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Equity, Urgency, Affordability: An ABM Exploration of Design Principles for Collective Action Institutions in Times of Crisis

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Abstract: Societal inequities and barriers to participation in societal decisions mean that some people and groups have difficulty in accessing sufficient resources to meet their essential needs. This increases the vulnerability of those who lack social and political capital in times of crises, such as climate change impact events. Collective action institutions can redress this inequity by facilitating the redistribution of essential resources from the wealthy to the vulnerable. In this article, we use a stylised agent-based model of a community subject to a climate change impact that affects the availability of an essential resource. We use it to explore the types of societal conditions and policies that contribute to the emergence of a collective action institution that effectively redistributes resources to ensure that people are able to maintain a sufficient level of welfare. We find that removing barriers to participation in societal decisions for vulnerable people, and increasing the sensitivity and urgency in the decision-making process to impacts in the community, help to realise effective collective action institutions. The key insight that our model helps to uncover is that participatory justice promotes timely distributive justice.

Keywords: Collective Action, Adaptation, Climate Policy, Equity, Institutional Design, Redistribution

Introduction

1.1 Social, economic, and political inequalities are persistent features of the collective human enterprise (Dorling 2015; Neckerman & Torche 2007; Alesina et al. 2016). These create barriers that reduce the ability of some people and groups of people to access resources and the means to secure their well-being (Neckerman & Torche 2007). This makes some people and groups more vulnerable in times of crisis, such as during climate change impacts (Faist 2018). While those on the bottom of the socio-economic ladder struggle to take (adaptive) action to maintain their well-being, those with wealth, privilege and power are better able to take care of themselves and even participate in societal decisions (Faist 2018; Islam & Winkel 2017). More often than not, decisions about access to essential resources are made when the interests and well-being of those with higher socio-economic capital and political voice are at stake (Rueschemeyer 2004; Beitz 2001; Przeworski 2015).

1.2 Addressing societal inequalities to reduce vulnerability and to achieve a societal state in which people are sufficiently able to meet their welfare needs is a matter of justice (Grasso 2007; Dow et al. 2006). As climate change and ecological overshoot are primarily driven by the inequitable over-consumption of natural resources by the rich and powerful (Stuart et al. 2020), there is also a moral case for seeking societal conditions, mechanisms and institutions that could facilitate more equitable levels of access to essential resources among people. The scale and severity of climate change and ecological breakdown mean that uncoordinated individual actions are insufficient to deal with their impacts (Sandler 2004). Adapting to (and mitigating) these impacts requires collective action in the form of a coordinated deployment and (re)distribution of resources at the societal level (Adger 2010).

1.3 However, such collective action is never guaranteed; rather, its likelihood depends on societal conditions and the circumstances and motivations of individuals (and groups) (Sandler 2004; Ostrom 2010b). Collective action is more likely to be achieved when individuals make decisions based on a calculus that prioritises long-term societal or communal well-being over short-term benefits to themselves (Ostrom 2010b,a). For example, if those who are wealthy and able to participate in societal decision-making feel more inclined to maintain high levels of personal welfare than to contribute to the public good, collective action institutions that facilitate equitable access to resources are unlikely to be realised.

1.4 Indeed, conventional collective action theory suggests that individuals will choose strategies that maximise their short-term personal benefits, resulting in an imperfect equilibrium from which no one is independently motivated to change their strategy (Sandler 2004; Ostrom 2010b). These assumptions lead to the prediction that the socially desirable outcome of collective action will not be realised "unless an external authority determines appropriate actions to be taken, monitors behaviour, and imposes sanctions" (Ostrom 2010b).

1.5 However, scholars also question the accuracy of the conventional theory of collective action, citing empirical evidence that contradicts it in the context of small- and medium-sized environmental and social dilemmas (Ostrom 2010b). They argue that an updated theory of collective action must consider aspects of human behaviour such as trust and reciprocity, as well as the social-environmental context that influences norms about appropriate actions (Ostrom 2010b). In contrast to the outcome of universal non-cooperation that the conventional theory of collective action predicts for societal action on climate change, real-world observations show that trust and reciprocity help to promote and sustain cooperation (Ostrom 2010a). Researchers have documented a variety of settings where people have made difficult and costly efforts to realise collective benefits, even without an external authority to impose rules, monitor compliance and assess penalties (Ostrom 2010a).

1.6 The likelihood of collective action also depends on whose needs and experiences are taken into account in deliberations about how to carry out the action (Sandler 2004; Ostrom 2010b), as well as its urgency, i.e. the level of impact required to motivate the deliberation (Van Vuuren & Stehfest 2013; Shue 2023). Wealthy people tend to be less vulnerable and exposed to climate change impacts on their well-being. If collective action is decided based on impacts on the well-off, it is bound to occur later, i.e. at higher levels of impact, than if the welfare of the less well-off is considered as the benchmark. Whose welfare motivates collective action decisions reflects the societal power structure and the level of (in)equity.

1.7 In this study we use an agent-based model to explore the conditions and policies that facilitate timely and inclusive collective action to manage access to resources. Agent-based modelling (ABM) is suitable for representing heterogeneous entities and their interactions with each other and their environment, and helps to reveal the emergent consequences of such interactions that are difficult to uncover using other modelling methods.

ABM representations of human decision-making

1.8 There are several approaches to modelling human decisions in agent-based models of coupled social-environmental systems. In microeconomic models, agents make decisions to maximise some utility, in contrast to our model where agents' decision-making is driven by the desire or need to maintain a sufficient level of welfare (An 2012). There are also psychosocial and cognitive models that try to represent decision-making as an interplay between agents and social structures, often attempting to incorporate the theory of interpersonal behaviour (An 2012). We do not use these approaches, however, as we do not wish to focus on the causes and drivers of behaviour and norm emergence. Instead, we aim to explore the potential outcomes of a well-established decision-making norm as it interacts with some societal conditions and policies on the realization and effectiveness of collective action.

1.9 Agent-based models have been used for conceptual and theoretical testing in thw social sciences for exploratory purposes, i.e. "to rigorously explore the consequences of assumptions about the general behaviour of a set of mechanisms using a computer simulation" (Edmonds 2017). Such models often have ad hoc rules that are used to test 'what if' scenarios. This is the approach of our model and study. Examples of such models include social dynamics simulations such as Deffuant et al. (2002) and Deffuant & Weisbuch (2007) to the study the behaviour of a class of continuous opinion dynamic models, and even models designed to answer archaeological questions of why ancient populations abandoned settlements or adapted to changing environmental conditions (Axtell et al. 2002; Kohler et al. 1996; Altaweel 2008; Morrison & Addison 2008).

1.10 Another application of agent-based modelling has been to model the emergence of collective action. Janssen & Ostrom (2007) and Bausch (2014) use it to examine how agent heterogeneity contributes to the emergence and evolution of social norms such as cooperation. Other studies that model the emergence and resilience of social norms of cooperation in times of resource scarcity and inequality include Schlüter et al. (2016), Rasch et al. (2016), and Nhim et al. (2018).

1.11 Our approach in this study, however, is not to explore the emergence and evolution of social norms, such as the cooperation required to achieve collective action institutions. Instead, we assume that the difficult task of achieving such a norm has already been realised endogenously or imposed through law or policy. Within such a societal context, we can then evaluate the effects of other contextual factors and policies that influence the design and implementation of collective action to achieve a sufficient level of welfare among community members.

Research question

1.12 What policy measures are effective in redistributing essential resources in crisis situations such as climate change impacts? We focus on a collective action institution with different rules for its design and organisation, and are interested in evaluating the effects of the following conditions and policies (or rules):

1. The social and political barriers to equitable participation (or inclusion) in decision-making (in terms of the operation of the collective action institution);
2. The urgency of the decision-making process, i.e. the level of societal impact or harm required to motivate it; the impact of the fiscal policy that funds the collective action institution, as well as the nature of the institution in terms of how it can translate individual contributions into public benefits; and
3. The lifespan of the collective action institution, which determines its total cost, the period over which it is accessible to those in need, and the frequency with which the decision to set up the institution needs to be made.

The Model

Purpose

2.1 In our model we present a stylised representation of a community characterised by an unequal distribution of the capacity to access and obtain an essential resource among its members. The community is subject to a periodic external (climate change) impact event that reduces the availability of the essential resource.

2.2 With this stylised agent-based model, we want to represent the inequality in people's opportunities to participate in societal decisions about access to essential needs. We use it to explore and identify some general contextual elements and principles that can help guide the design and implementation of policies that promote sufficient outcomes for people in crisis situations, such as during climate change impacts. We want to shed light on the possible effects of societal (pre)conditions and some implementation details relevant to carrying out the (adaptive) action or intervention, which policy- and decision-makers should keep in mind when societies face climate change impacts that threaten peoples' ability to meet their essential needs.

2.3 Given the shortcomings of conventional collective action theory outlined in the introduction, we do not use a game theoretic modelling approach to represent individuals' decision-making. Instead, we assume that the societal context is characterized by high levels of trust and cooperation, leading to a norm in which all individuals who have the capacity to contribute to collective action to realise a public benefit choose to do so. This simplification allows us to focus on representing and evaluating other societal conditions and policies that influence the realisation and performance of collective action institutions for the management and distribution of essential resources.

Which parameters and policies, and why?

2.4 The kinds of societal conditions and decision-making norms we represent will require significant societal changes and transformations, and seeking and achieving them will be a major cultural and political undertaking. Representing such transformations is beyond the scope of this article. For the purposes of our study, we are interested in exploring the impacts and effects of other system parameters and policy measures that influence the realisation and effectiveness of collective action.

2.5 These include the fact that social capital and political power are distributed unequally among different individuals and groups. Societal decisions on costly collective action to address external impacts and crisis situations may only be taken if they affect those who have economic and political influence (Rueschemeyer 2004; Beitz 2001; Przeworski 2015). This power asymmetry, and the resulting lack of urgency to act to minimize harm to the poor and vulnerable, often leads to the failure of collective action, or to ineffective and inadequate collective action. This can result in morally unacceptable levels of loss and damage to these vulnerable groups. Another aspect of interest is the tax structure imposed on the community to fund the collective action institution, which determines the extent or scale of redistribution of (access to) essential resources.

2.6 Finally, the function of the collective action institution as an aggregation technology (Sandler 2004), which determines the extent to which it is able to convert the level of tax funds collected into the level of public benefits realised, is also relevant in assessing which types of institutions are effective in different circumstances.

Model description

The societal context

2.7 To answer our research question, our first aim with this model is to capture a generic societal context of unequal vulnerability and climate change impact in a stylised form. The key drivers of system behaviour we want to represent are inequity among people in their ability to access resources, the relative costs associated with living and obtaining the resource, and the welfare levels that people want to attain and maintain by consuming the resource.

2.8 **Societal inequity and vulnerability**. We represent a community of people who harvest and consume an essential resource to maintain their well-being. However, their ability to harvest the resource is not equal; people are characterised by a 'resource access' attribute whose values are uniformly distributed across the population between 0 to 1. A person's resource access value determines the number of resource units they can harvest (and consume), and therefore the welfare levels they can achieve. People travel to the centralised resource region and derive well-being or welfare, represented as an energy gain, by harvesting and consuming resource units.

2.9 The community is subject to a climate change impact event that occurs with a certain periodicity and over a certain duration. The capacity of resource units to regenerate diminishes during the impact event. Unequal access to essential resources leads to unequal vulnerability among people in terms of their ability to maintain a sufficient level of well-being, especially during impact events.

2.10 **Sufficiency and the cost of living**. People need to consume resource units on a regular basis to cover their metabolic costs, an energy cost they incur each time period (tick), and travel costs, which they incur when moving a unit distance (across a patch). Peoples' well-being (or welfare level) is expressed as their energy balance:

$$energy\ balance = net\ energy\ gain\ from\ resource - (metabolic\ cost + travel\ costs) \quad (1)$$

2.11 People want to maintain at least a certain minimum acceptable energy balance, the threshold of sufficiency, while wanting to achieve a higher ('desirable') balance in proportion to their resource access value. When a person's energy balance reaches zero, they become inactive thereafter (or perish). Metabolic and travel costs increase during impact events.

2.12 **Resource consumption**. People must obtain and consume resource units when their energy balance falls below their desired energy balance level. They must leave their location (home patch) and travel to the resource region, where they must expend some energy to harvest or extract resource units before they can consume them to gain energy (welfare). The metabolic cost increases with the time that people spend away from their home patch, and they need to return to their home patch when this cost reaches a certain upper limit. This aspect reflects our fundamental need for periodic rest and recovery.

The collective action institution

2.13 Our second aim is to represent a collective action institution that seeks to address the problem of unequal vulnerability in terms of peoples' ability to maintain a sufficient level of welfare through redistribution. The key characteristics of such an institution that we want to stylise are the cost of setting it up and operating it, its operational lifetime, and the aggregation technology it represents or functions as. In addition, we also try to represent the policy instruments relevant to the institution, i.e. different tax policies to finance the collective action institution, and the urgency of this adaptive action, i.e. the level of societal impact needed to motivate it.

2.14 **The resource bank and (barriers to) its setup**. To help people maintain their well-being above the sufficiency threshold, the community can set up and operate a 'resource bank', which represents a collective action institution that facilitates the transfer and redistribution of essential resources in communities.

2.15 Setting up and operating a resource bank is costly, so it requires favourable societal conditions and policies. The first is the '**social inequity index**' global parameter, which represents the barriers for some people and groups to participate in societal decisions. Its value determines which people are included in the group that makes the decision on whether or not to set up the resource bank. (This group may can be called the 'governing' group and the rest the 'non-governing' group). For example, if the social inequity index is high, say 0.90, then only those people with a resource access value of 0.9 or higher are included in the governing group, and only their needs and experiences (welfare levels) are considered in the resource bank decision.

2.16 Another is the '**decision threshold**' global parameter, which represents the fraction (or percentage) of people in the decision-making group whose welfare level (energy balance) should have gone below the sufficiency threshold of energy balance to prompt the decision to setup a resource bank. This parameter is meant to quantify the urgency or sensitivity with which the decision to set up and operate the resource bank is taken, in particular the magnitude or level of impact required to motivate this collective action.

2.17 The decision to establish the resource bank is taken at the start of each '**decision period**', which corresponds to the operational lifetime of the resource bank. The value of this global parameter relative to the periodicity and duration of the climate change impact determines the extent to which the operation of the resource bank is synchronised with the impact periods. The decision is made when the number of people in the governing group with welfare levels below the sufficiency threshold is greater than the decision threshold percentage of the total governing group population.

2.18 **Fiscal policy and resource bank operation**. Setting up and operating collective action institutions such as the resource bank is costly, however, and therefore requires adequate funding. We assume that the cost of setting up and operating the resource bank is a function of its operational lifetime, and hence the value of the decision period parameter. The longer the decision period, the more funds need to be raised to set up the resource bank, but the longer it will last.

2.19 These funds are collected by taxing the welfare or energy balance of the members of the community. The tax policy chosen determines how much of the energy balance above the sufficiency threshold that people will donate to funding the resource bank. If it is '**flat rate**', then people donate half of their energy balance that exceeds the minimum acceptable energy balance, and if it is '**progressive**' they donate an amount proportional to their resource access attribute value. Under the latter tax policy, those with lower resource access values are required to contribute less to the resource bank than they would be under the former.

2.20 If sufficient funds have been collected to cover the set up and operation costs of the resource bank and the decision threshold criterion has been met, the resource bank is set up and operates for the duration of the decision period. The resource bank can be set up as a collective action institution that functions as one of two **aggregation technologies**: **summation** and **threshold**. An aggregation technology is the relationship between the contributions towards collective action and the realization of that collective action (Sandler 2004). In a summation aggregation technology, the scale or extent of collective action is proportional to the sum of individual contributions. In a threshold aggregation technology, contributions must exceed a minimum threshold for the collective action to be realised.

2.21 If we set the aggregation technology as threshold, then the resource bank is set up during a decision period only when the set up and operation cost has been collected. If it is a summation aggregation technology, the resource bank can be set up even if the (energy) funds collected fall short of this cost. However, it will only operate at a (partial) capacity in proportion to the amount of funds that were collected, e.g. if the individual contributions added up to 50% of the cost of a fully-functioning resource bank, then the resource bank is only able to accept and redistribute 50% of the energy funds that people are able to donate.

2.22 Once the resource bank has been established, people whose welfare level is above the minimum acceptable energy balance threshold can travel to the resource bank and donate a portion of their energy balance above the threshold according the prevailing tax policy. Those whose welfare level is below the sufficiency threshold can travel to the resource bank and receive energy funds that improve their welfare levels, thereby increasing their chances of remaining active (not perishing) and travelling to the resource region to harvest the resource. In effect, the resource bank facilitates some redistribution of welfare from the wealthy to the vulnerable.

Key performance indicator (KPI)

2.23 During a model run, people seek to maintain a welfare (energy balance) level above the minimum acceptable level of sufficiency, for which they must harvest and consume resource units. Those who have been unable to harvest enough resource units can seek energy funds from the resource bank, if one has been set up. Our objective is to discover which parameter settings, representing societal conditions and policies, minimise the number of people who are unable to maintain a sufficient welfare level and eventually perish (become inactive).

2.24 Our KPI is therefore the number or **percentage of people who (are able to) remain active**. This is effectively our metric for societal resilience under climate change impact(s).

Overview of model elements

2.25 The parameters, norms, and policies that we include in the model, which drive the agent and system behaviour, represent different aspects of a generalised and stylised societal context in which people seek to maintain their well-being at a sufficient level in times of crisis and resource scarcity.

2.26 Here we categorize our parameters, policies, and norms according to their function in the model.

Context	Uncertainties	Levers	KPI
pattern of societal inequity (re. involvement in decision-making)	resource bank cost	societal inequity	% people remaining active
aggregation technology characteristic of the resource bank	resource production	decision threshold	
decision-making criteria or norms	welfare (energy) gain from resource	tax policy	
resource access capacities	resource bank lifetime (and the associated decision period)		
	effect of climate change impact event		
	metabolic, travel, and resource harvest costs		
	desirable and sufficiency levels for resource consumption		

Table 1: Model elements categorised according to their function in the model.

Association of model concept with real-world scenarios

2.27 What real-world coupled social-environmental system(s) could our model claim to be a reasonable stylised representation of? First, our model captures these realities:

- That the ability to access and consume essential resources is unequally distributed among societal members.
- Resources are limited and often scarce, and their availability and regenerative capacity are declining due to the consequences of ecological overshoot, such as climate change.
- There is an energy cost to obtaining (or extracting) resources, as well as for the establishment of institutions that facilitate their redistribution.

2.28 Under these conditions, we could imagine that the resource whose consumption represented in the model could be food or water. The resource bank could then be a collective action institution that aims to improve food or water security by ensuring that those who are vulnerable and in need have sufficient access to these essentials.

2.29 If we consider the resource to be food crops, then the community we represent could be an agrarian one, and the value of the resource access attribute represents the relative amount of arable land that each person is able to cultivate. Contributions to the resource bank would be agricultural products. The community can also be imagined as a non-agrarian urban one, in which case the resource access attribute would represent a person's income level, which affects their ability to purchase sufficient food. The resource bank in this case could be thought of as a food bank or community kitchen that provides meals to those who cannot afford enough food. Donations to the food bank or community kitchen could either be direct donations of food, or they could be thought of as income donations that allow the food bank to purchase and stock up on food items.

2.30 Which of the two aggregation technologies would be used to the functioning of the resource bank in these scenarios would depend on whether or not the physical infrastructure for it exists already or needs to be built. If the infrastructure required is negligible or already exists, then the resource bank can operate as a summation aggregation technology, otherwise as a threshold.

2.31 If we consider the resource to be water, then the resource bank could be either a surface water reservoir or a groundwater well that the community must decide to build and expend energy and resources to do so. If it is a reservoir, it would be a summation aggregation technology because its size (volume) would be variable according to the amount of effort expended to build it. If it is a groundwater well, it would be a threshold technology because it would have to be dug down to at least a certain depth to reach the water table.

Model results

Overview of a model run

3.1 At the start of a run, people have a certain level of welfare or energy. This decreases each tick as a metabolic cost, and when a person's energy balance falls below a desirable level, they are motivated to travel to the resource region to harvest and consume the resource, resulting in a welfare or energy gain. However, people have different resource access capacities, which means that some are able to harvest more resources and gain more welfare (energy) levels than others. People seek to maintain at least a certain sufficient level of energy, and when their energy balance has decreased to zero, they become inactive (or effectively perish). The community is periodically subject to a climate change impact of some duration, which reduces the availability of the resource and prevents more people from achieving a sufficient level of welfare.

3.2 In our base case scenario, there is no societal norm to set up a collective action institution to facilitate the redistribution of wealth so that those in need can maintain it at a sufficient level. The scenario we want to evaluate and compare with the base case is one in which there is a societal norm to set up a collective action institution in the form of a resource bank does exist. In this case, the community can collect funds to set up and operate a resource bank that facilitates the transfer of wealth from the better off to those in need. Once the resource bank is established, people with welfare or energy levels above the sufficiency threshold can travel to it to donate some of their welfare, while those with lower levels can travel to it to gain welfare. Figure1 shows such a scenario with an operational resource bank as implemented in our model's UI.

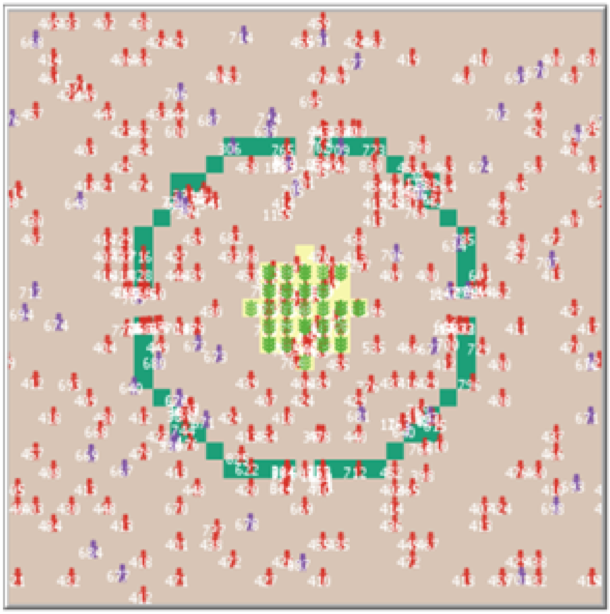

Figure 1: A screenshot of the community as represented in the model UI, depicting the central resource patches in yellow with green resource units, people (tagged with their energy balance) belonging to the governing group in red & those not included in that group in purple, and the green resource bank region that encloses the resource patches, from where people can access the resource bank.

3.3 The likelihood that the resource bank will be set up and effective at improving sufficiency levels depends on a set of contextual elements and policy measures, represented by a set of parameters whose influence we want to evaluate. Our goal is to find out which policies tend to yield an effective resource bank under different societal contexts, in particular under different levels of societal inequity in terms of the barrier to participation in collective action decisions.

Experiment setup

3.4 Our model's purpose is exploratory, and so we do not calibrate it with real-world data and use it to predict outcomes under different conditions and policies. Accordingly, our analysis will be a comparative one, with to the aim of identifying the combination of conditions, norms, and policies that tend to produce favourable outcome patterns. A comparative analysis by means of a generalized abstract representation of aspects of designing and operating a collective action institution, has the potential to shed light on the types of societal conditions to aim for in the long term, as well as the type of policies to put in place in the short run.

3.5 Our baseline scenario is the societal context in which there is no norm for attempting to establish the resource bank collective action institution. We compare the outcomes of societal contexts in which there is such a norm to outcomes of the baseline scenario and try to identify which policies lead to outcomes where the resource bank is (more) effective at facilitating sufficient access to essential resources for vulnerable people.

3.6 We record and plot our KPI against the **social inequity index** global parameter, which represents the extent of social and political barriers for different people to be able to participate in societal decisions: the higher the index, the smaller the number of people included in the decision-making group. We want to explore the effect of our other system parameters – the **decision threshold**, the **decision period**, the **tax policy**, and the **aggregation technology** – across the value range of the social inequity index. We are interested in finding out which value ranges and combinations of these parameters are likely to yield an effective resource bank.

3.7 We record outcomes at the 1500, 3000, and 7500 ticks marks, to be able to roughly track the evolution of each run, in particular its state at early, mid and late periods. We do this because some parameters and processes may be more or less influential at different periods. We do not record results earlier than 1500 ticks because we observe that the state of the community tends not to be very different from the initial state at such early stages of a run. On the other hand, by about 7500 to 10,000 ticks, the vast majority of runs will have either collapsed to a low (or zero) population or reached a steady-state number.

3.8 This is a stylised model designed to explore the types of outcome patterns that different relative valuations of our system parameters can produce. Table 2 shows the estimated parameters.

Parameter	Type	Values
Social inequity index	Contextual	0.00 – 1.00
Operate resource bank?	Contextual (Norm)	Yes or no
Resource bank setup cost	Contextual	0.00 – 0.10
Decision period	Contextual or policy	1 Tick – 100 Ticks (4x the duration of the climate impact event)
Decision threshold	Policy	0% – 100%
Tax policy	Policy	Flat rate or progressive
Aggregation technology	Contextual or policy	Summation or threshold

Table 2: Model parameters and their value ranges for the experiment.

Results & analysis

3.9 In our analysis we consider the collective action institution of the resource bank to have been effective if it leads to a higher number of people remaining active compared to the base case scenario.

Baseline scenario: No resource bank

3.10 Our baseline scenario is runs in which there is no societal norm to set up the collective action institution of the resource bank. We plot the results from the baseline runs and those from runs with the norm to set up the resource bank in adjacent panels to compare the resource bank's effectiveness under different conditions and policies. The dots in the plots are the values of our KPI at certain points of time (1500, 3000, and 7500 ticks) during a run, and the lines are local regression fits to those dots generated by the loess() function in R.

3.11 While the local regression trend lines are useful to get a summary view of the outcome patterns, we should be careful not to rely too much on them, as they necessarily average out very different results, which can lead us to wrongly assuming smooth and continuous result patterns and system behaviour. The distribution of the plot points themselves is our primary gateway to analysing our results.

Outcomes with the resource bank

3.12 In order to focus on the parameter value ranges that are more conducive to achieving an effective resource bank, we first calculate the linear correlation coefficients for the number of people remaining active at 7500 ticks with our key model parameters for these groups.

	Active population outcome correlation	
Model parameter	**Progressive tax**	**Flat rate tax**
Social inequity index	-0.12	-0.15
With decision threshold < 25%	-0.26	-0.32
Decision threshold	-0.25	-0.29
With social inequity index < 0.25	-0.38	-0.44
Decision period	0.034	-0.005

Table 3: Linear correlation coefficients between the active population outcome and our parameters of interest.

3.13 First, we find a negative correlation between the social inequity index and the active population, which means that as the former increases the latter tends to decrease. The lower the social inequity the higher the number of people remaining active tends to be. We also find a negative correlation between the decision threshold and the active population, which means that lower values of this parameter tends to favour a higher active population.

3.14 We find that a flat rate tax results in a higher negative correlation than a progressive tax between the social inequity index and decision threshold parameters and the active population outcome. The correlation coefficients suggest that lower social inequity and decision thresholds are conducive to achieving an effective resource bank. We do not find a meaningful correlation between the active population and the decision period parameter. Plotting the active population outcome against the social inequity index and decision threshold parameters confirms the trend suggested by the correlation coefficients.

3.15 We see that the active population is higher at low values of social inequity and approaches the outcomes of the baselinescenario with no resource bank at higher values (Figure 2, panel B). Low values of the social inequity index mean a greater number of people are in the governing group who make the decision to set up the resource bank. The lower the social inequity, the higher the number of people with lower social capitals that are included in the decision-making governing group.

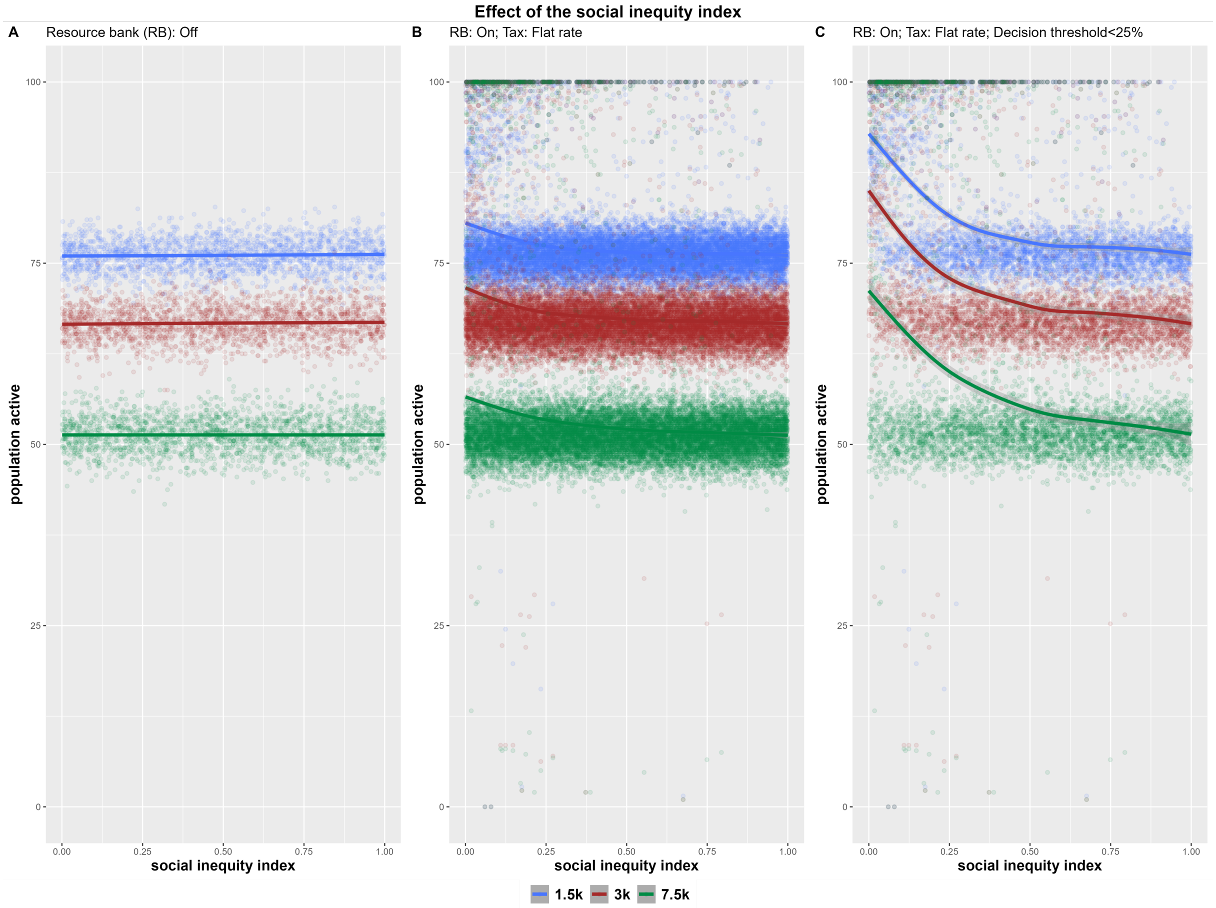

Figure 2: Percentage of people remaining active versus the social inequity index. Panel A shows results for the baselie scenario runs where there is no norm to set up the resource bank. Panel B shows results with the norm to set up the resource bank, and panel C results with the decision threshold restricted to lower values in its range.

3.16 We observe a similar result for the decision threshold parameter, with low values favouring better active population outcomes and higher values leading to the resource bank not being established (Figure 3, panel B). The lower the decision threshold the lower the societal impact (welfare decline below the sufficiency threshold) at which the decision to set up the resource bank is taken. This means lower decision threshold values allow for higher sensitivity to impacts on welfare in decision-making leading to greater urgency to set up the resource bank.

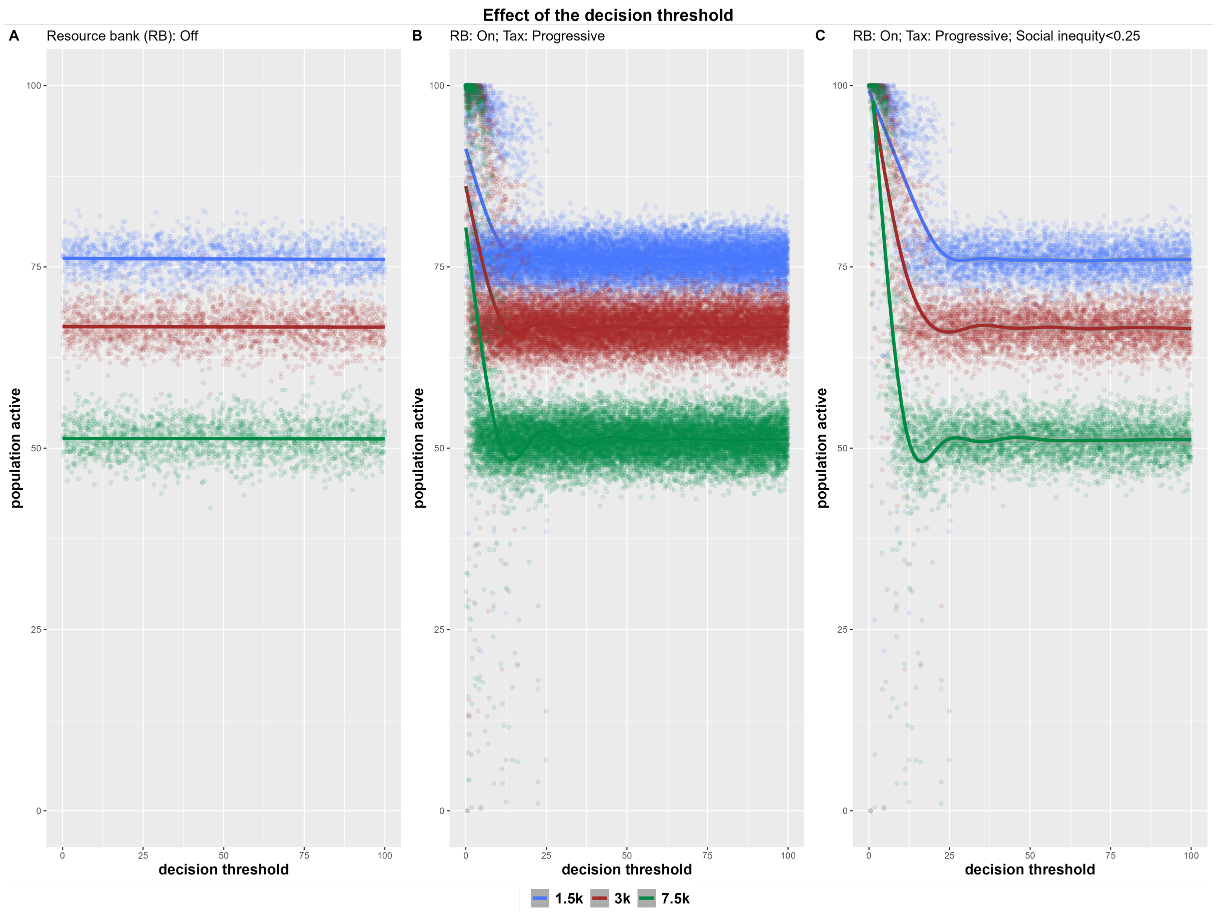

Figure 3: Percentage of people remaining active versus the decision threshold. Panel A shows results for the baseline scenario runs where there is no norm to set up the resource bank. Panel B shows results with the norm to set up the resource bank, and panel C results with the social inequity index restricted to lower values in its range.

3.17 Lower values of these two parameters are conducive to setting up the resource bank and redistributing welfare, while higher values pose a barrier that prevents the resource bank from being set up so that welfare redistribution does not occur. When we plot the active population outcome against the social inequity index while restricting the decision threshold to values at the lower end of its range, and then against the decision threshold while restricting the social inequity index to values at the lower end of its range, we find an even greater improvement (Figures 2 and 3, panels C). Low social inequity and decision threshold values offer the best conditions to realize a resource bank that is effective at redistributing welfare.

3.18 These results show that participatory justice in the form of greater inclusion of lower social capital people in the decision-making process is conducive to the timely realization of redistributive collective action institutions. Participatory justice helps foster distributive justice.

3.19 In our plots we find that there are some runs where the active population outcomes are worse than in the base case scenario of no resource bank. These represent cases in which the resource bank has been ineffective and in fact detrimental to peoples' welfare. The next step in our analysis is to identify the conditions and policies that lead to such an ineffective resource bank.

3.20 We did not find any conclusive correlation between the active population outcomes and the decision period parameter. However, when we set the size of the points according to the value of the decision period parameter in the plots of the active population against the social inequity index and decision threshold parameters, we see that the runs in which outcomes were worse than in the base case scenario are those with very low values of the decision period (Figures 4 and 5, panels B and C).

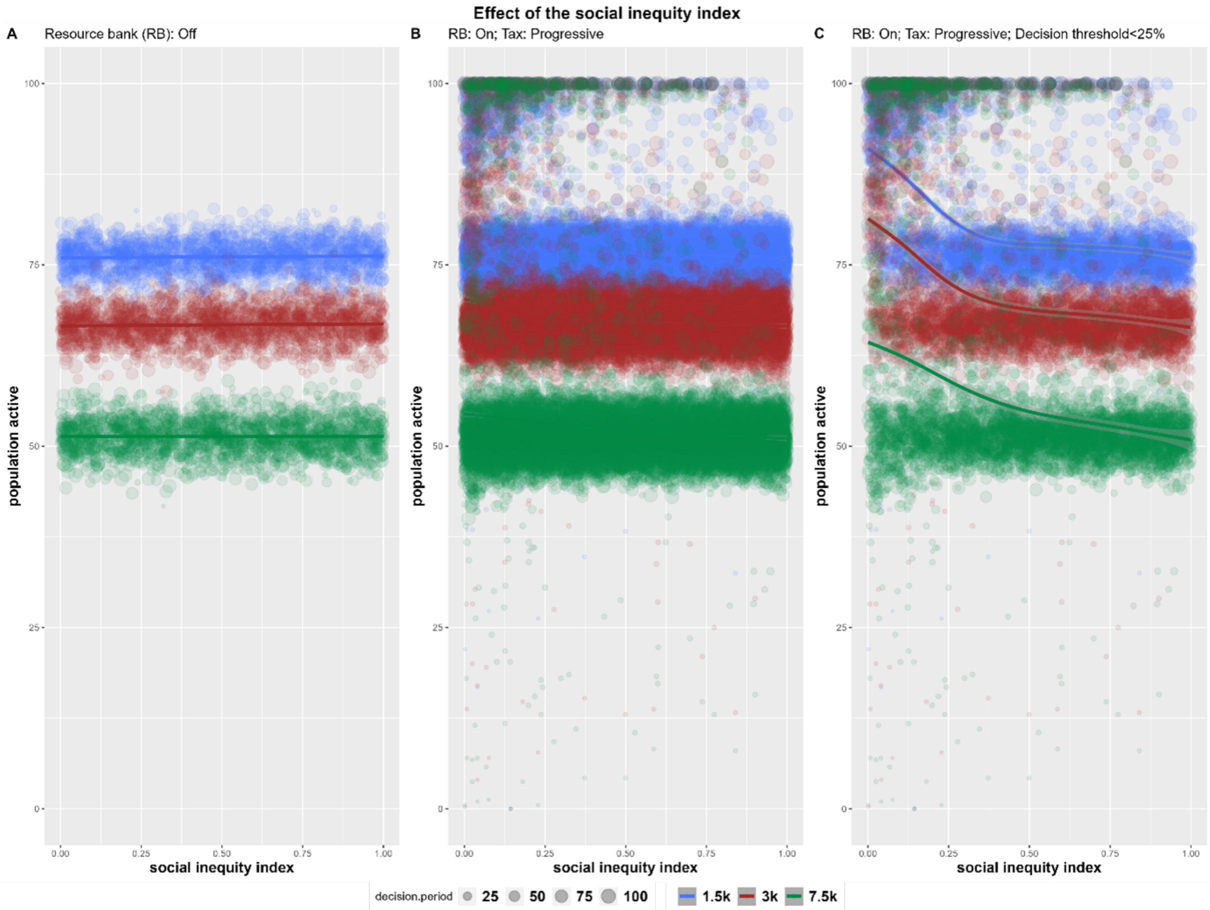

Figure 4: Percentage of people remaining active versus the social inequity index. Panel A shows results for the baseline scenario runs where there is no norm to set up the resource bank. Panel B shows results with the norm to set up the resource bank, and panel C results with the decision threshold restricted to lower values in its range. The size of points is based on the value of the decision period parameter during the model run.

3.21 As the decision period parameter represents the operational lifetime of the resource bank, this suggests that collective action institutions with lower lifetimes that require frequent investment to set up can prove ineffective by being a drain on a community's resources and welfare. We did not find any meaningful effect of the tax policy and the aggregation technology of the resource bank on outcomes, so we have left these out of our analysis and discussion.

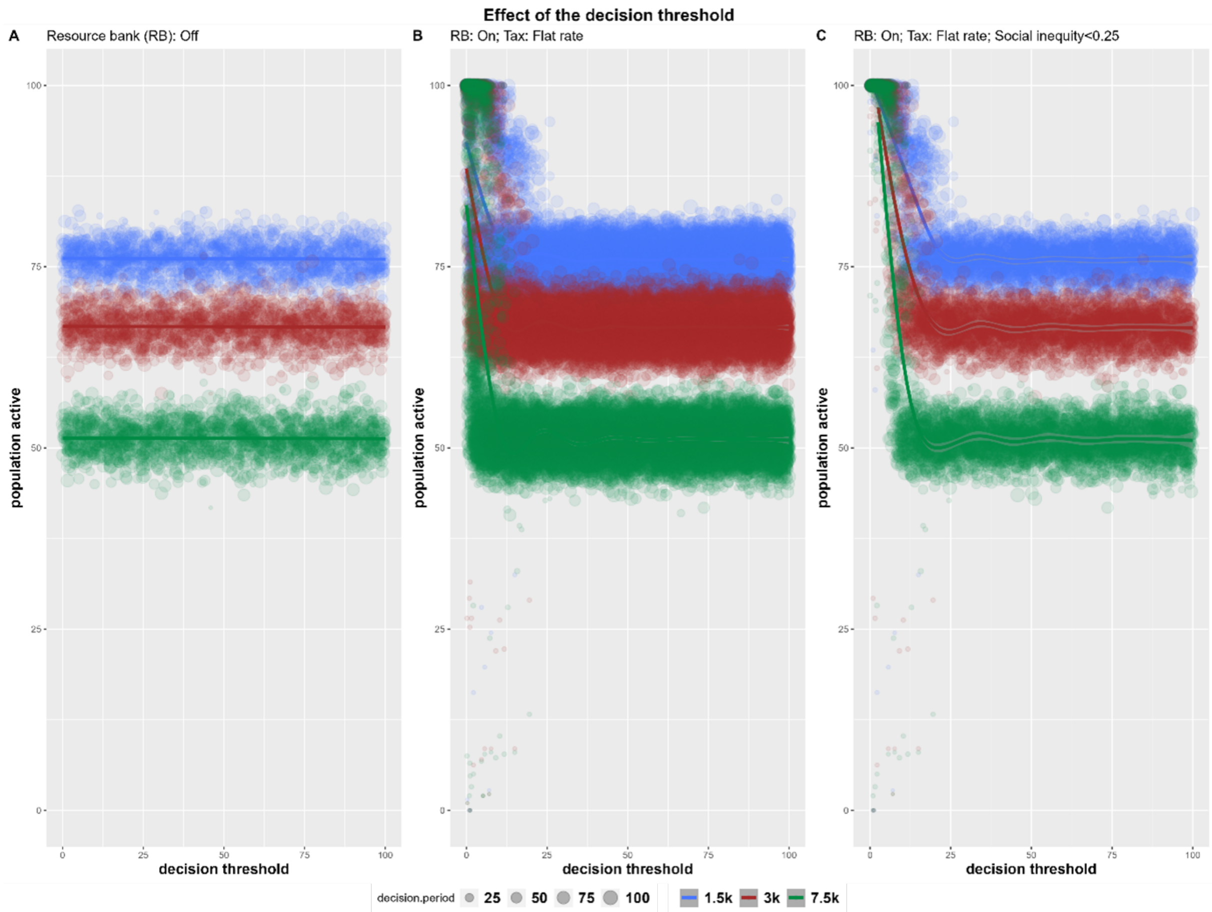

Figure 5: Percentage of people remaining active versus the decision threshold. Panel A shows results for the baseline scenario runs where there is no norm to set up the resource bank. Panel B shows results with the norm to set up the resource bank, and panel C results with the social inequity index restricted to lower values in its range. The size of points is based on the value of the decision period parameter during the model run.

Discussion

4.1 What do the patterns of outcomes we have seen suggest about what it takes to realise an effective collective action institution? We now discuss general but basic principles that emergence from our findings that should guide the design and implementation of collective action institutions in order for them to be effective in redistributing resources in times of crisis, such as during climate change impacts.

Social inequity

4.2 First, we can conclude that collective action institutions are more likely to be realised in communities where inequity between people in terms of their ability to participate in societal decisions is low. In order to achieve timely collective action that is effective at addressing vulnerabilities and improving welfare outcomes in crisis situations, it is crucial to include the voices and experiences of those who are vulnerable, as they tend to be the first to be affected. If societal decision-making responsibilities and privileges are limited to an elite group of wealthy people who tend to be less exposed to resource scarcity and other climate change impacts, and if this group makes decisions based solely on their needs and experiences, then the decision to establish the collective action institution is less likely. Participatory justice is therefore crucial to achieving distributive justice.

4.3 However, the level or extent of social inequity is a contextual issue rather than a policy measure with immediate impact potential. For communities with high levels of inequity where the governing elite does not adequately consider the welfare needs and experiences of the poor and vulnerable, the transition to a state of (much) greater equity, representation, and participation in societal decisions would be a major social undertaking, requiring much time and effort. Such a restructuring of relations and power dynamics in societies can only be achieved over the long term, if at all, but our findings suggest that such a societal state may be worth working towards, especially as climate change impacts rise in frequency and severity.

Urgency in decision-making

4.4 Our results also suggest that collective action institutions are most effective when they are implemented or organised with a high degree of urgency or sensitivity to community impacts. Our observation of the effect of the decision threshold parameter gives us the insight that it is important to initiate collective action early, at lower impact levels, rather than waiting for higher numbers of people to be affected. High urgency and sensitivity in decision-making also makes it easier for communities to bear the costs of collective action, as there are (necessarily) more community members able to contribute in the earlier stages of climate adaptation efforts than in the later stages.

4.5 Our work makes a strong case for societies to make decisions on and allocate resources to collective action urgently when climate change impacts are relatively small compared to future projections. A lack of urgency in collective action now is likely to lead to circumstances in which collective action becomes increasingly infeasible in the future. Action taken now is far more effective and valuable than action taken in the future.

Lifetime of the collective action institution

4.6 The lifetime of the collective action institution determines the time period over which it can facilitate the redistribution of wealth and the frequency with which the decision to set it up needs to be made. In addition, we assumed that longer-lived resource banks have higher setup costs, which implies a trade-off between the affordability of the resource bank and the duration over which it can function.

4.7 Our results suggest that a collective action institution cannot be effective if it is too short-lived, even though it is less costly to set up a short-lived institution. On the other hand, we also find that the longer the operational lifespan of institutions, and hence the higher their setup costs, the less effective they are at improving outcomes. Indeed, very long-lived institutions with fixed set setup costs are not even feasible.

4.8 What does this mean for the real world? We could think of short-lived, low-cost institutions as those that merely facilitate the redistribution of essential resources, but do not have the capacity to preserve and store them over time. Longer-lived institutions with higher up-front costs would facilitate redistribution as well as allow the preservation and storage of the essential resource for non-immediate use. For example, if the essential resource is food, then a short-lived, low-cost institution might be a food bank that simply redistributes food from the better-off to the needy, e.g. by providing meals. However, a longer-lived institution with a higher set-up cost might have the resources and infrastructure to preserve and store food for periods of scarcity, e.g. by drying, canning and pickling. If the essential resource is water, then a short-lived, low-cost institution could be an arrangement by which community members with inadequate access to water can obtain it from those with more than the minimum supply. A longer-lived institution with a higher set-up cost might be a system of reservoirs, such as ponds and tanks, to store rainwater for future use.

4.9 In such cases, the longer-lived institution with higher up-front costs clearly promises greater benefits to communities, but with diminishing returns as its size and scale pushes the limits of affordability. Adaptability and flexibility in the sizing and scaling of collective action institutions is desirable, especially given the range of climate-related impacts and challenges that will form a permanent backdrop for societies.

Our contribution to the literature (on institutional design)

4.10 Collective action institutions if designed according to some basic principles, can be effective in redistributing essential resources in communities where people have unequal capacity to access them. These principles involve both societal conditions and policy measures.

4.11 We show that barriers for vulnerable people to participate in societal decisions about collective action, lack of sensitivity to the impacts on the vulnerable and the resulting lack of urgency in decision-making, and an inadequate operational lifespan are detrimental to the goal of achieving an effective collective action institution.

Limitations and future work

4.12 Our model is a stylised one aimed to explore the consequences of specific societal contexts and policies on the realisation of an effective collective action institution. As such, it has limitations inherent to all abstract and stylised models, namely that it is not calibrated with real world data and that it is useful not for predicting specific outcomes but for comparing outcome patterns arising from differences in the quantification of parameters relative to each other. However, a strength of this approach is that it allows us to explore the consequences of alternative ways of organising societies and decision-making, which models based on current political and economic systems cannot do.

4.13 A notable limitation of our representation of a community experiencing climate change impacts is that these impacts will increase in frequency and severity, which means that the availability of essential resources will decrease. However, in our model, we only represent a non-escalating impact that occurs at a regular interval and severity for a regular duration.

4.14 Future work could include exploring the effects of different tax policies in adaptive collective action contexts, where they are a more important driver of behaviour and outcomes. Another aspect to be explored is peoples' contribution to collective action, which is not imposed by some authority, but rather influenced by policy measures such as incentives and penalties, and which evolves through learning from one's own and others' experiences.

Conclusions

5.1 In this study we have explored the implications of some principles for the design of collective action institutions that are effective in redistributing essential resources in crisis situations. These include the ability of vulnerable people and those with lower social and political capital to participate in societal decisions; the urgency or sensitivity of the decision-making process to the onset of impacts on community members; the operational lifetime of the collective action institution; the fiscal policy that funds the institution, and its nature as an aggregation technology.

5.2 To this end, we used an agent-based model in which we stylised a community whose members need to maintain a minimum sufficiency level of welfare by consuming an essential resource whose availability is subject to a periodic climate change impact. We found that lower levels of social inequity in terms of peoples' ability to participate in decision-making combined with urgency in decision-making arising from sensitivity to the welfare of the less wealthy, are conducive to the implementation of collective action institutions. Their effectiveness in redistributing essential resources and improving welfare also depends on their lifespan.

5.3 As we witness extreme weather events increasing in frequency and severity, often simultaneously in different parts of the world, our work suggests that societies should take urgent action now to realise collective action institutions that can effectively redistribute essential resources to the vulnerable. This is especially important as climate change impacts begin to be felt decades earlier than expected by climate scientists, and as the risk of disruptions to food and water supplies increases. With crises looming on the horizon for societies around the world, inclusive and urgent collective action is needed now to ensure that people, especially the less well-off, are able to maintain sufficient levels of well-being.

Model Implementation

The model has been implemented in NetLogo 6.2.0.

It is available at: `https://github.com/aashisjoshi/collective-action-institution-principles-ABM` and `https://www.comses.net/codebases/fedf4785-96fd-4c2a-8a64-848d07fcf943/releases/1.0.0/`

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Appendix: ODD Protocol

Purpose

Our model aims to capture a generic societal context of unequal vulnerability and climate change impact in a stylized form. The key drivers of system behaviour that we want to represent are inequity between people in their ability to access resources, the relative costs associated with living and obtaining the resource, and the welfare levels that people want to achieve and maintain by consuming the resource. Within a societal context where the norm to engage in collective action exists, we can then evaluate the effects of other contextual factors and policy measures that influence the design and implementation of a collective action institution that redistributes essential resources to facilitate a sufficient level of welfare among community members.

In particular, we are interested in evaluating the effects of the following conditions and policies (or rules) on realisation of a collective action institution that is effective at redistributing essential resources:

- The impact of social and political barriers to equitable participation (or inclusion) in decision-making (re. operating the collective action institution);
- The impact of the urgency of the decision-making process, i.e. the level of societal impact or hard required to motivate it; the impact of the tax structure or policy that funds the collective action institution, as well as the nature of the institution in terms of how it can translate individual contributions into public benefits; and
- The impact of the length of time the collective action institution functions once it has been set up, i.e. its operational lifetime, which determines its total cost, the time period for which it is accessible to those in need, and the frequency with which the decision to set up the institution is taken.

Entities, state variables, and scales

People, resource patches and units, and the resource bank are the three entities represented in the model. The state variables that characterise them are:

Attribute/Variable Name	Brief Description
Resource access	A person's resource access value determines the amount of resource units they can harvest (and consume), and therefore the welfare levels they are able to achieve.
Energy balance	The welfare level of a person at any point during a model run. Consuming the resource leads to energy gain.
Desired energy balance	The energy balance value that people desire to achieve. People will seek the resource when their energy balance falls below this level.
Minimum acceptable energy balance for sufficiency	The minimum level of welfare that is considered sufficient for people. If a person has an energy balance below this, they are not taxed.
Starting energy balance	Each person is endowed with an energy balance with a random value between the minimum acceptable energy balance for sufficiency and their desired energy balance at the start of a run.
Metabolic cost	A cost of living energy expense that people incur each tick.
Travel cost	An energy expense that people incur each time they move a unit distance.
In governing group?	If a person's resource access attribute is equal to or greater than the social inequity index, then they are part of the governing group that decides whether or not to set up the resource bank.

Table 4: Attributes and variable descriptions for people.

Attribute/Variable Name	Brief Description
Energy gain per resource unit	The amount of energy or welfare that a person gains when they consume a resource unit.
Energy cost per resource unit	The amount of energy or welfare that a person has to expend to harvest and consume a resource unit.
Impact sensitivity	The rate at which resource units regenerate during periods of the climate change impact is determined by this attribute. It is set at fixed value.

Table 5: Attributes and variable descriptions for resource units.

Attribute/Variable Name	Brief Description
Resource production capacity	The number of resource units that each resource patch can (re)generate. It decreases during periods of the (climate change) impact.

Table 6: Attributes and variable descriptions for resource patches.

The spatial and temporal scales in the model are not absolute but rather relative between people in the represented community and are the result of people being located at different distances from the resource region as well as the resource bank. This means that those who are nearer to these can access them quicker and incur a lower energy expense, which is an advantage over those who are located farther away. However, this advantage is largely cancelled out at the community level, as peoples' ability to consume the resource and increase welfare levels is mostly determined by their resource access attribute value, and people are located randomly regardless of their resource access.

Process overview and scheduling

1. During any given tick, the community is either experiencing the climate change impact event or not. This depends on the frequency and duration of the impact event (set in the code).
2. During periods (ticks) of the climate change impact event, resource units regenerate more slowly than compared to periods where the impact does not occur. This leads to a periodic scarcity of the essential resource.
3. Individuals lose a certain amount of welfare or energy each tick as a metabolic cost. If their energy (welfare) level goes below a certain value that they want to maintain, they will travel to the resource region to harvest and consume resource units. Traveling also costs energy (welfare).
    - The amount of resource units that each person can harvest is determined by the value of their resource access attribute, which follows a normal distribution from 0 to 1 centred around 0.5.
    - People also incur a wear-and-tear cost for each tick that they spend outside their home patch. When this cost becomes greater than the metabolic cost per tick, people return to their home patch to rest and replenish. When they do so, their wear-and-tear level is reset to zero.
4. If a person's welfare (energy) level goes below the sufficiency threshold and they do not have enough energy to travel to the resource region, they will travel to the resource bank to obtain welfare funds, if it has been set up.
    - If they welfare level drops to zero, they perish or become inactive for the rest of the run.
5. People can either belong to the governing group, which decides whether or not to set up the resource bank, or to the non-governing group, which isn't allowed to participate in the decision. A person belongs to the former group if their resource access attribute value is greater than or equal to the social inequity index.
6. If the norm of engaging in collective action to set-up the resource bank exists (is turned on), then people in the governing group will periodically take this decision. This periodicity is determined by the decision period parameter, which represents the operational lifetime of the resource bank.

- The governing group will decide to set up the resource bank if the percentage of people in that group with an energy balance lower than the minimum sufficiency threshold is equal to or greater than the value of the decision threshold parameter.
- To set up the resource bank, all people with an energy balance greater than the minimum sufficiency threshold are taxed a share of their energy balance. This share is determined by the tax policy chosen during the run.
- The resource bank gets set up if the amount of energy funds collected via tax is equal to or greater than the cost of setting up the resource bank.

Design concepts

Basic principles: The model is based on the premise that:

- The ability to access and consume essential resources is inequitably distributed among societal members.
- Resources are limited (and often scarce), and their availability and regenerative capacity are declining due to the consequences of ecological overshoot, such as climate change.
- Obtaining (or extracting) resources incurs a cost (in energy), as does operating institutions that facilitate their redistribution.

Emergence: The effectiveness of the resource bank in redistributing welfare from people with more than the minimum sufficient energy balance to those with a balance less than this threshold emerges from the interplay of model parameters such as the social inequity index, decision threshold, decision period (operational lifetime of the resource bank), and the cost of the resource bank as well as agent attributes such as peoples' energy balance, and the number of people remaining active (and therefore able to contribute to the resource bank).

Adaptation: Once the resource bank has been set up, then people with an energy balance (welfare level) above the minimum sufficiency threshold will donate some of their energy balance to the resource bank, while people with an energy balance below the sufficiency threshold will travel to the resource bank to obtain energy funds.

Objectives: Each person tries to achieve a desired level of welfare and wants to maintain at least a minimum level for sufficiency.

Learning: N/A

Prediction: N/A

Sensing: N/A

Interaction: At the start of each decision period, i.e. when the operational lifetime of the resource bank has expired, people in the governing group, whose inclusivity is determined by the social inequity index parameter, decide whether or not to set up the resource bank based on the value of the decision threshold parameter.

Stochasticity: The variation in outcomes results from the randomly drawn values (from a normal distribution, and within a range) of the resource bank set-up cost, the decision threshold and the decision period. Sources of stochasticity are the random normal distribution of the resource access attribute of people, their initial energy balance, and their distance from the resource region and the resource bank.

Collectives: People either belong to the governing group which makes the decision on whether or not to set up the resource bank, or to the non-governing group which is barred from participating in the decision. Those who have a resource access value equal to or greater than the social inequity index will be part of the governing group.

Observation: The main observable is the percentage of people who remain active (or haven't "perished") over the course of a run. In addition, it is interesting to observe the number of times and the duration for which the resource bank has operated, and the welfare redistribution is has facilitated.

Parameter	Value	Unit
Population	400	People
Social inequity index	Random float 0.00-1.00	
Decision threshold	Random float 0-100	% of People
Resource impact sensitivity	0.97	
Tax policy	Flat rate or progressive	
Aggregation technology	Summation or threshold	
Impact periodicity	25	Ticks
Impact severity	0.7	
Starting resource production capacity	5	Resource units per resource patch
Starting metabolic cost	0.2	Energy units per tick
Starting travel cost	Starting metabolic cost / 4	Energy units per tick
Starting exertion cost	Starting metabolic cost / 5	Energy units per tick
Minimum acceptable energy balance for sufficiency	400	Energy units
Decision period	(1 + random-float (2 * (impact periodicity + impact duration)))	Ticks
Resource bank cost	Random 0.00-1.00	
Resource bank operation cost per decision period	((population / 20) * (resource-bank-operation-cost / 2) * minimum-acceptable-energy-balance * decision-period)	Energy units

Table 7: Model global parameters.

Initialization and input data

The model isn't calibrated and initialised with real world data. The model does not use input data to represent time-varying processes. The range of outcomes from the model arises from the relative valuations of its parameters and entity attributes.

The global parameters in the model are:

The attributes that characterize people are:

Parameter	Value	Unit
Resource access	Random 0.00-1.00	
Desired energy balance	(minimum-acceptable-energy-balance * exp (resource-access))	Energy units
Starting energy balance	(minimum-acceptable-energy-balance + random-float (desired-energy-balance - minimum-acceptable-energy-balance))	

Table 8: Attributes of people.

The attributes that characterize resource units are:

Parameter	Value	Unit
Energy gain per unit	minimum-acceptable-energy-balance (for sufficiency)	Energy units
Energy cost per unit	(minimum-acceptable-energy-balance / 20)	Energy units
Impact sensitivity	(resource-impact-sensitivity) ∧ (1 / 5)	

Table 9: Attributes of resource units.

Sub-models

The following functions are used:

- The number of resource units that a resource patch is able to (re)generate is a function of the severity of the climate change impact event.

$$resource\_production\_capacity = (starting\_resource\_production\_capacity * (1 - impact\_severity))$$

- The metabolic cost for people is also affected by the impact event.

$$metabolic\_cost = (starting\_metabolic\_cost * exp(impact\_severity))$$

- As is the energy cost of travelling across a patch.

$$travel\_cost = (starting\_travel\_cost * exp(impact\_severity))$$

- During a climate change impact event, the likelihood of a resource unit regenerating depends on its sensitivity to the impact event.

$$if\ (ticks\ -\ harvest\_time) \geq (1 + tan(impact\_sensitivity * 90))\ then\ regenerate\ resource\ unit$$

- The number of resource units that a person can harvest and consume is determined by their resource access attribute.

$$harvest\_capacity = (resource\_access * resource\_production\_capacity)$$

- A person is part of the decision-making (or governing) group if their $resource\_access \geq$ the social inequity index.
- The decision to set up the resource bank is reached when the number of people in the decision-making group with $(energy\_balance < minimum\ sufficiency\ threshold) \geq decision\_threshold$.
- The amount of (energy or welfare) tax collected from a person whose energy balance is higher than the sufficiency threshold (minimum acceptable energy balance) under a flat rate tax policy:

$$energy\_surplus\_to\_donate = (0.5 * (energy\_balance\ -\ minimum\_acceptable\_energy\_balance))$$

- The amount of (energy or welfare) tax collected from a person whose energy balance is higher than the sufficiency threshold (minimum acceptable energy balance) under a progressive tax policy:

$$energy\_surplus\_to\_donate = (resource\_access * (energy\_balance - minimum\_acceptable\_energy\_balance))$$

References

Adger, W. N. (2010). Social capital, collective action, and adaptation to climate change. *Der Klimawandel: Sozialwissenschaftliche Perspektiven*, (pp. 327–345)

Alesina, A., Michalopoulos, S. & Papaioannou, E. (2016). Ethnic inequality. *Journal of Political Economy*, *124*(2), 428–488

Altaweel, M. (2008). Investigating agricultural sustainability and strategies in northern Mesopotamia: Results produced using a socio-ecological modelling approach. *Journal of Archaeological Science*, *35*, 821–835

An, L. (2012). Modeling human decisions in coupled human and natural systems: Review of agent-based models. *Ecological Modelling*, *229*, 25–36

Axtell, R. L., Epstein, J. M., Dean, J. S., Gumerman, G., Swedlund, A. & Harburger, J. (2002). Population growth and collapse in a multiagent model of the Kayenta Anasazi in Long House Valley. *Proceedings of the National Academy of Sciences*, *99*, 7275–7279

Bausch, A. W. (2014). Evolving intergroup cooperation. *Computational & Mathematical Organization Theory*, *20*(4), 369–393

Beitz, C. R. (2001). Does global inequality matter? *Metaphilosophy*, *32*(1–2), 95–112

Deffuant, G., Amblard, F., Weisbuch, G. & Faure, T. (2002). How can extremism prevail? A study based on the relative agreement interaction model. *Journal of Artificial Societies and Social Simulation*, *5*(4), 1

Deffuant, G. & Weisbuch, G. (2007). Probability distribution dynamics explaining agent model convergence to extremism. In B. Edmonds, C. Hernandez & K. G. Troitzsch (Eds.), *Social Simulation: Technologies, Advances and New Discoveries*. Philadelphia, PA: IGI Publishing

Dorling, D. (2015). *Injustice: Why Social Inequality Still Persists*. Bristol: Policy Press

Dow, K., Kasperson, R. E. & Bohn, M. (2006). Exploring the social justice implications of adaptation and vulnerability. In W. N. Adger, J. Paavola, S. Huq & M. J. Mace (Eds.), *Fairness in Adaptation to Climate Change*, (pp. 79–96). Cambridge, MA: MIT Press

Edmonds, B. (2017). Different modelling purposes. In B. Edmonds & R. Meyer (Eds.), *Simulating Social Complexity: A Handbook*, (pp. 39–58). Berlin Heidelberg: Springer

Faist, T. (2018). The socio-natural question: How climate change adds to social inequalities. *Journal of Intercultural Studies*, *39*(2), 195–206

Grasso, M. (2007). A normative ethical framework in climate change. *Climatic Change*, *81*(3–4), 223–246

Islam, N. & Winkel, J. (2017). Climate change and social inequality. United Nations Department of Economic and Social Affairs (DESA), Working Paper no. 152

Janssen, M. A. & Ostrom, E. (2007). Adoption of a new regulation for the governance of common-cool resources by a heterogeneous population. In J.-M. Baland, P. K. Bardhan & S. Bowles (Eds.), *Inequality, Cooperation, and Environmental Sustainability*, (pp. 60–96). Princeton, NJ: Princeton University Press

Kohler, T. A., Van West, C. R., Carr, E. P. & Langton, C. G. (1996). Agent-based modeling of prehistoric settlement systems in the Northern American Southwest. Proceedings of the Third International Conference on Integrating GIS and Environmental Modelling, Santa Fe, NM

Morrison, A. E. & Addison, D. J. (2008). Assessing the role of climate change and human predation on marine resources at the Fatu-ma-Futi site, Tituila Island, American Samoa: An agent-based model. *Hemisphere*, *43*, 22–34

Neckerman, K. M. & Torche, F. (2007). Inequality: Causes and consequences. *Annual Review of Sociology*, *33*, 335–357

Nhim, T., Richter, A. & Zhu, X. (2018). The resilience of social norms of cooperation under resource scarcity and inequality - An agent-based model on sharing water over two harvesting seasons. *Ecological Complexity*, *40*, 100709

Ostrom, E. (2010a). Analyzing collective action. *Agricultural Economics*, *41*, 155–166

Ostrom, E. (2010b). Polycentric systems for coping with collective action and global environmental change. *Global Environmental Change*, *20*(4), 550–557

Przeworski, A. (2015). Economic inequality, political inequality, and redistribution. Available at: `http://www.barcelona-ipeg.eu/wp-content/uploads/2015/09/inequality_final.pdf`

Rasch, S., Heckelei, T., Oomen, R. & Naumann, C. (2016). Cooperation and collapse in a communal livestock production SES model - A case from South Africa. *Environmental Modelling & Software*, *75*, 402–413

Rueschemeyer, D. (2004). Addressing inequality. *Journal of Democracy*, *15*, 76

Sandler, T. (2004). *Global Collective Action*. Cambridge: Cambridge University Press

Schlüter, M., Tavoni, A. & Levin, S. (2016). Robustness of norm-driven cooperation in the commons. *Proceedings of the Royal Society B*, *283*(1822)

Shue, H. (2023). Unseen urgency: Delay as the new denial. *Wiley Interdisciplinary Reviews: Climate Change*, *14*(1), e809

Stuart, D., Gunderson, R. & Petersen, B. (2020). Overconsumption as ideology: Implications for addressing global climate change. *Nature and Culture*, *15*(2), 199–223

Van Vuuren, D. P. & Stehfest, E. (2013). If climate action becomes urgent: The importance of response times for various climate strategies. *Climatic Change*, *121*, 473–486