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Applying Cultural Evolution to Sustainability Challenges

Cultural multilevel selection suggests neither large or small cooperative agreements are likely to solve climate change without changing the game

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Abstract Global climate change, one of the most formidable sustainability problems facing humanity, is a particularly challenging collective action problem, because it is global, requiring the cooperation of all or most countries. Efforts to foster global cooperation on mitigating climate change have centered on large international agreements, with limited success. As a consequence, some have suggested that the problem could be better solved through a "building blocks" approach, where smaller numbers of states form multiple cooperative agreements, called "climate clubs". Recently, sustainability scientists have applied a Cultural Multilevel Selection (CMLS) Framework to a variety of sustainability problems. The CMLS Framework suggests that sustainability problems requiring collective action can often be solved through competition at a higher level of organization. For example, collective action problems arising within a fishing village could be solved through competition between villages. Here, I apply the CMLS Framework to global climate change. I show that, while higher level selection may solve smaller scale sustainability problems, it cannot solve truly global problems like climate change. I also show that multilevel selection based on climate clubs is unlikely to foster cooperation in the way that some existing models suggest. I also suggest that a potential solution to climate change may be eliminating the collective action problem altogether through investment in technological innovation that might make fossil fuels costlier than their alternatives.

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Introduction

Global climate change is one of the most pressing challenges facing humanity. Due to the release of greenhouse gases, such as carbon dioxide and methane, the earth's average temperature is increasing, resulting in rapid changes in the earth's climate, agricultural productivity, ocean levels and acidification, ecology, and weather patterns. Climate change will also likely, and potentially catastrophically, alter the planet in ways scientists have not predicted.

Preventing catastrophic climate change is a global collective action problem of public goods provision. Greenhouse gases are emitted as a consequence of economic activity, such as burning fossil fuels for transportation, manufacturing, and electricity generation. Most of the planet is governed by politically-independent territorial states responsible for the environmental regulations and economic activity within their own borders. Greenhouse gas reductions are a public good. When a state pays the economic cost to reduce or eliminate its greenhouse gases emissions the planet is better off, but states that refuse to curtail emissions will, on average, economically out-compete those that do. Much of the effort to reduce global greenhouse gas emissions has focused on large international agreements to overcome this collective action problem.

International efforts, such as the 1997 Kyoto Protocol and the 2016 Paris Agreement, have sought to reduce greenhouse gas emissions and decrease the risk of catastrophic climate change. However, despite a large number of signatories, the Kyoto Protocol has not met even its modest reduction goals and the Paris Agreement, which does not contain an enforcement mechanism, is also unlikely to meet its goals. In addition, the world's second largest producer of greenhouse gas emissions, the United States, has pulled out of the Paris Agreement claiming that even its voluntary emissions goals and reductions were too objectionable. These agreements highlight that starting to solve a global collective problem is very different than actually solving it. Once an agreement is negotiated, there is little stopping states from abandoning or ignoring their provisions.

The inability of large top–down international treaties to solve climate change has led some researchers (Santos et al. 2012; Stewart et al. 2013; Keohane et al. 2015; Hannam et al. 2015) to propose a bottom-up "building blocks" approach, where smaller groups of states form their own agreements. In these groups, sometimes called "climate clubs", member states agree to decrease their emissions. If these groups are successful (i.e., the total benefits of reducing emissions within a club exceeds the total costs), non-member states would be motivated to join or form their own climate clubs, furthering emissions reductions. Since no successful climate clubs have yet been formed, it is an open question whether climate clubs would succeed, where international agreements have failed. In this paper, I examine the collective action problem of global climate change and the suitability for small groups like climate clubs to solve it.

Cultural multilevel selection framework

Recently, an interdisciplinary group of sustainability scientists have proposed a Cultural Multilevel Selection (CMLS) Framework (Waring et al. 2015) for analyzing and proposing solutions to sustainability problems. Based on a larger literature using cultural multilevel selection theory to describe collective action problems in a variety of contexts (Henrich 2004; Safarzyńska and Bergh 2010; Zefferman and Mathew 2015; Richerson et al. 2016), the CMLS Framework is a procedure to "detail how multilevel cooperative dynamics can determine outcomes in environmental dilemmas" Waring et al. (2015). The CMLS Framework is explicitly designed to account for the type of cross-group learning posited by proponents of climate clubs. It is also designed to help determine the proper level (e.g., global, club, state, and local) at which sustainability problems are best addressed.

The CMLS framework examines how cultural traits related to sustainability change due to processes at different levels of organization. The CMLS Framework treats a cultural trait as information that is transmitted between individuals and groups through learning from others. Traits that lead to successful outcomes, represented by higher payoffs at a given level, tend to spread. The dynamics of the resulting "cultural selection" resemble evolution through genetic selection in populations of organisms. In genetic selection, organisms with more successful genetic traits are more likely to pass those traits to the next generation. In cultural selection, groups with more successful cultural traits are more likely to pass those traits to the next generation. This does not require that less successful groups go extinct, only that the traits or policies of more successful groups are disproportionately emulated. Since the CMLS Framework explicitly looks at this process of disproportionate emulation at different levels of organization, dilemmas most usefully examined with the framework are those where the costs of adopting a cultural trait (such as a climate change mitigating practice) are felt at one level of organization while the benefits are felt at a different level.

In a number of case studies, Waring et al. (2015) found that collective dilemmas at a lower level of organization can be solved through learning at a higher level. For example, they examine a case where Fijian fishermen learn and adopt fishing practices from other fishermen in their village, while Fijian fishing villages learn and adopt fishing practices from more successful villages. Within a village, a Fijian might be more successful than his fellow villagers if he refuses to adopt sustainable fishing practices (for example, refraining from overharvesting). However, fishing villages with institutions that encourage more fishermen adopt sustainable practices will tend to be more successful than villages where fewer adopt them. Villages would likely emulate those with more sustainable institutions. Thus learning between villages, if strong enough, can overcome the collective action problem within villages. Waring et al. (2015) find similar results for their other case studies, suggesting that higher level selection is a general solution to collective action problems. However, I will show that this solution does not scale up to truly global collective action problems, like climate change.

To illustrate the difference between smaller scale sustainability problems and global climate change, I will be more mathematically explicit than (Waring et al. 2015) by adopting a mathematical tool, the Price Equation. The Price Equation, developed by evolutionary theorist George Price (1970, 1972), has been widely used in evolutionary biology (Frank 1995; Grafen 1985) and has more recently been adopted for modeling cultural evolution (Henrich 2004; El Mouden et al. 2014), including small-scale sustainability problems (Waring et al. 2017). An advantage of using the Price Equation for formal multilevel selection analysis is that partitions selection at each level of organization, so that each level can be analyzed independently. Another advantage is that the Price Equation is quite general, allowing the researcher to make general statements about selection on a cultural trait that are independent of the specific details of the process. This level of generality will be sufficient for showing why higher level selection cannot solve global collective action problems:

$$\underbrace{\overline{w}\Delta p}_{\substack{\text{Change in}\\ \text{Focal Trait}}} = \underbrace{\mathrm{cov}(\mathrm{p_v}, \mathrm{w_v})}_{\substack{\text{Village-level}\\ \text{selection}}} + \underbrace{\mathrm{E}(\mathrm{cov}(\mathrm{p_i}, \mathrm{w_i}))}_{\substack{\text{Individual level}\\ \text{selection}}}. \quad (1)$$

Equation 1 is a version of the price equation, adapted to the example of the Fijian fishing villages, useful for analyzing changes in the frequency of a focal cultural trait, Δp, due to selection at two nested levels of organization. The focal trait in this instance is a sustainable fishing practice, such as avoiding overfishing. Individual fishermen, indexed by i, make up the lower level of cultural selection and villages, indexed by v, make up the higher level. The process of cultural selection at the village level is represented by $\mathrm{cov}(\mathrm{p_v}, \mathrm{w_v})$, which is the covariance between the frequency of the individuals who adopt the sustainable fishing practice in a village, p_v, and the extent to which the village is emulated, w_v. If Fijian villages that adopt sustainable fishing practices are more successful and Fijian villages preferentially adopt fishing practices from successful villages, $\mathrm{cov}(\mathrm{p_v}, \mathrm{w_v})$ will be positive, since being copied at the village level positively covaries with the adopting sustainable fishing practices. This indicates that selection on sustainable fishing practices is positive at the higher (village) level.

The process of selection at the level of the individual fishermen is represented by $\mathrm{E}(\mathrm{cov}(\mathrm{p_i}, \mathrm{w_i}))$. This is the expectation of covariance, among individual fishermen within a village, between using the sustainable practice and extent to which individuals are emulated. If fishermen who over-harvest tend to do better, on average, than fellow villagers who do not and fishermen tend to emulate successful fishermen, $\mathrm{E}(\mathrm{cov}(\mathrm{p_i}, \mathrm{w_i}))$ will be negative, because, within each village, limiting ones harvest negatively covaries with being emulated. This indicates that selection on sustainable fishing practices is negative at the lower (individual) level.

The Fijian fishing villages are an example of how a sustainability problem can be represented and analyzed with the Price Equation. The extent to which traditional fisheries practices are adopted in Fiji depends, in part, on the tensions between selection at the village level (which would favor adoption) and selection at the individual level (which would dis-favor adoption). Waring et al. (2015) report that the rise of small-scale commercial fishing and the weakening of village-level institutions during colonization led to dominance of individual-level selection and the consequent loss of sustainable fishing practices.

The basic finding that higher level cultural selection can, under the right circumstances, overcome lower level collective action problems is a common theme in a variety of empirical contexts (Waring et al. 2015) and theoretical models (Waring et al. 2017). But can the same logic apply to global climate change? In the next section I use the CMLS Framework and the Price Equation to show that it does not.

The CMLS framework and climate change

The CMLS Framework, as outlined by Waring et al. (2015) requires that the researcher (1) identify a focal cultural trait of relevance to the sustainability problem of interest, (2) describe the organizational context of the sustainability problem and the focal trait, (3) describe the levels of organization of importance, and (4) describe the history of the sustainability problem and the focal trait. Here, I conduct a CMLS analysis for global climate change.

The focal cultural trait

The focal cultural trait of analysis for global climate change is climate change mitigation, which primarily involves reducing emissions of carbon dioxide, CO_2, from the burning of fossil fuels, and methane, CH_4, from livestock and agriculture. Mitigation can involve a variety of actions, such as energy conservation, replacing fossil fuels with renewable energy sources, or carbon sequestration (storing carbon in biomaterials or underground chambers). However, the results of these actions can be conveniently measured with a common currency—the reduction in "carbon dioxide equivalents"—a measure of the flow of all greenhouse gases into the atmosphere normalized to the equivalent warming potential of carbon dioxide.

The organizational context

The primary mode of political organization over the inhabited landmasses of the planet is the sovereign territorial state which has jurisdiction within its own borders. Territorial states exist in an international system governed by a "state of anarchy" (Waltz 1979), where no governing body has over-arching authority. Of their own accord, states may choose to join or leave international bodies, such as the United Nations, or international agreements, such as the 1997 Kyoto Protocol and the 2016 Paris Agreement which were made under the United Nations Framework Convention on Climate Change. Since greenhouse gases are long-lasting and well-mixed in the atmosphere, those emitted by one state will affect all others. The effects of each carbon dioxide equivalent are, therefore, non-excludable, since individual states cannot be individually excluded from the negative consequences.

Relevant levels of selection

The economic benefits of the industrial and agricultural production that result in greenhouse gas emissions are felt at the state and sub-state level. Since territorial states have responsibility for actions within their own boundaries, they are also dominant actors for regulating economic activities related to energy and agricultural policy. However, some have suggested that greenhouse gas emission reductions can be implemented at the level of small international agreements, such as climate clubs. The harms resulting from greenhouse gas emissions—desertification, melting ice caps, extreme weather events, and species extinction—are planetary.

History

Significant increases in greenhouse gas emissions by humans began around the industrial revolution, but have accelerated in the last century. The effect of greenhouse gases on global climate became noticeable by the 1960s and a scientific consensus that human greenhouse gas emissions were causing global warming was achieved by the 1980s. The first major international agreement to curb emissions was the Kyoto Protocol signed in 1997. However, most signatories have been unwilling or unable to meet their emission reduction targets. Although there is a scientific consensus that greenhouse gas emissions cause global warming and climate change, there is not currently a political consensus, with industries and some countries denying the need for collective actions. For example, the United States, one of the world's greatest emitters of greenhouse gases, has withdrawn from the 2016 Paris Agreement after electing a government which emphasizes the economic harms of reducing greenhouse gas emissions.

The problem of planetary selection

Equation 2 is a version of the Price Equation adapted to examine changes in greenhouse gas emissions. As described above, the levels of selection relevant to this problem are territorial states (who benefit economically from activities that produce greenhouse gases) and the planet (where the aggregate harms of all emissions are felt). Similar in form to the example of the Fijian fishing villages, Eq. 2 captures these two levels of selection, the lower (state) level, indexed by s, and the higher (planetary) level, indexed by p:

$$\underbrace{\overline{w}\Delta p}_{\substack{\text{Changein}\\\text{Emmissions}}} = \underbrace{\mathrm{cov}(\mathrm{p_p}, \mathrm{w_p})}_{\text{PlanetarySelection}} + \underbrace{\mathrm{cov}(\mathrm{p_s}, \mathrm{w_s})}_{\text{Stateselection}}. \tag{2}$$

The process of selection at the level of the territorial states is represented by $\mathrm{cov}(\mathrm{p_s}, \mathrm{w_s})$. This is the covariance among states between their amount of greenhouse gas reduced p_s and the extent to which they are emulated. If states that pay the economic costs of reducing greenhouse gases do worse economically, on average, than states who do not mitigate, $\mathrm{cov}(\mathrm{p_s}, \mathrm{w_s})$ will be negative because reducing greenhouse gases hurts a states economy and makes it less likely that a state will be emulated. This indicates that cultural selection on climate change mitigation is negative at the state level.

The process of cultural selection at the planetary level is represented by $\mathrm{cov}(\mathrm{p_p}, \mathrm{w_p})$. Here the problem of supposing that selection at the higher, planetary, level would solve the lower level collective action problem of climate change is apparent. There is only one planet and, according to the definition of population covariance, a population of size one necessarily has a covariance of zero. Therefore, planetary selection does not help solve the collective action problem. It is zero and should having no effect of emissions. This makes intuitive sense since, without another planet to emulate or be emulated, selection cannot occur. Since there can be no selection at the planetary level, changes in greenhouse gas emissions, according to the model in Eq. 2, are solely determined by selection at the level of territorial state. As long as $\mathrm{cov}(\mathrm{p_s}, \mathrm{w_s})$ is negative, greenhouse gas emissions should increase unabated.

This analysis demonstrates why global climate change is more than a "standard" small-scale collective action problem writ large. Ideas for solving smaller scale collective action problems that rely on group-level selection cannot be expected to scale up to global collective action problems like climate change. For smaller scale sustainability problems, where the harms of inaction are localized, selection between groups of local actors can create positive change. However, when the group suffering negative externalities of an action is the entire planet, there can be no selection at that level since there are no other groups on which selection can occur. This helps account for the inability of global agreements to appreciably decrease greenhouse gas emissions. The problem of global climate change likely needs to be addressed at another level.

The problem of club selection

A number of authors have suggested that instead of addressing the collective action problem of climate change at the global level, it could be better solved by many smaller groups of states joining together in "climate clubs". While climate club proposals vary in their details (reviewed by Hovi et al. 2016), they can be defined as groups of states that are smaller than the entire international system that cooperate on some aspect of climate change mitigation. To examine climate club proposals in the CMLS framework, one could add a level of organization above territorial states, but below the planetary level to Eq. 2. In this section, I will examine the potential of climate clubs to solve collective action problems explicitly with multilevel selection analysis.

Equation 2 can be modified to examine selection on greenhouse gas emission reductions at the level of climate clubs by adding the term $\mathrm{cov}(p_c, w_c)$ to account for selection at the club level, resulting in Eq. 3. This is the covariance among clubs between mitigating climate change and the extent to which clubs are emulated. If clubs who pay the economic costs of mitigation do economically worse, on average, than clubs who do not mitigate, $\mathrm{cov}(p_c, w_c)$ will be negative because mitigation makes it less likely that a club will be emulated. If clubs who pay the economic costs of mitigation do better, on average, than clubs who do not mitigate, $\mathrm{cov}(p_c, w_c)$ will be positive because mitigating climate change makes it more likely that a club will be emulated. In this section I will examine club proposals to see whether it is possible for selection at the club level to be positive for mitigating climate change.

Since states are embedded in clubs, state selection is now represented by $E(\mathrm{cov}(p_s, w_s))$ which is the expected covariance among states within climate clubs of climate change mitigation with the degree to which a state is emulated. As in the previous section, selection at the planetary level, $\mathrm{cov}(w_p, p_p)$, will be zero because there is only one planet. Therefore, the change in greenhouse gas emissions for the system depends on selection at only the club and state levels. Therefore, the multilevel selection analysis in Eq. 3 shows that the primary challenge for climate clubs, creating a positive covariance at the club level between greenhouse gas reduction and club-level benefits:

$$\underbrace{\overline{w}\Delta p}_{\substack{\text{Changein}\\ \text{Emmissions}}} = \underbrace{\mathrm{cov}(w_p, p_p)}_{\text{PlanetarySelection}} + \underbrace{\mathrm{cov}(w_c, p_c)}_{\text{Clubselection}} + \underbrace{E(\mathrm{cov}(w_s, p_s))}_{\text{Stateselection}}. \tag{3}$$

A fair amount of effort has gone into modeling the economics of climate clubs (reviewed by Hovi et al. 2015). The classic economic models of climate club formation (e.g., Chander and Tulkens 1992; Hoel 1992; Carraro and Siniscalco 1993) assume that all members of a climate club set their greenhouse gas emissions to optimize the joint absolute net benefits of all club members. Under this assumption, these models show that if clubs are sufficiently large, the member states can benefit enough from their greenhouse gas reductions to offset the cost. The optimistic conclusions of these models is that, as long as climate clubs start out sufficiently large, universal club membership is not initially required.

CMLS analysis, however, highlights two weaknesses with these models. The first is that the assumption of joint optimization ignores the potential for free-riding by states within clubs. That is, it ignores the last term of Eq. 3. Even if all other members of a climate club reduce greenhouse gas emissions, a state is still economically better off if it free rides. The models do not specify why states would choose to optimize the joint benefits of member countries at the expense of optimizing their own benefits. A model showing how climate clubs help solve climate change would need to show how this within-club free-rider problem would be solved. The second problem is that, since the benefits of climate change mitigation are non-excludable, countries who never join a climate club will still benefit from the mitigation efforts of club members. Regardless of the popularity of climate clubs, non-members would, on average, be economically advantaged over club members. We would expect club membership to be selected against. Models showing how climate clubs would help solve climate change would need to show how the free-rider problem of club membership could be solved.

These problems not been overcome in a standard economic analysis where forward-looking agents optimize absolute payoffs (Barrett 2007). However, cultural selection creates an even greater challenge since selection tends to optimize relative payoffs. Even if climate clubs can solve within-club free-riding and are large enough for the net benefits to member states to be positive, they will do worse, on average, than clubs who mitigate less greenhouse gas. The optimization of relative, instead of absolute, payoffs may help explain difficulty in achieving climate change mitigation relative to standard economic models (Grundig 2006).

Two recent theoretical models using a multilevel selection mechanism have been used to propose that selection between climate clubs can overcome free-riding. I will analyze these models with the CMLS Framework which will highlight their strengths and weaknesses in terms of their likelihood of solving climate. Due to the results of the CMLS analysis, I am not optimistic that the weaknesses can be overcome.

The first of these models (Santos and Pacheco 2011; Santos et al. 2012) is designed to show how competition between clubs "significantly raise the chances of coordinating to save the planet's climate, thus escaping the tragedy of the commons" (Santos et al. 2012). Unlike the classic economic models described above, strengths of their model are that it explicitly allows for the possibility of free-riding within clubs and, by incorporating selection, tends to optimize relative payoffs. In the model, states form clubs. Club members mitigate their greenhouse gas emissions and capture all of the benefits of their mitigation. Clubs with fewer states free-riding outperform clubs with more free-riding and are more likely to be emulated. Selection at the club level, therefore, decreases greenhouse gas emissions. Under some conditions, climate clubs eventually spread so that most, if not all, countries join clubs and mitigate their emissions. Given the assumptions of their model, $\mathrm{cov}(p_c, w_c)$ in Eq. 3 is positive, indicating that clubs would be a plausible mechanism for climate change mitigation.

However, a weakness of the model is a hidden assumption that the benefits of climate change mitigation by club members could be somehow excluded from non-club members. However, as discussed under the CMLS framework above, a unit of carbon dioxide, once emitted into the atmosphere, becomes a global problem that cannot be confined to one state or set of club members. Since the benefits of climate change mitigation are non-excludable, selection at the club level, $\mathrm{cov}(p_c, w_c)$, cannot be positive because any benefits of mitigation will be shared by all states. Furthermore, selection at the club level would necessarily be negative because clubs whose members pay the costs of mitigation will on average do worse economically than clubs whose members free ride. Thus CMLS analysis indicates that the hidden excludability assumption drives cooperation in climate change in the Santos and Pacheco (2011) and Santos et al. (2012) model. A model proposing the utility of climate clubs must, therefore, pay close consideration to the excludability and non-excludability of benefits and harms at each level of organization.

A similar club selection model (Hannam et al. 2015) improves on Santos and Pacheco (2011) and Santos et al. (2012) by modeling the benefits of climate change mitigation as at least partially non-excludable. In the model, a state's climate change mitigation results in a mixture of excludable domestic benefits that accrue to the state itself, excludable club benefits that are shared only by climate club members, and non-excludable public benefits shared by all states regardless of their club membership or mitigation effort. The excludable domestic benefits are intended to represent "domestic spill-overs", such as the incidental reduction of non-greenhouse gas pollutants, such as SOX and NOX, as a by-product of greenhouse gas reduction efforts. Non-excludable public benefits are meant to represent the global benefits of reducing greenhouse gas emissions. In our CMLS analysis, domestic benefits would be captured by the last, state-level selection, term of the right side of Eq. 3 and public benefits would be captured by the first, planetary-level selection, term. If planetary selection is zero and state-level selection is negative, CMLS analysis indicates that greenhouse gas emissions can only be reduced if the final, club selection, term is positive. CMLS analysis of the model in Hannam et al. (2015) suggest that this term is governed by the model's excludable club benefits.

While Hannam et al. (2015) do not indicate how inherently non-excludable benefits of greenhouse gas reductions can be made excludable, other scholars have suggested creating excludable benefits for climate change mitigation through "policy linkages" tying greenhouse gas emission reductions to other benefits. For example, states could form research and development (R&D) clubs in which club members create excludable benefits by sharing details of advances into greenhouse gas reduction technologies with members of the club (Carraro and Siniscalco 1995). States could also form trade partnerships with club members signing beneficial trade deals with other club members and/or imposing sanctions on non-members.

A weakness of these proposals is that, even if climate change mitigation is linked to benefits that are possibly excludable, there needs to be a mechanism for free riders and non-club members to be actually excluded. It is easy to ignore this possibility. For example, Hannam et al. (2015) model a cooperative strategy that provides club goods only to club members. However, they do not model an alternative strategy that also provides club goods to non-members. For reasons described below, these alternative strategies, if added to the model, should out-compete the modeled strategies. This competition would undermine the ability of climate clubs to provide global public goods.

For example, suppose a policy linkage where reductions in greenhouse gas emissions are linked to favorable trade deals with club members. Further suppose that a similar trade deal between a club member and a non-member would be mutually beneficial (after all, if a trade deal is an incentive for club membership it should be beneficial). Under these conditions, a member state would have every incentive to make the trade deal with the non-member state, even if the non-member chooses not to join the club or reduce emissions. It would be better to free ride by relying on other member states to withhold trade deals. Similarly, a member state would likely be harmed by imposing economic sanctions on a non-member states. It would be better for the member state to free-ride off of the sanctioning by other member states. Therefore, threats to sanction non-club members and greenhouse gas emitters can be regarded as non-credible (Barrett 2003).

Policy linkages based on R&D clubs have a similar weakness. They will only be successful in reducing greenhouse gases if states refrain from sharing technological innovations with non-members. Some models

(Carraro and Siniscalco 1995) simply assume that club members will not share technological developments with non-members. However, even putting aside the technological feasibility of excluding scientific developments from particular states, incentives work against such exclusion (Barrett 2003). Therefore, policy linkages to R&D clubs also rely on non-credible threats which limit the feasibility of club-level selection to reduce greenhouse gas emissions.

This is not to say that national-level sanctions and regional trade agreements are impossible. National-level sanctions can be imposed by individual nations to further their foreign policy objectives without the need to overcome collective action problems with other countries. Regional trade agreements can be entered when the parties to the agreement find the terms mutually beneficial and, also, do not require overcoming a collective action problem. Linking sanctions and trade to an unrelated collective action problem, like climate change mitigation, is much more challenging.

In summary, policy linkages, instead of solving the problem of non-excludability at the club level, create so-called "second-order" free-riding problems (Axelrod 1986; Boyd and Richerson 1992) where club members are better off if they free-ride off of other members sanctioning and withholding of trade deals. While Hannam et al. (2015) ignores the problem of second-order free-riding, a proposal for clubs to solve climate change would need to provide a mechanism by which it would be overcome. To my knowledge, no plausible mechanism has been suggested in the literature.

This CMLS analysis raises strong doubts about the feasibility of climate clubs to solve climate change. The over-arching problem for club selection proposals is that the benefits of climate change mitigation are inherently non-excludable and, for club selection to work, the benefits must be made at least partially excludable. Policy linkages between emissions reductions and excludable benefits, such as R&D and trade partnerships have been proposed, but these proposals are subject to second-order free-rider problems where states have an incentive to not exclude non-members. Since excluding non-members from these benefits is a non-credible threat, the utility of climate clubs for solving global collective action is in doubt. Recent multilevel selection models either ignored this problem by assuming the benefits of mitigation are excludable or by ignoring the second-order free-rider problem. These issues would be likely to cripple real-world efforts to mitigate climate change. If club-level selection is unlikely to solve climate change, CMLS analysis suggests that our efforts are better spent creating positive selection at another level.

State-level selection and innovation

If planetary-level selection cannot foster climate change mitigation and club-level selection is unlikely to foster it, Eq. 3 suggests that our best hope to address greenhouse gas emissions is selection at the state-level. Specifically, the direction of selection at the state level (i.e., the last term in Eq. 3) would need to go from negative to positive. How might this occur?

An instructive case is the global reduction in production of ozone depleting substances, especially chlorofluorocarbons (CFCs), sparked by the Montreal protocol of 1987. The collective action problem of CFC emissions reduction has many similarities to the collective action problem of greenhouse gas emissions reduction (Barrett 2003, 2007; Hannam et al. 2015). The benefits of reducing CFCs were global and non-excludable and required cooperation by every, or almost every, country. The Montreal protocol, unlike climate treaties, was a great success. It is instructive to look at the factors that contributed to that success in the framework of multilevel selection.

Three key factors contributed to the success of the Montreal protocol (Barrett 2003, 2007). First, ozone depletion disproportionately harms rich states because they happen to be closer to polar regions where CFCs are concentrated. Second, in those states the marginal damages caused by ozone depletion were high enough that the marginal cost of switching from CFCs to non-ozone-depleting replacements was much less than the cost of not switching. This gave each of those states an incentive to unilaterally eliminate CFC production, regardless of the actions of other states. Many of these states started reducing CFC emission before the Montreal Protocol was ratified or implemented (Murdoch and Sandler 1997). Third, the harms of ozone depletion to the wealthier states were high enough that it was cost effective for them to pay less wealthy states to limit or eliminate production of CFCs. These "side payments" from wealthy northern states to less wealthy lower latitude states was a major part of the Montreal protocol which can be interpreted primarily as an mechanism for wealthier countries to bargain over the amount each would pay poorer countries for CFC reduction (Barrett 2003, 2007).

Side payments are still a collective action problem since a rich state is better off not making side payments if the other rich states are willing. However, unlike greenhouse gas mitigation, the problem is not structured like a public goods game. Since each country would be willing to make side payments unilaterally, it is structured like an n-person snowdrift game. When playing a public goods game, it is better to not cooperate even if no other players cooperate. In a snowdrift game, it is better to cooperate when no other players cooperate. This makes snowdrift of games much easier to solve than a public goods game. As in the case of the Montreal Protocol, states can choose to make side payments more efficient by bargaining over their respective share of the payments instead of negotiating side payments independently with states receiving payments. Written treaties, like the Montreal Protocol, helpfully record the results this bargaining process in the same way that written contracts helpfully recording the results of bargaining over, say, the agreed price of a used car.

Unfortunately, climate change mitigation may not have many of the same properties as CFC reduction. The countries most threatened by climate change are small island nations threatened by sea-level rise, not the largest or wealthiest nations with the means to make side payments to other countries. Furthermore, unlike reducing ozone emissions, reducing greenhouse gas emissions is currently so costly that few states have an incentive to unilaterally reduce emissions themselves, let alone pay other countries to do the same.

However, there is some promise that this last problem can be solved. The cost of substituting energy production from burning fossil fuels with production by solar and wind has been decreasing and in some cases wind and solar energy is cheaper than fossil fuels. In addition, advances in battery technology are turning electric motors into a cost-effective replacement for fossil fuel engines in transportation. Like CFC replacement, if alternatives to fossil fuels become sufficiently cheap, states will have the incentive to use them, regardless of what other countries choose. Selection at the state level on emissions, $\mathrm{cov}(w_s, p_s)$ in Eq. 3 will then go from positive to negative. This would solve the collective action problem of greenhouse gas reduction by eliminating it entirely.

To the extent that states, and corporations within states, could capture early-mover advantages for new sustainable technologies, they would compete to bring down the cost. Those who would produce sustainable technologies more efficiently would out-compete those who did not. States who did not adopt more sustainable energy and transportation technology or incentivize domestic research and development would under-perform their peers. Under the right conditions, this could set up an evolutionary dynamic where less sustainable states would adopt the strategies of more sustainable states. If sustainable technologies became sufficiently inexpensive the payoff structure of greenhouse gas mitigation may begin to resemble that of CFC reduction which would make cooperation more feasible. In short, a better allocation of effort for solving the global collective action problem of climate change may not be designing voluntary international agreements to foster greenhouse gas reductions, but may be, instead, fostering competition on innovative technologies that would diminish the threshold for collective action.

While this scenario is possible, there is no guarantee that the technologies that might bring about a sustainable future can be made inexpensive enough to spur cooperation. For example, if these technologies are easily copied so there was little first-mover advantage, they may not be developed at all. There also may be physical constraints on technology, such as the amount of energy that can be extracted from sunlight, that no amount of innovation could overcome. On-going competition over design and production of solar cells, batteries and lighting is driving up their efficiency and driving down their cost is evidence that this dynamic can work. However, just because this CMLS analysis suggests innovation may be a prerequisite to international agreements, does not mean it will be ultimately successful.

Discussion

The CMLS Framework is a useful tool for examining sustainability problems, and the global sustainability problem of climate change is no exception. The CMLS Framework is particularly useful because it lets us examine the costs and benefits of different actions at different levels of analysis and reason through the implications. Applying the framework to the problem of climate change, at least as I have done here, allows us to draw three conclusions. First, climate change is not just a "typical" sustainability problem writ large. Unlike smaller scale sustainability problems, such as those examined by Waring et al. (2015), climate change cannot be solved by cultural selection at higher levels of organization. Climate change is a global problem with the harms non-excludable at levels lower than our single planet. Selection cannot operate on a population of one.

Second, creating intermediate levels of organization, such as climate clubs, are unlikely to help solve collective action either. Prominent models of climate clubs either ignore the possibility of free-riding within clubs or assume that the harms of greenhouse gas emissions are excludable. Club selection favoring climate change mitigation may be possible if policy linkages can successful tie mitigation to excludable benefits created by other policies. However, policy linkages are likely to fail due to second-order collective action problems and non-credible threats. Some existing models showing the success of climate clubs have simply ignored these problems, but the existence of those problems may explain why there have been no successful examples of climate clubs outside of the models.

Finally, if selection cannot reduce greenhouse gas emissions at the planetary or club level, our last recourse may be at the level of sovereign territorial states. The global elimination of CFC production provides some precedent for this. However, this would require that the cost of alternatives to greenhouse gas generating processes become sufficiently cheap. If they become sufficiently cheap, enough countries may adopt them and, if those countries control enough wealth, they may be willing to make side payments to late adopters. While it is important to consider that there is no guarantee that technological innovation will be sufficient to replace fossil fuel burning before it is too late, recent trends have been encouraging.

A limitation of the CMLS framework is that it assumes backwards-looking learning agents instead of forwards-looking rational actors. However, in the case of greenhouse gas mitigation, forward-looking agents are susceptible to the same collective action constraints as backwards-looking agents and I reach similar conclusions to a more traditional economic analysis with forward-looking agents Barrett (2003, 2007). This CMLS analysis indicates that selection and, specifically, group selection with competing climate clubs does not create an escape from the climate change dilemma. Additionally, an anonymous reviewer suggested that the dilemma can be solved if states are both forward-looking and have altruistic preferences. I agree with the reviewer that the assuming altruistic preferences makes collective action problems trivially easy to solve in theory. However, the revealed preferences of states involved in negotiating and implementing climate change treaties does not give one much reason to believe they are altruistic in practice.

Despite its limitations, the CMLS Framework is useful in that it takes culture and selection at multiple levels seriously. A major insight of the framework is that solving collective action problems may be possible when success at one level of organization can overcome costs at another level. However, this general finding, reached with the CMLS analysis of small-scale collective action problems, is not helpful for solving global public goods because there is no larger scale under which selection might operate. This analysis suggests that resources spent crafting and negotiating greenhouse gas reduction agreements, either large-scale or small-scale might be better spent finding and promoting alternatives to the greenhouse gas emissions themselves.

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