effect … subjects in the geoengineering condition did not become sanguine about climate change risks. Indeed, on the whole, they displayed *more* concern over climate change than ones in the control condition' (Kahan et al., 2014: 15). Finally, a public discussion group in the UK found that 'No-one saw the benefit of geoengineering without mitigation' (Integrated Assessment of Geoengineering Proposals, 2014: 3).

Basic economics of substitutes

The second approach to examine the CE MH-RC concern is through the basic economics of substitutes. Suppose that global society is simultaneously a consumer and a producer of various responses to climate change risks. These will have costs which increase for each additional unit 'purchased' (or, better stated, 'invested in') because society would try to begin with the least expensive actions before moving to the more expensive ones. This gives an upward-sloping marginal cost curve. In comparison, the shape of the marginal benefit (or utility) curve is less certain: it is often assumed to be upward-sloping, but it may be horizontal on average, in that the damage averted by reducing warming from 5°C to 4°C may be equivalent to that averted from 1°C to 0°C. Future costs and benefits are included and discounted, in that they are reduced by a compounding rate in order to reflect opportunity costs and the preferences to have benefits sooner and to incur costs later.[6] This yields single marginal cost and marginal benefit curves using present values, even though the costs and benefits will actually occur at various times. Furthermore, in each case, the curves can incorporate other positive or negative effects. For example, mitigation will also reduce other forms of environmental damage, and adaptation will also make society more resilient to natural disasters. A world with elevated atmospheric CO_2 and SRM climate engineering may have higher crop yields (Xia et al., 2014), but precipitation patterns would change (Kravitz et al., 2014b), possibly in harmful ways. These benefits and costs could even include social and political effects, such as the potential misuse of SRM climate engineering and its need to be sustained for a long time, as well as aggregate normative preferences, such as the beliefs that we should minimize human interference in the natural world and that it is better to address a problem closer to its cause.[7] It is important to note that these curves remain uncertain; they could have greater or lesser slopes and could be highly nonlinear. For now, let us maintain five simplifying assumptions: (1) that mitigation is the only possible response to climate risks; (2) that decisions are made by a single, omnipotent benevolent decision-maker; (3) that the decision-maker is omniscient; (4) that the preferences of people coincide; and (5) that decision-makers are rational. With this single response option, society invests in mitigation until an optimal, efficient quantity, where the additional cost of one more unit equals the additional benefit of that unit.

Now the first four assumptions can be removed stepwise, the first of which is to now consider multiple responses to climate risks. (The assumption of rationality will be maintained.) After the introduction of a second response, the imperfect substitute of climate engineering implementation, the marginal benefit of mitigation will decrease because some desire to reduce climate risks will have been met through climate engineering. As a result, the optimal quantity of mitigation will also decrease. However, the net benefit (which includes and is most likely dominated by the reduction of climate risks) will increase. After all, if the net benefit *did not* increase – which could be the case if all the incorporated secondary costs caused the optimal amount of climate engineering to be zero or less – then there would have been no investment in climate engineering implementation, given the current assumptions. This is essentially a case of simple substitution following neoclassical economics. Because the benefit curves for both mitigation and climate engineering include all effects and normative preferences, one cannot simply state that mitigation is the preferred option. Under this, any reduction in the quantity of mitigation after the introduction of climate engineering implementation is both rational and net beneficial to humans and the environment.[8]

In reality, there are at least four top-level response categories: mitigation, climate engineering, adaptation and suffering climate change damages.[9] The last of these is not purchased but instead manifests as human suffering, environmental damage and reduced economic activity. Climate engineering implementation would decrease investments in mitigation and adaptation through substitution, and would decrease climate damages through its primary intended effect. At the same time, because climate engineering implementation is expected to have very low financial costs[10] while those of mitigation, adaptation and climate change damages will be great, this will liberate some of society's financial resources, a portion of which could be used for mitigation.[11] Thus, there would be counteracting effects of climate engineering implementation on the amount of mitigation: a substitution effect, described in the previous paragraph, which would decrease it, and several income effects, described here, which would increase it. It is theoretically possible that climate engineering implementation could increase mitigation through dominant income effects.[12] These income effects would be stronger as the costs of mitigation, adaptation and climate change damages approach a greater portion of total economic activity. However, these are each currently estimated to be only a percent or two of economic activity. On the other hand, they might turn out to be higher, and one can also imagine a scenario in which voters endorse setting aside only a certain percentage of society's income for climate purposes, which would increase the relative importance of the income effect. Nevertheless, the possibility of these multiple income effects actually dominating the substitution effect is interesting but seems unlikely.

Lifting the second assumption transfers decision-making from a single decision-maker to numerous states which pursue their self-interests and can negotiate with each other in various forums. Let us examine in some depth the resulting effects on each of the three primary responses to climate change risks. First, mitigation presents a global, transgenerational collective action problem. In a hypothetical world of homogenous states, the benefits of each country's costly mitigation are diluted across the globe, causing them to each mitigate suboptimally. This is the classic underproduction of a public good. In the real world, those countries that are better positioned to mitigate (i.e. the industrialized countries) are generally less vulnerable to climate change, exacerbating this underproduction. Moreover, the costs are borne now and the benefits reaped later, whereas political decision-makers lack the necessary incentives for this transgenerational investment. Barring unprecedented levels of international trust, self-sacrifice and enforcement in international cooperation, mitigation will be very suboptimal. Second, although adaptation is, for the most part, not a collective action problem, it too will likely be under-provided because the more vulnerable developing countries have less capacity to adapt. Optimal adaptation will require enormous and politically unpopular international wealth transfers from the industrialized ones to the developing ones. Thus, independent of climate engineering, adaptation and especially mitigation will be significantly suboptimal in a world of many countries.

The effect of multiple decision-makers on climate engineering implementation will depend on its form. CDR is much like mitigation, and will follow a similar pattern with the magnitude of its underproduction dependent on the various techniques' costs, risks and capacities. The case of SRM varies by the method's specific scale of impact. At one extreme, it could hypothetically be implemented locally.[13] Each country would provide for its own SRM at its locally optimal level, with some positive and negative side effects for other countries. Negotiations between countries for payments could lead to compensation for victims of negative side effects, to reimbursement for positive effects, or to an agreement to adjust the magnitude of local SRM climate engineering. In this situation, SRM would be provided at a level close to its optimum, but probably somewhat higher because of uncompensated negative externalities. At the other extreme, SRM could be completely global, with no capacity for local optimization. In an ideally cooperative world, countries would agree upon a level of SRM which maximizes total net benefits with side payments to compensate any losers, or – barring that – upon a level which would maximize total net benefits without leading to net harm for any country (see Kravitz et al., 2014b; Moreno-Cruz et al., 2012). In reality, any negotiations would occur among states with diverse levels of power, interests and capabilities. Considering its low expected financial cost, and assuming that countries may increase but not decrease the intensity of SRM, the amount of global SRM might be determined by the country that preferred the highest SRM intensity while possessing sufficient international power and influence to withstand any retaliation or reputational damage from those which preferred a lower intensity.[14] Assuming no correlation between countries' power and SRM preference, SRM climate engineering in this scenario would then be over-implemented, the magnitude of which would depend upon the degree of alignment among countries' SRM preferences. One study modelled the preferred intensity of global SRM for 22 different regions (Ricke et al., 2013).[15] The highest preferred SRM intensity among the regions was approximately 20% greater than that of the lowest. This general alignment among regions implies that, in the world of selfish 'great powers' described above, global SRM climate engineering implementation is likely to be overproduced, but not by a very large amount. In reality, SRM intensity will likely be less extreme through technical measures, such as optimization by latitude (MacCracken, 2009; MacMartin et al., 2013; Modak and Bala, 2014) and by time of year, and through social measures, such as implementation through multinational coalitions (Ricke et al., 2013).

Therefore, the inclusion of multiple decision-makers leads mitigation and adaptation to be suboptimal, independent of climate engineering. In the presence of climate engineering implementation, these two might be somewhat more suboptimal while SRM climate engineering may be slightly over-implemented.

The third assumption to remove is that of omniscience. Thus far, I have assumed that decision-makers knew the shapes of the marginal cost and marginal benefit curves for each response. As noted above, climate science and economics are uncertain. Both mitigation and climate engineering pose uncertainty, some of which can be reduced through research and some of which may remain irreducible. As the reality of climate change and our responses to it unfolds, decision-makers can adjust policies as they learn more about the consequences of earlier actions.

The implications of uncertainty for mitigation and SRM climate engineering are not equal. The latter poses greater uncertainty both because there has been much less research to date, and because it relies upon intentional interventions in a highly complex system which has already been subject to other (unintentional) interventions. In contrast, mitigation has been studied for decades, and its irreducible uncertainty is lesser because it would reduce interventions in complex climate systems (although it would increase interventions in complex economic systems). Thus, assuming that society is risk averse, decision-makers should be willing to increase mitigation and to decrease climate engineering relative to their risk-neutral optimal levels. This would result in greater financial costs and environmental damage, but this does not imply that such risk aversion is irrational.

As research reduces the uncertainty for a given climate change response option, its expected costs, benefits and optimal amount often change. That is, later research may yield results contrary to initial expectations and preliminary research. Again, this has different implications for mitigation and climate engineering. Because researchers have been refining the costs and benefits of mitigation for decades, it seems unlikely that society would now aim for an optimal mitigation level which later mitigation research reveals to be dramatically different from optimal. In contrast, future climate engineering research may point toward an optimal level which is indeed dramatically different from what we now believe. Because the expected optimal level of mitigation is influenced by the expected optimal level of climate engineering via imperfect substitution and possible income effects described above, this creates the first of three potential deleterious CE MH-RC effects which this paper identifies. If (1) the initial expectations of climate engineering implementation were highly positive, (2) this reduced mitigation via expectations of a beneficial substitution effect and (3) later research or experience yielded more negative results, then net climate risks would increase (see Moreno-Cruz and Smulders, 2010). However, the reverse could be true as well, in which an excessively pessimistic view of climate engineering would hinder its research and development, also increasing net climate risks. Regardless, all these scenarios call for further research.

Furthermore, mitigation and SRM climate engineering differ in how decision-makers learn from and respond to the effects of their policies. In both cases, decision-makers may aim for a level which they believe to be optimal but, because of lingering uncertainty, only after implementation learn to be significantly different from than optimal. In the case of mitigation (as well as CDR climate engineering), because climate change and its damages lag for decades behind the greenhouse gas emissions which cause them, the benefits of mitigation will also lag. Furthermore, mitigation itself – new technologies, policies, infrastructure, agricultural practices, ecosystem management practices, etc. – is slow to implement. Once decision-makers learn more about the magnitude of climate change and its damages, as well as about the revised level of optimal mitigation, excessive or insufficient mitigation cannot be rapidly corrected. In contrast, the intended effects of SRM climate engineering implementation would be felt on a relatively short timescale. If society were to implement a level of SRM which it later learned differed significantly from optimal, then this level could be adjusted upward or downward relatively rapidly, at least with the most widely discussed SRM methods which appear to be effective and inexpensive, such as stratospheric aerosol injection and marine cloud brightening (Kravitz et al., 2014a). Of course, in the meantime, the costs of insufficient or excessive SRM would be borne by humans and the environment. Although the SRM intensity could be adjusted relatively quickly to respond to global temperatures, the observation and attribution of some secondary effects of SRM climate engineering implementation, such as precipitation changes, could require many years, and any corrections would be subsequently delayed.

Finally, let us remove the assumption that all people in a given country have similar preferences. This leads to the last two potential deleterious CE MH-RC effects. For one thing, the preferences of decision-makers and the broader population may not coincide. For example, they may have different discount rates, magnitudes of risk aversion, preferences for maintaining a more natural world, and preferences for addressing a problem closer to its source. They could also live in different locations and thus give different weight to particular effects of climate change and responses thereto. That is, the personal costs and benefits for the various climate response options may differ between the two groups. There is therefore a risk of a genuine bias if decision-makers prefer a higher level of climate engineering and a lower level of mitigation relative to the genuine population. Of course, the reverse may be true.[16] The third and final potential deleterious CE MH-RC effect could arise if there were temporal misalignment of preferences. If earlier generations were to prefer a higher level of climate engineering and a lower level of mitigation relative to future generations, then the results could be suboptimal. Again, the reverse may turn out to be the case.

To summarize, this section's simple economics of substitutes indicates that, even if climate engineering were to reduce mitigation, then its implementation could still provide net benefits through substitution. This conclusion continues to hold when considering several responses to climate change risks and many independent decision-makers. Through multiple income effects, it is theoretically possible that climate engineering implementation could even increase mitigation. The relative impact of uncertainty is less clear, in part due to lesser current knowledge regarding climate engineering relative to that of climate change and mitigation. Nevertheless, the response times of mitigation, adaptation and SRM climate engineering implementation indicate an advantage for the latter in response to learning. This section identified three potential deleterious CE MH-RC effects: (1) inaccurate initial expectations for mitigation and especially for climate engineering; (2) misalignment of the preferences of decision-makers and those of the general population; and (3) misalignment of the preferences of earlier generations and those of later generations. Each of these could decrease or increase the level of mitigation with respect to its optimal level.

Policy options

Assuming that policy-makers wished to reduce any potential CE MH-RC effect, independent of whether their concerns were warranted, then what could they do? We can first examine policies in other areas with ex ante moral hazard or risk compensation. The former is caused by information asymmetry between a principal and an agent regarding the risky behaviour of the agent. One response is for the principal to adopt policies which reduce the information asymmetry. For example, insurers offer lower rates if insurees demonstrate that they behave in certain low-risk ways. Another response to ex ante moral hazard is policies wherein the insuree shares some risk, such as through deductibles and co-payments. Although ex ante moral hazard is a weak analogy, the suggestion that the present generation should *increase* its exposure to climate risks is considered further below.

Policies regarding risk compensation are more instructive although, as noted, imperfect. Here, the technology or the regulation which induces the risk compensation is generally promoted or required because it leads to a net decrease in harm, despite the compensating behaviour. In the best-studied case, people drive automobiles more riskily with seat belts, air bags and improved lighting, and thus cause slightly more accidents. However, these safety devices are promoted or required because they lead to net reductions in injuries and fatalities. The mirror-image of this is when people drive more carefully when they are intoxicated or use a mobile telephone, behaviours which are discouraged or prohibited because they increase harm despite the more careful driving. After all, the reduction of injuries and fatalities (balanced with rapid transportation) is the goal of automobile safety policies; encouraging cautious driving is merely one means to that end. Some economists have made a tongue-in-cheek proposal that, if the goal were indeed to be cautious driving, then a spike in the centre of the steering wheel pointed at the driver would be preferable to a seat belt (McKenzie and Tullock, 1981: 40). Other examples of risk compensation are promoted by similar policies or norms in the cases of sports safety equipment, gun storage and public health measures. Furthermore, large public investments are made in developing treatments for medical conditions which are caused by personal choices, such as lung cancer and type 2 (adult onset) diabetes. These approaches are consistent with the simple economics described above, in which the introduction of a substitute might reduce cautious behaviour but results in decreased net harm.

A notable exception to this pattern is when the behaviour is condemned by some as immoral. As noted above, harm reduction policies with regard to non-marital sex and illicit drugs are often opposed not because of their likely effect on tangible harms (although opponents sometimes also try to make that argument) but because they would likely increase the occurrence of the condemned behaviour. Here, the disagreement is over the policy goal. If the goal is to reduce the tangible harms, then these harm reduction policies are beneficial. However, if the goal is to reduce the condemned behaviour, then the measures are opposed because they would lead to an increase in the behaviour's occurrence. Indeed, from this perspective, the risks of the behaviour should intentionally be kept high.

These examples shed light on the CE MH-RC debate. If the goal of climate policy is to minimize climate risks to humans and the environment, then climate engineering should be seriously considered, at the present time through research. However, if its goal is mitigation itself, then climate engineering and its research should be taboo.

In this context, it is relevant to consider the history and current status of adaptation in the climate change discourse. In the 1990s, there was widespread concern that consideration of and research into adaptation to a changed climate would hinder mitigation. It was called 'an unacceptable, even politically incorrect idea' because, among other reasons, it 'could make a speaker or a country sound soft' on mitigation (Burton, 1994: 14). Along similar lines, then-US Vice President Al Gore initially called adaptation 'a kind of laziness, an arrogant faith in our ability to react in time to save our skin' (Gore, 1993: 240). During this time, 'the first obstacle to adaptation is reluctance to contemplate it' (Waggoner, 1992: 146), and it 'was viewed with the same distaste that the religious right reserves for sex education in schools. That is, both constitute ethical compromises that in any case will only encourage dangerous experimentation with the undesired behaviour' (Rayner and Thompson, 1998: 292). However, adaptation is now a second widely accepted category of responses to climate risks. This change was due to the facts that some climate change cannot be avoided and that the burdens of it will fall largely on the world's poor. Gore now admits that he was 'wrong in not immediately grasping the moral imperative of pursuing both policies [mitigation and adaptation] simultaneously, in spite of the difficulty that poses' (Lind, 2013). Although there cannot be a 'control group' in order to compare the climate change discourse with and without the consideration of adaptation, it would be difficult to argue that the mainstreaming of adaptation has significantly reduced mitigation. It is unclear how and why climate engineering is fundamentally different from adaptation in this regard.

Let us concede for a moment that policies should indeed strive to reduce any CE MH-RC effect, regardless of whether the concern is warranted. At this point in time, the issue is whether and how to discuss and research climate engineering.[17] The assertion that the taboo against publicly discussing climate engineering should be reinstated or that climate engineering research should be severely restricted (or at least not be publicly funded) is an argument that climate engineering constitutes a form of 'forbidden knowledge' and is, at its core, a case for sustained wilful ignorance in the face of large risks to humans and the environment (see Rayner, 2014). This is even more so because of the uncertainty of climate change. Climate sensitivity may turn out to be much higher than expected; harm to humans and the environment from climate change may be greater than expected; the capacities of ecosystems and society to adapt may be much lower than expected; and mitigation and adaptation may remain too low. In these events, climate engineering could be more beneficial than it is now understood to be because of the possibilities of rapid and unilateral implementation, as described above.[18] Indeed, prohibiting or restricting climate engineering research could increase the likelihood of a hazardous CE MH-RC effect resulting from lingering but unsubstantiated expectations of climate engineering's potential to reduce climate risks, and would lead to future decision-making to be based upon a thinner knowledge base.

Recently, papers by two legal scholars proposed policies which would attempt to reduce any CE MH-RC effect (Lin, 2013; Parson, 2013). Some of these proposals, such as international deliberation regarding the circumstances under which climate engineering would be warranted, public outreach to counter perceptions that climate engineering would 'solve' climate change and accountable oversight (Lin, 2013) would aim to reduce two of the potential deleterious CE MH-RC effects cited in the previous section, those due to high expectations and to different preferences between decision-makers and the general population. Other norms and rules, such as open publication of results and no patents on SRM technologies, could also reduce these potential negative effects (see Bipartisan Policy Center Task Force on Climate Remediation Research, 2011; Leinen, 2011; Rayner et al., 2013; Solar Radiation Management Governance Initiative, 2011).

More ambitiously, the authors propose that climate engineering research or implementation could be contingent upon whether states meet mitigation targets.[19] While this logic from our current vantage point may appear wise, imagine if those targets are not met – which seems not unlikely assuming that the targets are meaningful – and climate engineering were then not permitted. Should – and would – global society or individual nations then forego an option which may reduce climate risks, or would such an agreement lack credibility? Other writers have posited that climate engineering should not be considered whatsoever, and among their reasons is the CE MH-RG concern (for example, see Hamilton, 2013; Winter, 2011). These are often arguments that considering climate engineering would discourage normatively desirable behaviour, but I assert that they may have mistaken the means (i.e. mitigation) for the end (i.e. risk reduction) of climate policy. Whether through linkage agreements, restrictions or prohibitions, a denial of a potential means to reduce climate risks is arguably equivalent to intentionally increasing risk in order to incentivize mitigation.[20] This is analogous to the spike in the automobile's steering wheel, described above, increasing the driver's risk in order to incentivize cautious driving. More accurately, it would be like a spike in front of a passenger, as it is largely the current residents of wealthy countries who are shaping climate policy but future generations and the world's poor who will bear most of the climate change harm. It seems unwise and unethical to increase climate risks which will largely be borne by others as an assertion of mitigation's primacy or as a sort of high-stakes wager that mitigation and adaption will be sufficient, and that climate engineering would never be beneficial.

An exception among these authors' proposals is the most sophisticated of Parson's (2013) proposed means to link mitigation and climate engineering. In this, he suggests that nations agree to a treaty in which those states that fail to meet their mitigation targets would be excluded from decision-making regarding climate engineering implementation. The author acknowledges its shortcomings. For example, if states' preferences for the form and intensity of climate engineering were to be closely aligned, as implied by some studies (Ricke et al., 2013), or if effective and affordable localized SRM methods were developed, then they would have little incentive to participate in the agreement. Furthermore, if the mitigation requirements were quite aggressive – which appear necessary in order to significantly reduce climate change risks – then powerful countries might not participate in the treaty or fail to meet their targets, with the knowledge that they would have enough international power and influence to later implement climate engineering regardless of the agreement. Moreover, climate engineering presently remains too uncertain to serve as an effective inducement to mitigate, although this may change in the future. Nevertheless, Parson's proposal warrants further consideration.

Discussion and conclusion

This paper has attempted to demonstrate three things. First, the empirical evidences of ex ante moral hazard and risk compensation in general and of a CE MH-RC effect specifically are not fully conclusive. Indeed, the limited empirical evidence thus far indicates that climate engineering could present a reverse CE MH-RC effect. Second, and independent of the first conclusion, the simple economics of substitutes suggests that, to the extent that climate engineering implementation might actually reduce mitigation through substitution, this could be rational and beneficial. In fact, it is theoretically possible that implementation could increase mitigation through strong income effects.

Third, technologies and regulations which cause risk compensation – the better analogy of the two – are usually promoted. Even if policy-makers wanted to reduce any CE MH-RC effect, regardless of its actual existence, restricting or prohibiting climate engineering research would likely do net harm, would not be feasible and might be unethical.

In the process, this paper identified three potential mechanisms of deleterious CE MH-RC effects. First, expectations of mitigation and especially of climate engineering may differ significantly from what is later learned. Second, the relevant preferences of decision-makers and those of the general population may not coincide. Third, the relevant preferences of earlier generations and of later generations may not coincide. To the degree feasible, effective and ethical, policies should be adopted which would reduce the likelihood and intensity of these mechanisms, or at least of the first two. As noted above, more and better research into all response options – including that of climate engineering – to climate change risks would more quickly reduce uncertainty and bring expectations closer to reality. Public consultation, international deliberations, accountability, transparency and intellectual property restrictions could reduce the negative impacts of the first two mechanisms. The third possible mechanism is particularly thorny, as preferences are dynamic and are partially dependent upon the actions of previous generations (see Norton et al., 1998). In particular, the development of new technologies can have a strong influence upon future generations' preferences. The present generation makes value-laden decisions, such as trade-offs between incommensurable goods, in certain ways, and does not wish to be constrained to doing this exactly as previous generations would have done. Likewise, future generations presumably will not want to be constrained to doing exactly as we do. It is unclear to what extent we should attempt to influence the preferences and constrain the behaviour of future generations in order to reduce the likelihood that they will make choices contrary to current preferences.

However, these three potentially problematic mechanisms are not limited to climate engineering, climate change or even the environment but instead are present in many – and perhaps all – significant social undertakings, ranging from the relatively mundane (e.g. land use planning) to the extraordinary (e.g. war). Similarly, even when considering only the climate engineering discourse, these three mechanisms point to challenges which are broader than the CE MH-RC concern, such as regulatory capture, technocracy, scientism, hype, technological lock-in and the so-called slippery slope. These challenges are not unique to climate engineering and it is not immediately evident why climate engineering policy should be held to especially high standards in these regards.

In addition, all three mechanisms could operate in manners which would increase mitigation and suppress climate engineering, even to harmful degrees. The presently expected net benefits of mitigation and those of climate engineering could be greater and less, respectively, than actual reality. Decision-makers could be more favourable to mitigation and more averse to climate engineering than the general population. Future generations could also be more averse to mitigation and more favourable to climate engineering than earlier ones. These are, to some degree, empirical matters whose answers are not obvious.

We should not assume that the CE MH-RC concern is warranted and that any substitution of climate engineering for mitigation would be negative. Even in the cases of the potential mechanisms which might cause deleterious mitigation reduction – mechanisms which go beyond the scope of the CE MH-RC concern and which are also present in many other policy choices – we should not assume that optimal mitigation is always the victim. Policy should be rationally designed and based upon the central goal of minimizing net climate risks to humans and the environment in accordance with society's preferences. I assert that those who argue that consideration of and research into climate engineering should be restricted because of the CE MH-RC concern have the burden to demonstrate that such effects are likely and would be harmful, and that humans and the environment would be better protected by foregoing this option. Until then, this concern should not be grounds for restricting or prohibiting climate engineering research.

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Notes

1. This is intended to be a broad definition with an emphasis on efficiency (i.e. welfare) concerns (per Hale, 2012). Below I try to incorporate what Hale calls responsibility and vice considerations.
2. For reviews of insurances such as annuities, automobile, crop, health, housing, life and long-term care, see Chiappori and Salanié (2013) and Cohen and Siegelman (2010). See also the examples of automobile repairs (Hubbard, 1998), deposit insurance (Gropp and Vesala, 2004), international lending (Dreher and Vaubel, 2004), public bailouts of banks (Nier and Baumann, 2006) and unemployment insurance (Chetty, 2008).
3. Actual climate engineering implementation may transfer risks onto others by, for example, changing precipitation patterns, and those who would choose to research and implement it may, in fact, have greater information than those who would bear the increased risk. However, as noted, the transfer of risk would neither be made socially inefficient by this information asymmetry nor be part a consensual insurance-like agreement. At the same time, if anything, climate change itself presents a similar dynamic in that those whose actions create or increase the risk – that is, mostly wealthy countries (or technically, the residents thereof) in the past and present – transfer those risks onto others – mostly poor countries in the future – and thus suboptimally mitigate (Samson et al., 2011). Andrew Parker (personal communication, 2014) speculates that this dynamic could fuel a form of climate engineering moral hazard in which wealthy countries which presently feel insulated from climate change risks will insufficiently research climate engineering, in the process leaving vulnerable countries exposed to greater climate change risks.
4. The Intergovernmental Panel on Climate Change recently reported that ‘Models consistently suggest that SRM would generally reduce climate differences compared to a world with elevated greenhouse gas concentrations and no SRM’ (Boucher et al., 2013: 575). See also Kravitz et al. (2014b).
5. In some studies, respondents expressed a CE MH-RC concern, but this implies nothing as to whether these concerns are warranted.
6. Although discounting is widely accepted, intergenerational discounting is somewhat controversial, even though its assumed value is perhaps the most important variable in climate economics. See Nordhaus (2007).
7. This paper adopts a consequentialist approach, and does not directly address deontological ethics. However, here I attempt to incorporate individually held normative preferences. This implies that those who hold these preferences would be willing to pay for them in terms of greater damage to humans and the environment as well as greater financial costs.
8. Climate engineering as a partial or imperfect substitute for mitigation has also been discussed by Barrett (2008); Bickel and Lane (2010); Emmerling and Tavoni (2013); Goeschl, Heyen and Moreno-Cruz (2013); Moreno-Cruz and Smulders (2010); Moreno-Cruz (2011) and Rickels and Lontzek (2012).
9. Davies wrote that ‘it seems far from impossible that policy packages will ultimately include a mix of reduced emissions, climate intervention, and acceptance of warming. One does not need to believe that geoengineering may be a complete solution, or a best option, to believe that it may be a desirable element of a realistically achievable total policy package’ (Davies, 2010: 269–270).
10. Estimates for the direct financial costs of implementation for the most effective yet inexpensive proposed climate engineering method, stratospheric aerosol injection, are on the order of a few to tens of billions US dollars annually (McClellan et al., 2012). In terms of climate economics, this is ‘essentially costless’

(Nordhaus, 2013: 153). The costs of mitigation, adaptation and climate change damages are each orders of magnitude greater.

11. An income effect is more prominent if the good in question is necessary and as it accounts for a greater portion of the consumer's budget. It has been empirically observed to dominate the substitute effect in the case of, for example, dietary staples among poor consumers (Jensen and Miller, 2008).
12. As a notable aside, other studies have modelled how climate engineering could lead to an increase in mitigation. Millard-Ball (2012), Moreno-Cruz (2011) and Urpelainen (2012) each considered a case in which countries are asymmetrical. Countries which could be harmed by the negative secondary effects of climate engineering would increase mitigation or be more likely to participate in mitigation agreements in order to reduce or prevent implementation of climate engineering by other countries. Goeschl et al. (2013) found that a present generation which researches and develops climate engineering could simultaneously increase its mitigation level if it believed that future generations would have a strong bias in favour of climate engineering implementation.
13. Localized SRM is offered here primarily as a theoretical exercise. Current assessments of proposed SRM methods show them to be either inexpensive and global (e.g. stratospheric aerosol injection) or expensive and potentially localized (e.g. surface albedo modification). Some researchers are presently discussing limited seasonal and latitudinal variation (MacCracken, 2009; MacMartin et al., 2013; Modak and Bala, 2014). In this paragraph, assume that an inexpensive, effective, local SRM method becomes available in the future.
14. Weitzman (2013) calls this a 'free-driver externality'.
15. This model assumed that the regions desired their 1990 conditions.
16. Although it may be tempting to portray decision-makers as being captured by powerful wealthy interests who favour continued greenhouse gas emissions, note also that aggressive mitigation would hinder economic development in poor countries.
17. This is not to say that *how* climate engineering is considered and researched will have no impacts on how it might be implemented and on mitigation.
18. Of course, the opposites may turn out to be true, and knowledge of climate engineering would have less value. I emphasize its potential value in the event of greater climate damage because people tend to be risk averse and because SRM climate engineering could be rapidly implemented.
19. Note that Parson uses this proposal primarily as a logical stepping stone to others, which he then endorses more strongly.
20. This assertion brings up the distinction, or lack thereof, between doing and allowing (see Morrow, 2014). However, note that a conscious decision to deny the possibility of climate engineering, perhaps through a taboo or a prohibition, could be considered a 'doing' action.

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