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Voting Sustains Intergenerational Cooperation, Even When the Tipping Point Threshold is Ambiguous

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Abstract

Sustaining future generations requires cooperation today. While individuals' selfish interests threaten to undermine cooperation, social institutions can foster cooperation in intergenerational situations without ambiguity. However, in numerous settings, from climate change to the biodiversity crisis, there exists considerable ambiguity in the degree of cooperation required. Such ambiguity limits the extent to which people typically cooperate. We present the results of an intergenerational public goods game, which show that a democratic institution can promote cooperation, even in the face of ambiguity. While ambiguity in previous work has proved a challenge to cooperation (although we find sometimes only small and non-significant effects of ambiguity), voting is consistently able to maintain sustainable group-level outcomes in our study. Additional analyses demonstrate that this form of democracy has an effect over and above the impact on beliefs alone and over and above the structural effects of the voting institution. Our results provide evidence that social institutions, such as democracy, can buffer against selfishness and sustain cooperation to provide time-delayed benefits to the future.

Keywords Intergenerational goods games · Voting · Climate change · Sustainability · Ambiguity · Tipping points · Threshold

1 Introduction

Providing for future generations is central to the survival of species at all levels of biological organisms, from bacteria to humans (Nowak 2006). In contrast to genetic evolution, economic systems and human societies can employ foresight in order to achieve

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sustainable outcomes (Arrow 1962; Norton et al. 1998). Nonetheless, even in human society, providing for the future poses a cooperative challenge: the current generation bears the cost of cooperation needed to sustain resources for the future, while future generations reap the benefits (Fischer et al. 2004; Hauser et al. 2014; Lohse and Waichman 2020; Fornwagner and Hauser 2022). Previous work has highlighted that the overexploitation of renewable resources often has dire consequences for the welfare of future generations (Hardin 1968; Ostrom 1990; Milinski et al. 2006; Wade-Benzoni and Tost 2009; Levin 2010; Dennig et al. 2015).

Intergenerational cooperation is particularly challenging because the cooperative failure of a single generation can have detrimental effects for all future generations. In particular, so-called “tipping points”, in which there is an abrupt and often irreversible change in a system (OECD Environment Directorate 2022), are critical to the success—or failure—of sustaining a resource into the future (Kessler and Cour-Palais 1978; Austin et al. 1999; Tavoni et al. 2011; Polasky et al. 2011; Barrett and Dannenberg 2014; Bentley et al. 2014). In the classic Tragedy of the Commons example, fisheries depleted past a certain threshold die out and cannot be brought back (Hardin 1968). More recently, the Intergovernmental Panel on Climate Change has recommended limiting global warming to 1.5 °C (Hoegh-Guldberg et al. 2018). This is because 1.5° is an estimated threshold beyond which researchers predict particularly detrimental outcomes for future generations, including extreme drought, higher flood risk, irreversible biodiversity loss, and significantly reduced farmable land area (Hoegh-Guldberg et al. 2018).

Yet tipping points in natural systems are rarely known perfectly in advance (Pindyck 2020); instead, considerable ambiguity typically exists around tipping points, and even to what extent they are strictly irreversible (within certain ranges) (Scheffer et al. 2001; Schneider 2006; Lenton et al. 2008; Kriegler et al. 2009; Polasky et al. 2011; Abou Chakra and Traulsen 2014; Scovronick et al. 2017; McKay et al. 2022; OECD Environment Directorate 2022). For example, in the context of climate change, it seems plausible that tipping points exist, but their exact location is often unclear (Watson et al. 2001; Mastrandea and Schneider 2004; Rockström et al. 2009; Randalls 2010; McKay et al. 2022; OECD Environment Directorate 2022). While the appropriate course of action depends on society’s preferences, ambiguity in a tipping point’s location or consequences may mean that it is prudent to choose to act in anticipation of the worst-case threshold—requiring higher levels of cooperation today to sustain life tomorrow (Millner et al. 2013; Lemoine and Traeger 2015; Abou Chakra et al. 2018; Fillon et al. 2023). For instance, threshold ambiguity was a key factor in the IPCC’s decision to change their recommended global warming maximum from 2° to 1.5° (Carbon Brief Staff 2014).

While ambiguous thresholds necessitate greater cooperation today than when tipping points are known, past work has found that ambiguity in public goods games typically erodes cooperation (Barrett and Dannenberg 2012, 2014; Kotani et al. 2014; Dannenberg et al. 2015; Guilfoos et al. 2019; Hopfensitz et al. 2019). Research has also found, however, that institutions can dramatically affect the rate of overexploitation of intergenerational resources, in general leading to more sustainable outcomes (Hauser et al. 2014; Löschel et al. 2017; Kamijo et al. 2017, 2019; Shahrier et al. 2017; Blanco et al. 2018; Kesberg and Pfattheicher 2019; Wolf and Dron 2020; Timilsina et al. 2021; Bosetti et al. 2022; Freitas-Groff et al. 2023).

While democracy has shown promise to sustain intergenerational cooperation (Hauser et al. 2014), particular democratic institutions can also backfire and lead to lower overall cooperation. For instance, this can be the case when democracy is enacted through elected representatives who then make decisions on behalf of their electorate (Milinski et al. 2016), and in the case that policies would have their positive impacts through general equilibrium effects which are often discounted by voters (Dal Bó et al. 2018). Nonetheless, institutions that harness social preferences for cooperation (Capraro 2013; Kesternich et al. 2014; Timilsina et al. 2017; Gallier et al. 2017; Capraro et al. 2019; Barfuss et al. 2020; Böhm et al. 2020; Capraro and Perc 2021; Freitas-Groff et al. 2023) can lead to more sustainable outcomes (Andreoni and Petrie 2004; Shao et al. 2019; Danku et al. 2019; Shahen et al. 2021). In standard public goods games, democracy has been found to improve societal outcomes by aligning individual and societal interests (Walker et al. 2000; Ertan et al. 2009; Putterman et al. 2011; Bernard et al. 2013; Gallier et al. 2017).

Even in intergenerational goods games (IGGs) where alignment of individual and long-term societal interest is not possible, Hauser et al. (2014) show that democratic institutions can lead to sustainable outcomes when the tipping point is known with certainty. In that setting, democracy is achieved through median voting, a system in which all individuals propose solutions, and then the median solution is enacted by all participants. Median voting is successful because it frees conditional cooperators to act in the interest of society and curbs the effect of defecting outliers (Hauser et al. 2014).

In this paper, we draw on the literature of democratic institutions to test whether voting can help overcome the “tipping point ambiguity” problem in intergenerational dilemmas. We show that a median voting institution can sustain intergenerational cooperation even under high ambiguity, resulting in far higher societal payoff across generations. Consistent with past literature, we also show that voting continues to yield high intergenerational cooperation in the absence of ambiguity (Hauser et al. 2014). However, when there is no voting, and participants are free to extract as much as they want from the common pool, we find that cooperation with future generations is rarely established at high levels: a large proportion of participants choose an amount that maximises their individual outcome, whether the threshold is known or ambiguous. As a result, the resource pool is often depleted so that future generations cannot access it at all.

We further investigate how participants’ (non-incentivised) beliefs explain their decisions in the voting and no-voting conditions. When there is no voting, individual decisions are best predicted by beliefs about what the mean decision-maker is going to extract. In contrast, when voting is present, beliefs of what the *median* voter will do has a larger predictive power for a participant’s decision, suggesting that participants accurately understand how this democratic institution creates a keystone role for the median voter in determining extractions in the voting treatment. Both with and without voting we therefore observe participants adjusting their behaviour in accord with their belief regarding the pivotal decision-maker; evidence which is consistent with participants following conditional co-operation strategies.

Voting facilitates conditional cooperators to act pro-socially and further enhances cooperation by allowing the group to reign in defectors. While ambiguity does not significantly reduce cooperation in our study, group outcomes in the no-voting condition with and without ambiguity are similarly low in sustainability, whereas those cooperative group-level outcomes are restored through voting in both ambiguous and non-ambiguous settings. We find that voting works by reigning in defectors and enabling—both through mechanical channels due to the voting institution itself and through non-mechanical channels—(conditional) cooperators to cooperate more, leading to more sustainability at the group level.

2 Methods

2.1 Intergenerational Goods Game (IGG)

The setup of our experiments is similar to that of previously published work on IGGs (Hauser et al. 2014) (see Appendix 1 for the experimental design as shown to participants). Participants are randomly assigned to groups (or, as we refer to them in this paper, as generations) of five. At the start of the game, the first generation is given access to a renewable resource pool of 100 units.[1] Each participant extracts between 0 and 20 units from the pool. For each unit a participant extracts, they receive 5 cents as a bonus payment.

Abstracting somewhat from the real-world, we employ a particularly parsimonious version of a tipping point, in the form of a depletion threshold. If total extraction goes beyond this threshold, the resource does not replenish. Specifically, the depletion threshold is set at 40. If a generation extracts 40 or fewer units from the pool, then the pool refills to 100 units for the next generation. However, if a generation extracts more than 40 units from the pool, then that pool is exhausted, and no future generations can benefit from the pool. For the remainder of the paper, we discuss the rate at which generations choose to extract no more than 40 units as the rate pools are replenished.

Regardless of whether or not the pool is replenished, a new generation occurs with a probability of 70%, leaving 30% probability that there are no further generations. The fixed continuation probability used in this game means that the maximum number of generations for a given pool is uncertain, and potentially infinite, hence often being referred to as an “infinitely repeated” game (Dal Bó 2005; Dal Bó and Fréchette 2011). Henceforth, if the realisation of this continuation probability is positive, such that a future generation occurs, then that pool is said to be continued.

If a new generation occurs, it will inherit either a sustained or exhausted pool. A pool is considered sustained if the previous generation (and all generations before it) have collectively not extracted more than 40 units, and in each generation that pool has been continued. In the case of a sustained pool, the new generation is faced with the same dilemma as the generation before them. If the pool is exhausted, the new generation (and all subsequent ones) have no opportunity to extract any units at all. Rather than facing a decision, participants assigned to a pool in which a future generation has exhausted the pool are told that the pool has been exhausted and their payoff is 0.

2.2 Conditions

We divided participants randomly into four conditions using a 2×2 factorial design. The differences between the conditions were (a) whether or not the participants knew the depletion threshold with certainty, crossed with (b) whether or not the participants could vote on how many units to extract. The baseline condition is a known threshold with no voting (see Condition 1 in Fig. 1). In this treatment, participants know the exact value of the threshold with certainty, and each participant’s decision is implemented as the quantity of resource they extract.

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[1] Participants in the first generation are informed that they are the first generation; all later generations are not informed about the exact position in the sequence and they only know that a previous generation came before them (who either replenished the pool or did not replenish the pool).

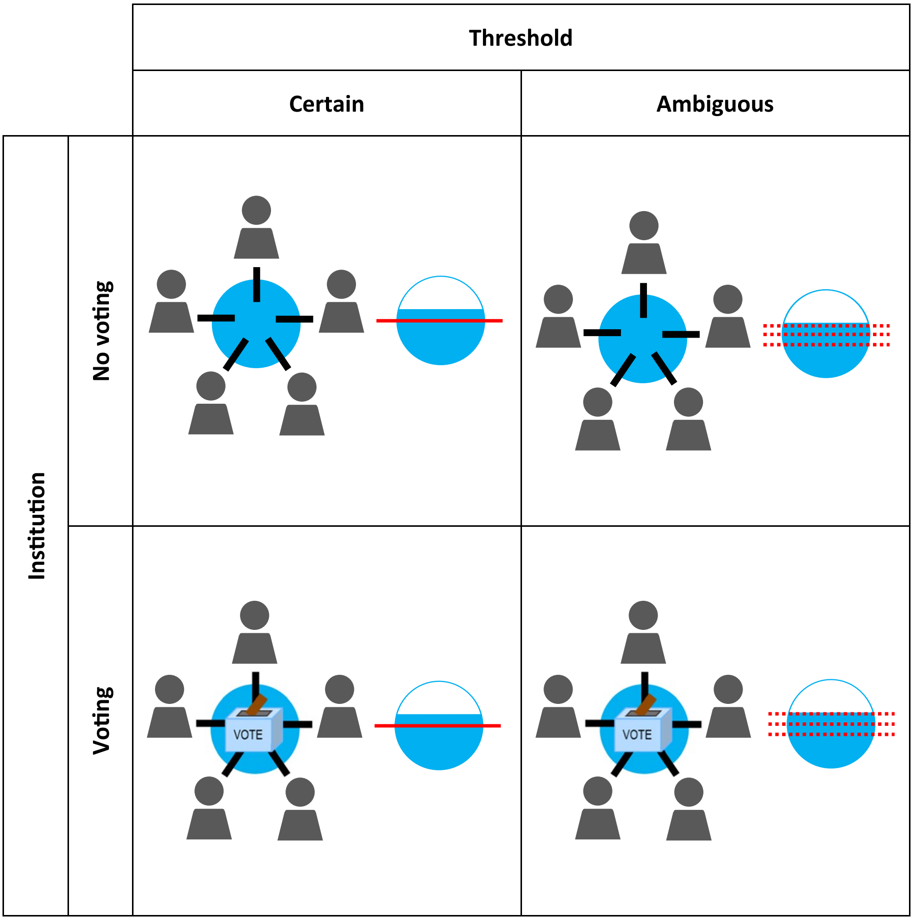

Fig. 1 Experimental design. Top left: In Condition 1, the baseline condition, participants extract from the resource pool, and if total extractions summed across all five players are no more than the threshold, the pool survives to the next round. Top right: In Condition 2, ambiguity is introduced: participants are no longer told the exact threshold but rather the range in which the threshold lies. Bottom left: In Condition 3, institution of voting is introduced, and threshold certainty is restored. Bottom right: In Condition 4, voting remains but threshold certainty is removed once again

2.3 Ambiguity

The first treatment considers the role of ambiguity in the value of the threshold. There is a growing body of evidence (McBride 2006; Barbieri and Malueg 2010; Barrett and Dannenberg 2012; Dannenberg et al. 2015; Hopfensitz et al. 2019) that shows ambiguity and uncertainty frequently erode cooperation. We build on these previous studies by including experimental conditions to test for these effects in an IGG. As Fig. 1 shows, participants in Condition 2 (Ambiguity) are only told that the threshold is between 30 and 50. To ensure a clean comparison between the certain and ambiguous cases, the threshold in the ambiguous case was still 40 throughout.

2.4 Voting

Next, we explore the role of a specific democratic institution in solving the problem of cooperation: median voting. Again, median voting is a particularly parsimonious democratic institution, which allows us to explore how one form of democracy might facilitate cooperation despite the lack of a private incentive to cooperate. Indeed, while median voting in a public goods game is sufficient to align social and private incentives (Bernard et al. 2013), that is not the case in IGGs, where cooperation is never privately beneficial. However, previous work (Hauser et al. 2014) has demonstrated that in an IGG a median voting rule is able to maintain cooperation and therefore sustain the pool over many generations. We build on this prior work by testing whether median voting can continue to sustain cooperation despite threshold ambiguity.

Under median voting, each member of the generation's decisions is a proposal for the number of units they think everyone should extract from the pool. Out of the five proposals put forward in a group in a given generation, the median proposal is selected as the amount that each individual in that generation extracts. In practice, the median vote is determined by arranging all five proposals in a group from smallest to largest and then selecting the proposal in the middle. This is the median voter's proposal which is then implemented as the extraction decision for every member of the group (Ertan et al. 2009; Bernard et al. 2013; Hauser et al. 2014). Each participant therefore receives the median proposal as their share of the resource, and in total the group extracts five times this median proposal amount. As such, median voting does not constrain an individual's strategy set (they can still choose any integer between 0 and 20). Similarly, the *range* of possible group extraction levels remains unchanged (falling between 0 and 120). However, the total extractions are now constrained to being multiples of five.

As shown in Fig. 1, median voting is crossed with the ambiguity treatment such that in Condition 3**,** participants cast their votes knowing that the depletion threshold is exactly 40 units. In Condition 4, participants vote on how much to extract but are given only ambiguous information about the threshold (as in Condition 2 they are only told it is between 30 and 50 units).

Thus, the four conditions are: Condition 1 no voting, certain threshold, Condition 2 no voting, ambiguous threshold, Condition 3 voting, certain threshold, Condition 4 voting, ambiguous threshold.

2.5 Beliefs

In addition to making an extraction decision or proposal, we also elicit non-incentivised beliefs. Specifically, subjects are asked to predict the extraction decision, or proposal, for each of the four other members of their group.

2.6 Subjects

Participants were recruited through the online labour market, Amazon Mechanical Turk. 415 individuals participated across the four conditions.[2] All subjects were paid a

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[2] A further 316 participants were recruited but were assigned to a pool that was previously exhausted. These individuals went through the experiment, reading all instructions and answering comprehension questions, but when they reached the decision page, they were informed that the pool had been exhausted

participation fee of $0.75. In addition, they could each earn a bonus of up to $1.00, based on how many units they extracted from the resource pool.[3] All rules of the game are made clear to the participants in each generation (including if they are in the first generation or not), and participants must pass comprehension questions in order to continue.

2.7 Analytical Methods

We use five complementary analyses to analyse how voting and ambiguity affect individual decisions and group-level outcomes.

OLS regressions: group-level replenishment. First, we use standard ordinary least-squares (OLS) regressions to estimate the causal effects of the randomly assigned treatment. The outcome variable for group-level analysis is whether a pool is replenished based on a group's total extraction from the pool. The total extraction varies by condition: individual decisions are aggregated according to each condition's rule, i.e. in the no-voting conditions, the sum of individual decisions; and in the voting conditions, the median voter's proposal multiplied by five. The replenishment (or group-level) outcome is assigned value 1 if the total extraction equals 40 or fewer units (the level of the threshold) and value 0 if the total extraction is above 40 units. The independent variables in the regressions are the treatment dummies: whether the participant is assigned to a condition without voting ($=0$) or with voting ($=1$) and whether the participant is assigned to a condition without ambiguity ($=0$) or with ambiguity ($=1$). We additionally consider these regressions in each subsample. First, we split the sample by whether the threshold is certain or ambiguous, and regress replenishment on a treatment dummy for voting. Second, we split the sample by the voting treatment, and regress replenishment on a treatment dummy for threshold ambiguity.

Throughout, we use cluster robust standard errors at the pool level. That is, standard errors are clustered across participants assigned to the same resource pool in the same treatment regardless of the participants' generations. Econometrically, this is the most conservative clustering level given our setting.

Bootstrapped simulations: random re-matching. Next, to mitigate against the potential that our results are driven by the random assignment of individuals to specific groups (generations), we conduct bootstrapped simulations to study alternative assignment to group to check that our results hold. The bootstrapping operates similar to previous research in this domain (Hauser et al. 2014): We produce 20-generation long histories for each of 1000 unique pools for each treatment by randomly sampling (with replacement) the decisions made by the participants in the respective treatment. First-generation decisions all come

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Footnote 2 (continued)

and they could not make a decision or earn a bonus. These participants were paid a participation fee but could not earn a no bonus. However, there is one instance of a pool not being sustained in generation 10, but then one subsequent generation mistakenly being invited, and paid, to make extraction decisions. This subsequent generation also exhausts the pool. This happens in the voting with certainty treatment. As such, excluding the data from the (wrongly elicited) 11th generation would only serve to make the positive effect of voting (and the negative effect of ambiguity) stronger. We therefore make the conservative assumption—from the point of view of estimated effects—to retain the extra generation's data in our analysis. Furthermore, excluding these 5 participants does not qualitatively change our results.

[3] We note that these stakes, although low, are comparable to those used in similar settings in online labour markets (e.g. Hauser et al. 2014), and that the magnitude of stakes appears to have limited impact on participant behaviour (Amir et al. 2012; Pulford et al. 2018).

from participants who participated in the first generation within the experiment,[4] and decisions for participants in later generations are all drawn from the participants who took part in later generations. Once decisions are simulated for all generations within a pool, we implemented the extraction decision implied by the generation's decisions and the pool's treatment. We explore results through OLS regressions similar in form to those used for the "raw" data. Specifically, whether a pool is replenished in a given generation is regressed against dummies for voting and whether the threshold is ambiguous, with the standard errors again clustered at the pool level. In contrast to the raw data, the decisions of generations assigned to previously-exhausted pools are observed and included in these bootstrapped regressions.

Bootstrapped simulations: the "mechanical" effects of voting. Voting may have its effects through shifting behaviour (people make lower proposals than they would extraction decisions) and/or through mechanically constraining would-be defectors. To ascertain which channel drives the treatment effects, we also conduct bootstrap simulations in which we hold fixed the decisions made by participants but instead implement a median voting institution in *all* conditions, thereby aggregating all decisions similarly into a group outcome. The difference between outcomes with the two different aggregation rules—totalling extractions under no voting and multiplying the median by five in the simulated voting case—show the mechanical effect of voting. Any remaining difference between the no voting treatment but with simulated voting aggregation and the voting treatment are then the result of changes in behaviour caused by assignment to voting conditions. The results of these simulations are analysed through the same regression specifications as used for the bootstrapped simulations without mechanical voting.

OLS regressions: individual decisions. Similar to the group-level analysis described above, we also run regressions on the individual level to study individual decision-making. The outcome variable for this analysis is the amount that a participant extracts (in the no-voting conditions) or proposes should be extracted by all participants (in the voting conditions). This value varies between 0 and 20 units at the individual level.

We also study whether participants are "cooperators" or "defectors": this variable is defined by whether the participant extracts or proposes to extract an amount that is at or below the value of the threshold divided by five: in our setting, this value equals 8 because 8 units extracted by 5 players equals 40 units in total extraction which is right at the threshold. That is, cooperators are assigned value 1 if they extract 8 or fewer units; otherwise they are assigned 0. Finally, as above, the independent variables in the regressions are the treatment dummies: whether the participant is assigned to a condition without voting (=0) or with voting (=1) and whether the participant is assigned to a condition without ambiguity (=0) or with ambiguity (=1).

OLS regressions: the role of beliefs. Finally, we analyse the impact of average beliefs on decisions through further OLS regressions. When using just one measure of the average belief as a predictor, these regressions use the measure of the average—either mean or median—which is anticipated by theory to be the key predictor. Note that, as there is no theoretical prediction about how ambiguity in the threshold should affect which measure of the average belief is most important, it is not included as an explanatory

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[4] We sample first-generation decision only from the set of first-generation decisions because participants assigned to the first generation are informed of their position in the sequence (i.e. that they are the first in the sequence), while later generations are not informed of their position in the sequence. Therefore, with this sample method, any effects that are unique to first-generation participants remains contained to the first generation in the bootstrap simulation and does not spill over to later generations.

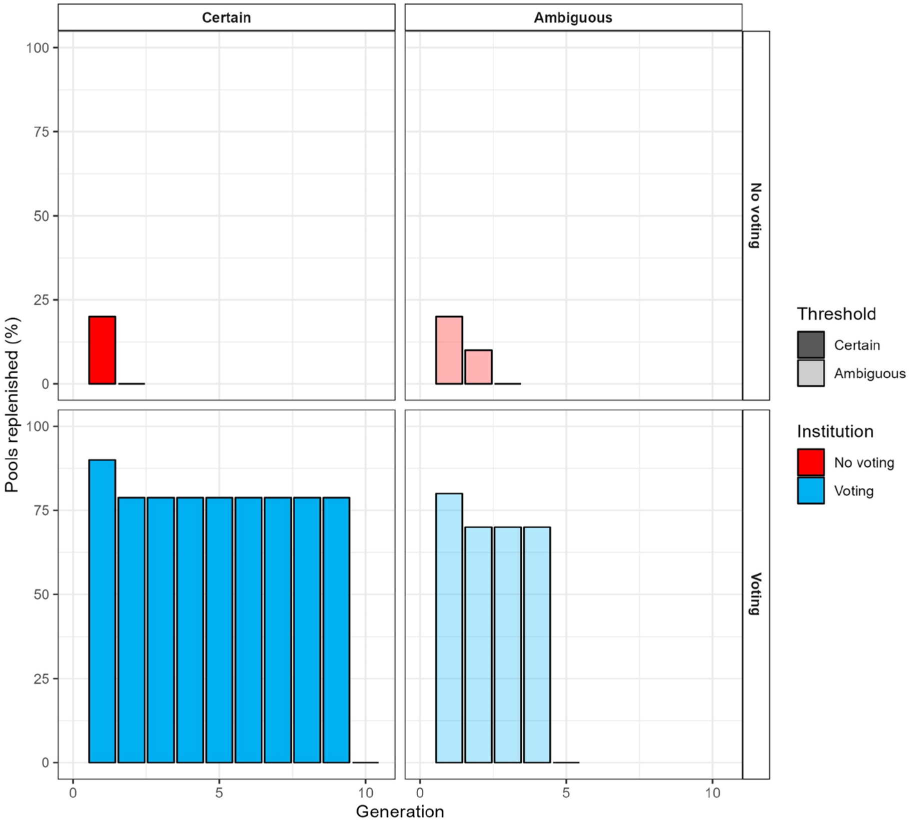

Fig. 2 Proportion of pools replenished by institution and threshold. Bar charts show the proportion of the pools in each generation which have been replenished in all proceeding generations. These are arranged by treatment, with the results for the no voting conditions in the upper panel and in red (voting below in blue) and the certain threshold in the left-hand plots and solid fill (ambiguous threshold on the right and translucent fill). Clearly, voting substantially increases the rates at which pools are replenished, despite ambiguity in the threshold reducing this rate. Within voting treatments, the sharp declines in the proportion replenished in the voting treatments (generation 10 for the certain threshold, generation 5 for the ambiguous threshold) occurs when just one pool is sustained until that generation (i.e. the other replenished pools are not continued), and then the sole surviving group extracts more than 40

variable in these regressions. We run subsequent regressions in each case to ascertain that the role of one measure of the average is not simply through its close association with the other measure of the average.

3 Results

3.1 Group Level Outcomes

We begin by examining extraction behaviour in the IGG at the group level. Figure 2 displays the proportion of pools sustained to a specific generation which are then replenished

Table 1 The percentage of pools which are replenished in each treatment

Institution	Threshold	
	Certain (%)	Ambiguous (%)
No voting	16.7	23.1
Voting	87.5	84.6

Table 2 Linear probability model estimating the effect of institution on whether pools are replenished. Robust standard errors clustered at the pool level

	1st generation	All generations
1 = Ambiguous	0.000 (0.189)	0.0641 (0.153)
1 = Voting	0.700 (0.167)***	0.708 (0.126)***
1 = Ambiguous × Voting	−0.100 (0.252)	−0.093 (0.176)
Constant	0.200 (0.133)	0.167 (0.091)*
R^2	0.43	0.41
N (generations)	40	83
Clusters (pools)	40	

*p < 0.10; **p < 0.05; ***p < 0.01

that generation by treatment. In our baseline condition (Condition 1) with known thresholds and no voting (top left panel, solid fill red bars), we see that less than 25% of pools are replenished in the first generation. None of the sustained pools are then replenished in the second generation. This striking pattern of pools being exhausted absent voting is in line with previous findings (Hauser et al. 2014).

Next, we study the introduction of ambiguity around the threshold (Condition 2, top right panel, translucent red bars). In contrast to the wider literature on ambiguity (e.g. Barrett and Dannenberg 2012; Dannenberg et al. 2015), we do not find a negative effect of ambiguity in the raw data in our setting.[5] Table 1 displays the mean rate at which pools are replenished across generations: the ambiguous threshold even slightly increases the rate of cooperation across all generations (23.1%), as compared to the certain threshold condition (16.7%); however, as shown below, this difference is not statistically significant.

Table 2 presents regression results for the impact of both the threshold and institution of the probability that a pool is replenished. First, restricting to the first generations' decision, there is no effect of the ambiguous threshold condition on group sustainability, relative to certain threshold: the coefficient is 0.000 and not statistically significant. When we pool across all generations, and in line with the raw data, there is a slight increase in replenishment (0.064) but this is not statistically significant. Compared to the wider literature which has found that ambiguity severely hampers cooperation in within-generation games, we speculate that the limited impact we observe may be because of the substantially lower rates of pool replenishment in the certain threshold condition to start with—a finding that is common in inter-generation games (see Hauser et al. 2014 and Lohse and Waichman 2020).

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[5] If anything, while the same proportions are replenished in the first generation in both the ambiguous and certain conditions, some sustained pools are then replenished in the second generation under ambiguity but not certainty.

Table 3 Linear probability model estimating the effect of institution on whether pools are replenished for different subsets of the data. Robust standard errors clustered at the pool level

	Certain	Ambiguous	No Voting	Voting
1 = Ambiguous	–	–	0.064 (0.156)	−0.029 (0.088)
1 = Voting	0.708 (0.105)***	0.615 (0.143)***	–	–
Constant	0.167 (0.091)*	0.231 (0.125)*	0.167 (0.092)*	0.875 (0.051)***
R^2	0.46	0.37	0.01	0.00
N (generations)	44	39	25	58
Clusters (pools)	20			

*p < 0.10; **p < 0.05; ***p < 0.01

Turning to the impact of voting on outcomes under a certain threshold (bottom left panel of Fig. 2 solid blue bars), we find that group-level sustainability (i.e. pools being replenished) is much higher. While some pools are not replenished in the first or second generation, from the third generations onwards, all pools are replenished in each generation. Indeed, the apparent drop in the rate at which pools are replenished in the 10th generation is because just one pool is sustained to that point (owing to others not being continued). These visual inspections from Fig. 2 are backed up by the statistical analysis: across all generations, pools in the voting condition (with certain threshold) are replenished at a rate of 87.5% (Table 1), which represents a 70 percentage points increase relative to the no-voting condition (with a certain threshold), which is highly statistically significant ($p < 0.001$, Table 2).

Comparing the lower two panels of Fig. 2, ambiguity (presented on the right hand side with translucent blue bars) seems to qualitatively lower group-level sustainability outcomes but not dramatically (84.6% under ambiguity, compared to 87.5% under certainty, in Table 1).[6] A visual inspection also suggests that pools are still replenished at a far higher rate than absent voting (upper panels of Fig. 2).

Statistically, we can be more precise: while the point estimate of the coefficient in Table 2 is negative, ambiguity in the presence of voting does not significantly reduce group-level outcomes relative to the certain threshold with voting (p = 0.746, Table 3); nor is the interaction effect between ambiguity and voting significant (p = 0.601, Table 2). Nonetheless, the rate at which pools are replenished under an ambiguous threshold is far higher with voting than without (p < 0.000, Table 3).

3.2 The Impact of Random Formation of Generations

A key concern in these results may be that the realised group outcomes could have been very different had the random allocation of participants to groups resulted in some other allocation. Recall that participants are randomly assigned to groups when they make their decisions, which are then aggregated at the group level and used to compare the effects of

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[6] We note that Tables 2 and 4 show that sustainability under ambiguity is lower than under certainty, which is consistent with the wider literature. Given that we did not see any negative effect of ambiguity in the no-voting conditions but we do see a negative effect in the voting conditions, we speculate that this is because there is no "room" for a negative effect of ambiguity in the very low sustainability outcomes (i.e. floor effect) in the no-voting conditions; but there is plenty of room for ambiguity to have a negative impact in the voting conditions, which is directionally what we are observing.

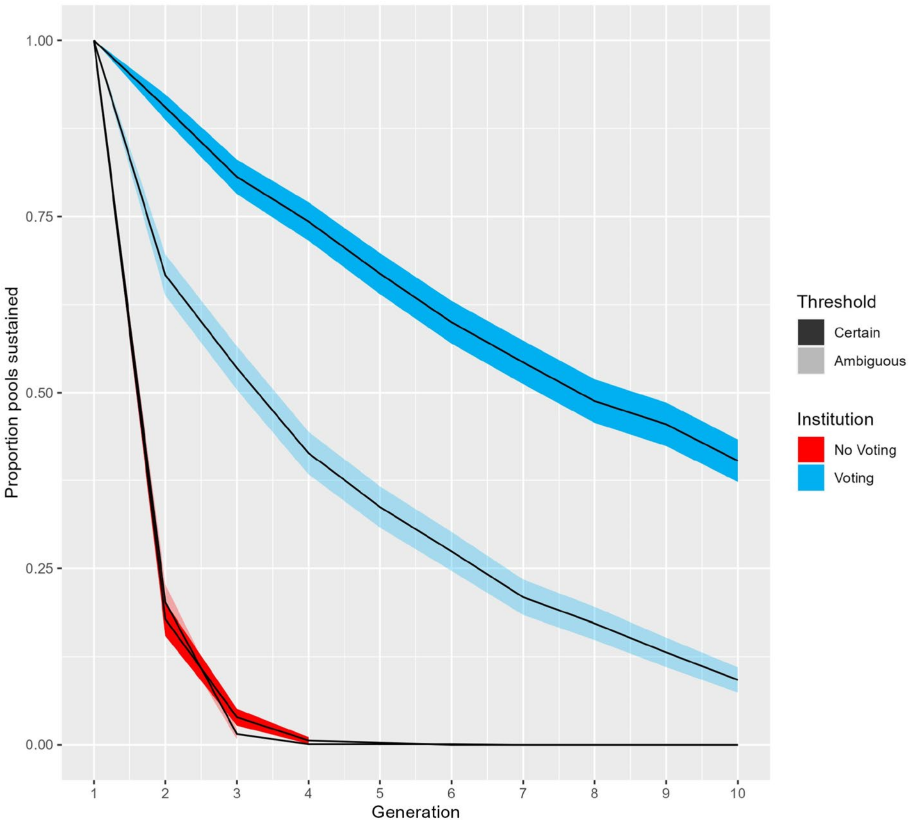

Fig. 3 Bootstrapped simulations of the decline in sustainable pools. The results of computer simulations in which groups are formed randomly using the data generated by our participants. A series of generations is formed by randomly sampling (with replacement) participant decisions which are then aggregate into a group extraction by applying the appropriate aggregation rule. Pools are sustained through generations if all previous generations replenish the pool, and the mean proportion of pools sustained is the line for each treatment. The ribbon shows the 95% confidence interval around this estimate. Pools are very rarely sustained when there is no voting (red), but when voting is introduced (blue) this pattern is reversed such that most pools are replenished each generation and the proportion of pools sustained declines much more slowly. Despite ambiguity in the threshold (translucent rather than solid fill) lowering the rate at which pools are replenished, voting still ensures that cooperation rates are far higher than absent voting

the different conditions. As a result of this random assignment process, it is possible that different random group assignments could have led to different group level outcomes and affected the observed differences between conditions.

To better understand the impact of the initial random group allocations, we conduct bootstrap simulations to mitigate these concerns. The results from these simulations are displayed in Fig. 3. No voting conditions are displayed in red, and voting in blue. Solid fills are used when the threshold is known, and translucent fills when the threshold is ambiguous.

The broad patterns accord with those found in our previous analysis. First, absent voting, pools are rarely replenished. Indeed, as highlighted in the first column of Table 4, in each generation only 19.1% of pools are replenished when the threshold is known, and it is just 8.1% when the threshold is ambiguous ($p<0.001$). Furthermore, we observe again that

Table 4 Linear probability model estimating the effect of institution on whether pools are replenished for the bootstrapped simulations. The first column is when decisions in the no voting condition are aggregated through totalling decisions in the group. The second column instead aggregates decisions in the no voting column with the use of the median voter rule, negating the mechanical effect of voting. Robust standard errors clustered at the pool level

	No voting	Mechanical voting
1 = Ambiguous	−0.111 (0.003)***	0.231 (0.005)***
1 = Voting	0.711 (0.004)***	0.575 (0.004)***
1 = Ambiguous × Voting	−0.009 (0.005)*	−0.350 (0.006)***
Constant	0.191 (0.003)***	0.327 (0.003)***
R^2	0.51	0.21
N (generations)	80,000	
Clusters (pools)	40	

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$

the introduction of voting substantially and significantly increases the proportion of pools which are replenished (effect = 0.71, $p < 0.001$), a pattern that can also be observed clearly in Fig. 3. Specifically, under a certain threshold, 90.3% of pools are replenished and, while the proportion is lower in the case of an ambiguous threshold (78.3%), it is still substantially higher than either condition absent voting.

3.3 The Mechanical Effect of Voting

The effectiveness of voting could come through changing the impact of (a fixed set of) decisions, or additionally through directly affecting those decisions. The former effect of voting is a "mechanical" result of the fact that voting prioritises the median voter's decision over an outlier's decision, which implies that a majority of cooperators are able to replenish the pool even when a minority defects. In the absence of the voting institution, a minority of defectors who choose to extract a relatively high level of resource could lead to the exhaustion of the pool. In contrast, the same minority of defectors in the voting condition would not exhaust the pool because the majority's preferences would be implemented. For instance, consider a group with decisions 3, 6, 8, 15, 20. Absent voting, this group exhausts the pool (total extraction is 52, with mean extraction of 10.4). Yet when voting is present, the same five decisions would result in the pool being replenished (because the median decision is 8, all participants extract 8 from the pool and thus the total extraction is 40). Therefore, the median voter rule ensures that outliers do not unilaterally determine whether the threshold is crossed, and a pool could be replenished solely through a mechanical effect.

Voting might—additionally—encourage participants to choose to extract lower resource levels. It might do so by alleviating the fear of individual players that they may be willing to cooperate but if others do not (either in their generation or in future ones), they forgo additional resource extraction in vain. We refer to these participants as "conditional cooperators": participants who wish to cooperate, but only if many (or most) of their group do so as well (Fischbacher et al. 2001). When there is no voting, there is no way for these conditional cooperators to ensure that if they do cooperate, the rest of their generation does too. However, with voting, that is precisely what happens: each player in a generation gets exactly the same pay-off, so only if the majority of other participants forgo some resource

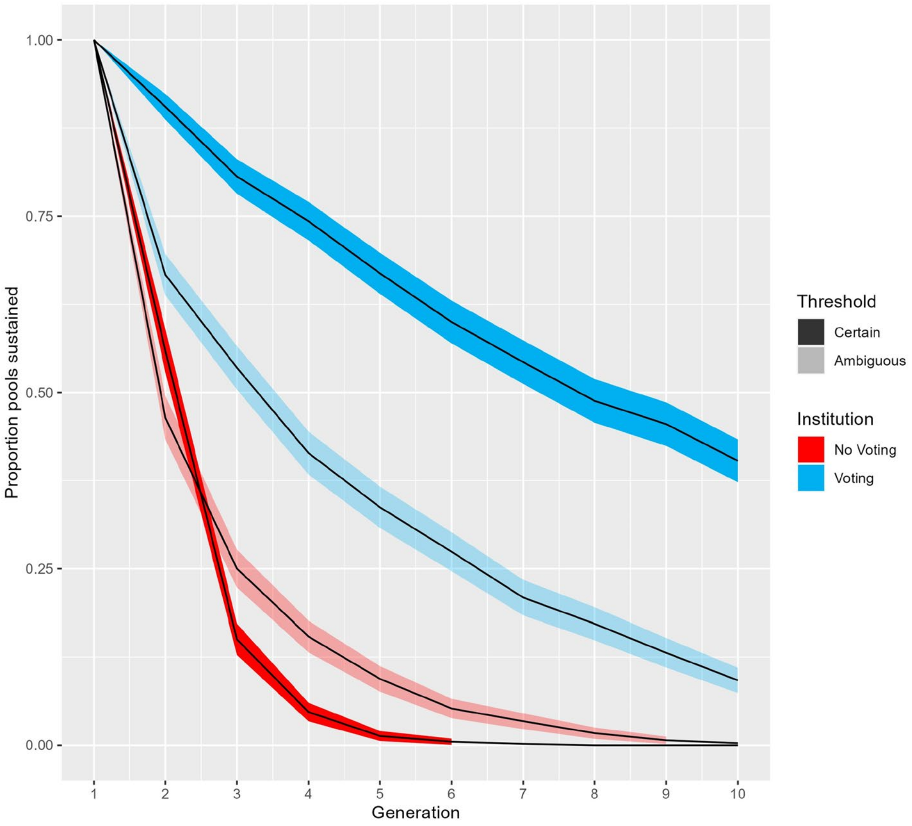

Fig. 4 Bootstrapped simulations of the decline in sustainable pools after accounting for the mechanical effect of voting. As in Fig. 3, we conduct bootstrap simulations of the rate at which pools are sustained across generations. The key difference between is that participants assigned to no voting treatments now have their decisions aggregated *as if* they were assigned to voting. That is, we imagine their extraction decisions were instead proposals and each then extracts the median proposal. In so doing, the mechanical effect of voting is negated. The solid lines again show the mean proportion of pools replenished in each generation, with the ribbon showing the 95% confidence interval around this. Comparison to Fig. 3 shows that negating the mechanical effect of voting does mean that pools are more frequently sustained in no voting conditions (red). However, they are still substantially less likely to be replenished than when voting is present (blue). Thus, a substantial proportion of the effect of voting is driven by people acting more cooperatively

for the good of future generations, would the conditional cooperator have to forgo any resource extraction. This effect may be particularly important given how common conditional cooperators tend to be (Chaudhuri 2011).

To identify the impact of these differential channels that contribute to the voting institutions' high sustainability outcomes, we conduct another bootstrap analysis by applying the voting aggregation to decisions in the no-voting treatments. By comparing the group sustainability outcomes between the baseline conditions without voting (as initially designed) and with (mechanically) applying the voting institution post-hoc (which we refer to as "no-voting with mechanical voting" condition below), we can isolate the effect of voting

Table 5 The percentage of pools which are replenished in the bootstrap simulations, by treatment. This includes two rows for the no voting treatment. The first row comes from a simulation in which the total decisions were enacted as the extraction. The second row instead imagines that the decisions were the same but these represented proposals under median voting. Hence to the extent that median voting has its effect through the mechanical channel, this is accounted for in the second row

Institution	Threshold	
	Certain (%)	Ambiguous (%)
No voting—total extraction	19.1	8.1
Mechanical voting—no voting decisions with median voting applied	32.8	55.8
Voting	90.3	78.3

through these two channels. The results of this exercise are presented in Fig. 4 and Tables 3 and 4.

As in Fig. 3, conditions in Fig. 4 are distinguished by different fills (thresholds), and colours (institution). Figure 4 shows that the voting works in both hypothesized ways: the mechanical effect of voting leads to an increase in the proportion of pools that are replenished in the "no-voting with mechanical voting" conditions. This can be seen when comparing the no-voting conditions across Figs. 3 and 4. However, the second hypothesized (non-mechanical) channel also has an effect: a substantial gap between the voting and no-voting treatment remains in Fig. 3. Even after accounting for the mechanical effect of voting, the (original) voting conditions lead to higher sustainability outcomes.

Indeed, the results in Table 5 suggest that the roughly 70-percentage point gap between voting and nonvoting under the certain threshold is only closed by 13 percentage points by the mechanical voting effect. Figure 4 also highlights that this mechanical effect seems more important for the ambiguous rather than certain threshold.[7] In fact, turning to the data in Table 5, for the ambiguous threshold the mechanical effect is more substantial, closing the 70-percentage point gap by 48 percentage points.

We conclude that the mechanical effect of voting is meaningful, but the voting institution additionally affects decision directly: the remaining gap cannot be explained by the mechanical effect of voting. To better understand these patterns, we now turn to individual level decisions and the role of beliefs.

3.4 Understanding Treatment Effects at the Individual Level

As described above, a key channel through which voting has an effect is by changing individual behaviour. Figure 5 displays the individual decisions. Bar charts show the mean decision, with 95% confidence intervals around these estimates (with standard errors clustered at the pool level). The points also show how the distribution of decisions changes across treatments.

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[7] This slightly higher sustainability in the ambiguous (versus certain) threshold no-voting condition might suggest that, in the ambiguous no-voting condition, the presence of ambiguity but the absence of voting lead to a wide "spread" of decisions by participants (i.e. large deviations from the [unknown] threshold of 40). When voting is later mechanically applied, those outliers (in either direction) are no longer a deciding factor and instead the median decisions (closer to the threshold) lead to more sustainability at the group-level.

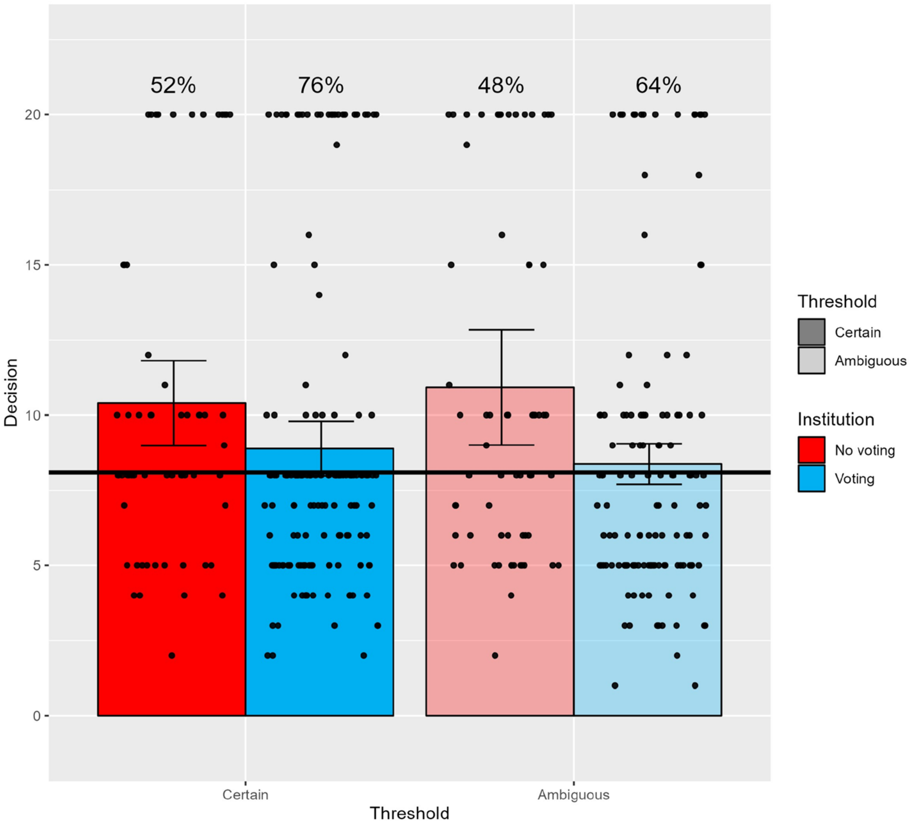

Fig. 5 Plots of individual decisions on extraction amount. Bar charts show mean decisions with individual points representing individual decisions. The solid horizontal line shows the maximum extraction decision for our definition of a cooperator (extraction decision or proposal is no more than eight units), and the numbers above each of the bars summarise percentage of individuals who are cooperators. Cooperators are defined as participants who extract or propose 8 or fewer units (i.e. 8 units is an individual participant's maximum extracted, or median proposed, to arrive at the group threshold of 40 units). Error bars around mean decisions are the 95% confidence intervals, calculated as mean ± 1.96 × standard error of the mean (SEs clustered at the pool level). As OLS regressions of behaviour (decision/proposal and whether an individual is a cooperator) show no significant effect (all p-values > 0.15) of the generation in which a subject participates, we pool the data across generations in this figure. Regardless of whether the threshold is certain (left hand side, solid fill) or ambiguous (right hand side, translucent fill), voting (blue) increases cooperation compared to no voting (red), measured both as a binary (whether an individual is a "cooperator" or not), and continuously (how much of the resource people decide to extract)

Absent voting (red bars), ambiguity around the threshold value (translucent fill) results in participants tending to be less willing to cooperate (48%) relative to under a certain threshold (solid fill, 52%) and tend to extract more resources on average. While Table 6 shows that these effects are not statistically significant, the slight reduction in willingness

Table 6 Linear probability model estimating the effect of institution on likelihood of being a cooperator (defined as extracting, or voting to extract, no more than 8 units; col 1 and 2). Linear regression estimating the effect of institution on the average decision (col 3 and 4), be that the amount that the participant decided to extract (decision) or the amount they voted for (proposal). Standard errors clustered at the generation level

	Cooperator?		Decision/Proposal	
	1st generation	All generations	1st generation	All generations
1 = Ambiguous	−0.080 (0.112)	−0.040 (0.090)	0.040 (1.349)	0.523 (1.048)
1 = Voting	0.220 (0.091)**	0.240 (0.058)***	−1.300 (1.192)	−1.506 (0.853)*
1 = Ambiguous × Voting	−0.080 (0.132)	−0.078 (0.099)	−0.880 (1.669)	−1.040 (1.154)
Constant	0.540 (0.071)***	0.517 (0.049)***	10.500 (0.819)***	10.400 (0.747)***
R^2	0.05	0.05	0.03	0.03
N	200	415	200	415
Clusters	40			

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$

to cooperate is in line with theoretical predictions and the prior literature, especially given that the value of the public good to decision-makers is low (McBride 2006).[8]

Under a certain threshold, voting (blue bars) substantially increases the fraction of participants who are classified as cooperators ($p < 0.001$, Columns 1 and 2 in Table 6) as they vote to extract less of the resource ($p = 0.075$, Columns 3 and 4 in Table 6). Hence there is a shift in individual behaviour, which explains why a gap in group level outcomes is maintained even when the mechanical effect of voting is accounted for. We do not find any significant effect of ambiguity on amounts extracted or likelihood of cooperators (all p values > 0.45, Table 6).

Returning to the why mechanical impact of voting is larger for the ambiguous treatments, this can be explained by the changes in the distribution of individual decisions. Under ambiguity in the threshold, participants are far less likely to extract precisely eight units of the resource than when the threshold is known. Instead, participants are more likely to either extract no more than six units of the resource or extract ten units of the resource, leading to a wider spread of individual decisions in the ambiguous no-voting condition. As a result, in the bootstrapped simulations and focussing on treatments without voting, individual decisions have a significantly higher mean under ambiguity than under a certain threshold (12.1 vs 9.9 units, $p < 0.000$) but a lower median (8 vs 9, chi-squared test, $p < 0.000$). These results highlight the individual behaviours at play and how democratic institutions might interact with those behaviours to shape the sustainability of outcomes.

3.5 Changes in Individual Behaviour Through Beliefs

Finally, we investigate what drives these shifts in individual decisions by examining participants' reported beliefs. We find that participants are more likely to extract lower resource amounts if they believe the other participants are also likely to be cooperating. Across

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[8] In our case, by construction, the benefit of cooperation to decision makers is always 0, as all benefits are accrued to future generations.

Table 7 OLS regression estimating the effect of mean and median beliefs on individual decisions (extraction in no voting; proposal in voting conditions). Data is pooled across ambiguous and known thresholds, and split by whether there is no voting or voting. Standard errors clustered at the pool level

	Outcome variable: Individual decision (extraction or proposal)						
	No voting		Voting		All data		
Mean	0.68 (0.09)***	1.73 (0.81)**	–	0.33 (0.30)	0.78 (0.06)***	–	1.73 (0.80)**
Median	–	−1.03 (0.80)	0.82 (0.07)***	0.50 (0.29)	–	0.75 (0.06)***	−1.03 (0.79)
Voting	–	–	–	–	–	–	−3.06 (1.14)***
Voting × Mean	–	–	–	–	–	–	−1.39 (0.85)
Voting × Median	–	–	–	–	–	–	1.53 (0.84)*
Constant	4.15 (0.98)***	3.89 (0.96)***	1.07 (0.60)*	0.83 (0.64)	1.81 (0.60)***	2.24 (0.59)***	3.89 (0.94)***
R^2	0.32	0.34	0.41	0.41	0.37	0.36	0.41
N	125		290		415		
Clusters	20				40		

*p < 0.10; **p < 0.05; ***p < 0.01

treatments, the slope of relationship between mean belief and decision is 0.78 and slope of relationship between median belief and decision is 0.75 (Table 7). While it is not possible to determine the causal nature of the relationship in our setting, this is the expected pattern for individuals following a "conditional cooperator" strategy (see also Gächter et al. 2017).

We further investigated whether people appear to condition their own behaviour on their beliefs about the behaviour of others, and whether they differentially condition their behaviour on mean or median beliefs depending on the voting treatment. We did this by comparing the impacts of mean and median beliefs in the presence and absence of voting across the conditions.

Theoretically, when there is no voting, the sum of individual decisions is critical in deciding the final group outcome. Individual decisions are captured by the mean decision across participants in a group. Specifically, if in our setting, if the mean decision is lower or equal to 8 units in the no-voting conditions, the sum of decisions is always below or at the threshold of 40 units. However, under the median voter rule, the median belief should influence an individual's decision, as the median voter's proposal gets implemented for everyone and is therefore critical in deciding the group outcome. In our setting, if the median decision is lower or equal to 8 units in the voting conditions, the median proposal multiplied by five (the number of players) is always below or at the threshold of 40 units.

Table 7 presents the results of OLS regressions examining how beliefs predict decisions. Across specifications, mean beliefs positively and significantly correlate with decisions when there is no voting, even after accounting for median beliefs which are not significant. In contrast, in the voting case, median beliefs positively and significantly correlate with decisions. After accounting for mean beliefs (which are not significant), this relationship is maintained, although near marginal ($p = 0.102$). While accurately capturing beliefs is challenging, and as such the results should be interpreted somewhat cautiously, it seems unlikely that participants would have known to systematically misreport their actual beliefs in such a way as to be consistent with the theoretical predictions.[9]

Finally, while mean and median beliefs change in accordance with the relevant condition, the impact of voting on individual decisions is only partly explained through the beliefs channel. Returning to Table 7, pooling data across the no voting and voting conditions, we see that voting affects decisions significantly more than is mediated through the beliefs channel alone: after accounting for beliefs, including any impact voting has through shifting mean and median beliefs, decisions are 3.06 units lower than when voting is present ($p = 0.010$).

In sum, this suggests that conditioning on the same beliefs, participants are more likely to act pro-socially in the voting conditions than in the no voting conditions. In other words, the difference in behaviour in the voting conditions and the no-voting conditions is not solely explained through the beliefs channel; instead, the voting institution itself motivates additional cooperation.

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[9] We note that we did not incentivize the accuracy of beliefs. We are encouraged by the fact that the mean beliefs and median beliefs align in the no-voting and voting conditions, respectively, with the theoretical predictions, which might suggest that participants took the exercise of providing beliefs seriously. However, we encourage future research to investigate whether specific incentives in belief elicitation leads to different results (see also Danz et al. 2022 for a discussion of "simple" belief elicitations).

4 Discussion

We find evidence that despite concerns that ambiguity generally hampers cooperation, democracy maintains intergenerational cooperation, resulting in more socially equitable and more socially efficient decisions in an intergenerational goods game. By maintaining and fostering democratic institutions, societies may be able to provide for future generations, even if that means forgoing consumption today.

It is perhaps interesting to speculate as to why median voting is so effective in maintaining high rates of replenishment when the wider literature suggests that the introduction of ambiguity to systems in which cooperation rates are high is to substantially lower cooperation. It is plausible that median voting is able to maintain cooperation in these systems simply because it is a strong institution under which cooperation seems extremely robust (Hauser et al. 2014; Camerer et al. 2018).

One further explanation is the certainty that median voting offers to conditional cooperators mitigates against the ambiguity introduced into the environment in which they are making decisions. While each individual is uncertain as to whether their proposal will be material in determining whether the pool is replenished (the probability of being the median voter is 1 in 5), median voting reduces the impact of the (potentially larger) variability in group members' proposed extractions—that is, conditional cooperative participants need only have sufficiently optimistic beliefs about the median voter's proposal, even if uncertainty of the threshold might induce more pessimism about some participants' willingness to cooperate. However, given that these ideas are speculative, further research will be needed to better understand the pathways in which voting upholds cooperation in the presence of ambiguity.

Our experiment comes with limitations that we hope future research will address. For example, while lab and online experiments are rich source for controlled scientific insight in the social sciences (Falk and Heckman 2009), behaviour in abstracted public goods games is not uniformly related to real voluntary climate action (Goeschl et al. 2020) and more research is required to enhance the external validity of lab experiments like ours. Indeed, the lack of progress on issues such as climate change, despite democracy being relatively commonplace globally, suggests that other factors are also key in fostering cooperation. For instance: these global issues clearly have a different scale of stakes; necessitate far more actors cooperating for global public goods (Hauser et al. 2016); involve actors who may each represent a democracy rather than simply representing themselves in some democratic institution; and potentially incorporate actors with different capabilities and endowments (Hauser et al. 2019) who therefore might expect a different distribution of the costs of taking action; as well as the possibility that different actors and different societies might value the lives of future generations differently (e.g. see global variations in morality in Awad et al. 2020).

Future studies could also explore the question of how democratic institutions are initiated (Gallier et al. 2017). One may speculate that democracies might endogenously emerge in societies which were highly likely to cooperate absent such institutions, which would limit the marginal impact of democracy observed in the real world compared to the effect that is estimated from the exogenous imposition of voting from lab and online experiments.

Furthermore, our experiment examined one particular democratic institution and one value for the threshold. Future research could explore the role of different forms of democracy, for instance elected leaders, as in Milinski et al. (2016) or in which subsequent decisions are required of voters (Kesternich et al. 2014; Gallier et al. 2017; Dal Bó et al. 2018).

Finally, while exploring the impact of the threshold value on results may be interesting, given prior research (Hauser et al. 2014) in which the threshold was varied, we predict that most of our findings would generalise.

Finally, our results have implications for policymakers and society. While the world continues to grapple with climate change, mass extinction, pandemics, stock depletion, biorisk, antibiotic resistance, space debris and AI alignment issues (Ord 2020), key tipping points are often ambiguous and unknown in advance. Investment in, and maintenance of, democratic institutions may be a viable path to securing resources for future generations.

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