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Social discounting, inequality aversion, and the environment

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ABSTRACT

Measures of inequality aversion are elicited using hypothetical decision tasks. The tasks require an assessment of projects in the presence of environmental inequalities across space and time. We also test the effect of different environmental domains (air pollution, recreational forest and soil fertility) and contextual framings (gain/loss, within/between regions and present–future/past–present inter-temporal trade-offs). Estimated mean inequality aversion is higher in the intra-temporal framing (an elasticity of 2.9), than in the inter-temporal framing with either negative (2.0) or positive (1.4) growth in environmental quality. Differences across environmental domains exist but are less pronounced. Similar results hold for pure time preference. Losses are associated with a lower pure rate of time preference but higher inequality aversion compared to gains. The results indicate how domain-specific 'dual' discount rates or rather changing relative shadow prices for the environment might be calibrated. Yet, seen as an exercise in empirical social choice, the context dependent results reject the classical Utilitarian formulation of a single Ramsey Rule.

Introduction

There is growing concern that environmental quality (e.g. air pollution, forest cover and green spaces) is experienced unevenly across society (Hamann et al., 2018; Day and Maddison, 2015; DEFRA, 2006). There are also concerns about the distribution of environmental quality over time, as a result of climate change for instance (Hsiang et al. 2017, p. 1367). If society is averse to unevenness in the distribution of environmental quality over space and time, the effect on social welfare should be reflected in welfare evaluation and Cost–Benefit Analysis (CBA). Indeed, recent analyses have shown that the welfare effects are likely to be non-trivial in determining the Social Cost of Carbon (Kornek et al., 2019; Anthoff and Emmerling, 2019). A key question for economic welfare analysis remains though: How averse is society to environmental inequalities over different domains, and over space and time, and what is the Social Discount Rate (SDR) for environmental quality? In this paper we provide experimental evidence that aversion to environmental inequalities (η_{EE}) is substantial and often equivalent to income inequality aversion reported elsewhere (Groom and Maddison, 2019; Saelen et al., 2008). We also show that environmental inequality aversion varies depending on whether inequalities are over time or space, whether environmental quality is improving or worsening over time, over gain–loss framings, although not across different environmental domains. For instance, we find that inequality aversion differs across intra-temporal $(\eta_{EE} = 2.9)$ and inter-temporal settings with a degrading environment $(\eta_{EE} = 2.0)$ or an improving environment $(\eta_{EE} = 1.4)$. The pure rate of time preference (δ) also varies across some of these dimensions.

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Estimates of environmental inequality aversion (η_{EE}) and the pure rate of time preference (δ) can be used to operationalise "dual" Social Discount Rate (SDR) or equivalently calculate relative price effects for environmental CBA (Drupp et al., 2018). Measures of inequality aversion can also be used to estimate distributional weights for environmental Cost–Benefit Analysis. Our estimates of environmental inequality aversion suggest that a simple Ramsey environmental SDR: $SDR_E = \delta + \eta_{EE} g_E$, would be *negative* for typical (negative) estimates of growth in environmental quality, g_E (Baumgaertner et al., 2015), implying steeply rising relative prices for the environment in the future.[1] In eliciting these social preferences we also test the "dual-discounting" framework, the chief normative framework for inter-temporal welfare analysis of consumption and environmental quality. This exercise in empirical social choice, confirmed by replication, shows that individuals' normative conceptions of inter- and intra-temporal fairness cast doubt on the simple and extended Ramsey frameworks, since inequality aversion and pure rates of time preference vary by context. The paper is therefore an iteration towards a Rawlsian *reflective equilibrium,* through which normative ideas are iteratively tested against their implications, and a firmer basis for welfare analysis found.

The paper is motivated by growing concern about inequality in general, which has focussed on the financial dimensions of wealth (e.g. Piketty, 2014; Stiglitz, 2012). Aversion to inequality of this type stems from normative views surrounding fairness and equity, as well as from more positive arguments associated with economic performance or political stability (e.g. Persson and Tabellini, 1994). Yet an important component of wealth is natural capital, which is the source of ecosystem service flows. Some ecosystem services increase well-being through income generation, but natural capital itself and the many associated ecosystem services often generate well-being directly. Air and water quality, climate regulation, amenity values of landscapes, existence values for biodiversity and habitats, and noise are, inter alia, examples of such services (IPBES, 2019). If people are averse to inequality in the financial dimension, it seems reasonable to assume that there will be aversion to environmental inequalities also. A great deal of work is going into understanding how environmental costs and benefits are distributed across space and different demographic groups (e.g. Boyce et al., 2016; Zwickl et al., 2014). However, very little is known about societal aversion to these inequalities. The typical assumption is that aversion to income inequality is a sufficient proxy.

Also of concern in the environmental domain are the trade-offs over time that society finds acceptable. Such preferences should be reflected in the SDR in Cost–Benefit Analysis (CBA) and related economic welfare analyses. Typically in such analyses it is assumed that environmental stocks and flows, if they contribute to social welfare at all, are perfectly substitutable with consumption goods. Hence, an implicit assumption in CBA is that in order to evaluate the distributional consequences of public policy on environmental outcomes, either at a given point in time using welfare weights, or when evaluating trade-offs over time using an SDR, it suffices to use measures of aversion to *income* inequality. Importantly, ignoring the special way environmental stocks and flows enter into in social welfare means that changes in their relative scarcity are also ignored in welfare analysis. This oversight, ignoring relative scarcity, can seriously underestimate the likely gains from climate change mitigation policies, for instance (see Hoel and Sterner, 2007; Drupp and Hänsel, 2021). Fortunately, the 'dual-discounting' literature shows that changes in relative scarcity can be reflected in CBA by either calibrating a separate environmental discount rate, or by carefully projecting changes in relative shadow prices to reflect changes in scarcity. The two procedures are largely equivalent (Weikard and Zhu, 2005). Intuitively, the dual environmental discount rate contains an environmental 'wealth effect' which is the parallel of the consumption wealth effect in the standard Ramsey framework. The magnitude of this wealth effect depends on the growth of environmental quality, and aversion to environmental inequality. Higher growth means more inequality inter-temporally, leading to a higher discount rate in the presence of environmental inequality aversion, and vice versa. Estimating the environmental discount rate, or the change in relative shadow prices, therefore requires some measure of environmental inequality aversion, and has potential applications to public project appraisal.[2]

Finally, a typical argument in the realm of empirical social choice concerns the acceptability and validity of a normative framework for application in public policy. One test of acceptability is whether the public 'understands' the framework in question in the sense of making ethical decisions which do not deviate excessively from it (e.g. Gaertner and Schokkaert, 2012). For instance, even if environment features separately in social welfare, the extended Ramsey Rule does not allow inequality aversion to vary between contexts of space and time (e.g. Emmerling et al., 2017), and neither the simple nor extended Ramsey Rules accept sensitivity to framing, such as reference-dependence in the gain–loss or growth dimensions (Dietz and Venmans, 2019). The typical Ramsey or dual discounting/relative price frameworks do not typically admit differences in the pure rate of time preference across environmental (or indeed consumption) domains. Furthermore, typical applications make iso-elastic assumptions (e.g. constant relative inequality aversion, see Quaas et al., 2020), and assume that relative prices do not vary across environmental domains (e.g. Sterner and Persson, 2008), which is also restrictive. An important question from this social choice perspective is, therefore, do people make social decisions in accordance with the extended Ramsey framework, with all the restrictions on social preferences that this entails, and are parametric assumptions justified? A priori, it is certainly not clear. Anecdotally, people who are highly inequality averse in relation to incomes today, perhaps from the political left, could well disagree with the higher discount rate

[1] δ is the pure rate of time preference, η_{EE} is environmental inequality aversion, and g_E is growth in environmental quality. This is the SDR when cross-elasticities between consumption (C) and environment (E) are zero, or where any inequality in environmental outcomes cannot be compensated by consumption (see (Weikard and Zhu, 2005)). Cross elasticities are considered in Section 'Inequality aversion, environment and the Social Discount Rate (SDR)'. The dual-discount/relative price effect here therefore stems from inequality aversion rather than the limited substitutability of environmental resources found in e.g. Drupp, 2018.

[2] The UK Government will review environmental discounting in 2021. The Netherlands and France already emphasise relative prices in CBA guidelines (Freeman et al., 2018, Groom and Hepburn, 2017).

that this would imply (via the wealth effect), due to concern for future generations. In relation to environmental inequalities, strong intra-generational inequality aversion could well be accompanied by a low SDR for the environment, or a low SDR in general.

With these empirical questions in mind, we developed hypothetical decision tasks like those typically used in the 'empirical social choice' literature to evaluate ethical frameworks (e.g. Gaertner and Schokkaert, 2012). The decision tasks allowed us to estimate inequality aversion over different domains of environmental quality, in contrast to most research on inequality aversion which elicits preferences over monetary trade-offs (e.g. Groom and Maddison, 2019). We used a multiple price list approach in which respondents allocated environmental quality to one of two projects against a backdrop of different distributions of environmental quality over time and space, with different framings (loss–gain, within/between-regions) and different domains of environmental quality (forests, clean air and soil fertility). We sampled 363 respondents, received 40747 responses, and replicated the experiment on a sample of 183.

Our paper contributes to a broader literature on the experimental measurement of inter-temporal preferences and inequality aversion which focused on: individual discount rates for the environment (Viscusi et al. 2008, Hardisty and Weber 2009); different commodities (Weatherly et al. 2010); social discount rates for consumption (Howard, 2013); estimating parameters of a social welfare function including income inequality aversion (Groom and Maddison, 2019); discounting of health (Dolan and Tsuchiya, 2011; Cropper and Raich, 2016; Robson et al., 2016). Organising around the Ramsey Rule, and testing multiple framings across environmental domains, compliments these revealed and stated preference studies. Yet, while aversion to environmental inequality is borne out, individuals' conceptions of fairness do not always agree with the extended Ramsey Rule.

Inequality aversion, environment and the Social Discount Rate (SDR)

Our experimental set-up and empirical analysis of environmental inequality aversion is organised around the traditional Utilitarian Social Welfare Function (SWF). The intra-temporal SWF sums utility across individuals i: $W = \sum_i U\left(C_i\right)$, where C_i denotes consumption, broadly defined. Inequality aversion, η, is typically defined as the elasticity of marginal utility with respect to consumption (or income), $U_C\left(C_i\right)$:

$$\eta(C) \equiv -\frac{dU_C}{dC}\frac{C}{U_C} = -\frac{dlnU_C}{dlnC}. \tag{1}$$

This is intuitive because for any given pair of individuals in society, the ratio of their marginal social welfares can be approximated as follows:

$$ln\left(\frac{dW/dC_i}{dW/dC_j}\right) \approx \eta\left(C_i\right) ln\left(\frac{C_j}{C_i}\right) \tag{2}$$

where η scales proportional differences in income between persons i and j into proportional differences in their marginal social welfare. In this sense η reflects the ease with which one can transfer income from one person to another whilst maintaining social welfare, W, with larger values meaning that a reduction in income to the poor must be compensated by larger increases in income for the rich, and vice versa.[3] Based on the normative property of constant relative inequality aversion: society's aversion to inequality ought to be independent of the level of income at which it is evaluated, Atkinson (1970, p. 251) motivated an iso-elastic utility function: $U\left(C_i\right) = (1-\eta)^{-1} C_i^{1-\eta}$, in which case the elasticity of marginal utility, η, is a fixed parameter and the ratio of marginal welfares becomes: $\left(dW/dC_i\right)/\left(dW/dC_j\right) = \left(C_j/C_i\right)^{\eta}$. Experimental approaches to estimating η in this context are numerous, Okun's leaky bucket experiment being a typical example.[4] However, such estimates could capture two sources of inequality aversion, over income and utility, if the SWF is non-linear. Our empirical analysis measures the sum of these two sources of inequality aversion and is unable to distinguish their values separately.[5]

To formalise aversion to environmental inequality, we maintain the linear additive SWF, but separate environmental quality, E, from consumption C, in the utility function. The SWF is then: $W = \sum_i U(C_i, E_i)$. We measure aversion to environmental inequality using the elasticity of marginal utility with respect to the environment:

[3] With two agents $W = U\left(C_1\right) + U\left(C_2\right)$. If agent 2 is x% richer than agent 1, and 1 suffers a marginal loss of consumption, the transfer to 2 that maintains social welfare is θ%, where $\theta = \eta(C)x$.

[4] A "leaky bucket" experiment: are you willing to transfer T, from a rich person with income C_{high} to a poor person with income C_{low}, if the latter's income increases by £X? If "yes" when X = T this indicates aversion to income inequality. X* defines the point at which the answer becomes "no" as X is reduced, and the Maximum Tolerable Leakage (MTL) as $(T-X^*)/T$. With iso-elastic utility $\eta = \ln(1-MTL)/\ln\left(C_{high}/C_{low}\right)$. The "equal absolute sacrifice approach" applied to income tax schedules is a related approach (Stern, 1977; Groom and Maddison, 2019).

[5] If the SWF weighs individual utilities with an iso-elastic transformation: $w(U) = (1-\eta)^{-\alpha}(1-\alpha)^{-1}U^{1-\alpha}$, an additive SWF takes the following form:

$$W = \sum_i w(U_i) = \sum_i \frac{\left[(1-\eta)^{-1} C_i^{1-\eta}\right]^{1-\alpha}}{(1-\alpha)(1-\eta)^{\alpha}} = \sum_i \frac{\left[C_i\right]^{1-\eta^*}}{1-\eta^*}$$

and the relative weights placed on individual incomes become: $\left(dW/dC_i\right)/\left(dW/dC_j\right) = \left(C_j/C_i\right)^{\eta^*}$, where $\eta^* = \eta + \alpha - \alpha\eta$, reflecting inequality aversion over income (η) and over utility (α).

$$\eta_{EE} \equiv -\frac{dU_E}{dE}\frac{E}{U_E} = -\frac{dlnU_E}{dlnE}. \tag{3}$$

As with consumption and income, if η_{EE} is large, marginal utility increases quickly as the environment degrades, and a social planner would place increasing weight on the 'environmentally poor'. Importantly, in the case of a two good utility function it is not entirely obvious that environmental inequality aversion, η_{EE}, ought to remain constant across all levels of E and C. While this may well be a desirable property, in most formulations η_{EE} will depend on both. Any empirical strategy will have to accommodate this possibility.[6]

An estimate of inequality aversion is also a key ingredient when considering inter-temporal welfare and the Social Discount Rate (SDR). If the inter-temporal SWF takes the Discounted Utilitarian form: $W = \sum \exp(-\delta t)U(C_t)$, the rate at which marginal welfare declines from period $t = 0$ to τ, the SDR, is given by the Ramsey Rule:

$$SDR_\tau = -\frac{1}{\tau} ln\left(\frac{dW/dC_\tau}{dW/dC_0}\right) = \delta + \eta(C)\, g_C \tag{4}$$

where δ is the pure rate of time preference, $\eta(C)$ is the elasticity of marginal utility with respect to consumption, and g_C is the annualised mean growth rate of per capita consumption. If there is aversion to inequality the future ought to be discounted more heavily if there is income growth, and vice versa if there is an economic contraction. ηg_C is commonly described as a wealth effect. Inequality aversion plays the same role in this inter-temporal context as it does in the intra-temporal context described above, scaling proportional differences in income into proportional changes in marginal social welfare.[7]

The Ramsey Rule can be extended to account for environmental quality in the inter-temporal SWF by assuming that it enters as a separate argument in the representative agent's utility function (e.g Weikard and Zhu, 2005; Hoel and Sterner, 2007). The SWF then becomes: $W\left(\{C_t\},\{E_t\}\right) = \sum_{t=0}^{T} \exp(-\delta t)\, U\left(C_t, E_t\right)$ and the SDRs appropriate for consumption C_t and environmental quality, E_t, are then[8]:

$$SDR_C = \delta + \eta_{CC} g_C + \eta_{EC} g_E \tag{5}$$

$$SDR_E = \delta + \eta_{EE} g_E + \eta_{CE} g_C \tag{6}$$

where $\eta_{ij} = -\frac{U_{ij}(C,E)}{U_i(C,E)} i$ for all $i = E, C$ and $j = E, C$, η_{CC} reflects aversion to income/consumption inequality, η_{EE} measures aversion to inequality in environmental quality, and η_{CE} and η_{EC} are the cross elasticities. These "dual" discount rates are conceptually similar, containing the pure rate of time preference, δ, a wealth effect: $\eta_{CC} g_C$ for consumption and $\eta_{EE} g_E$ for environment, and substitution effects $\eta_{EC} g_E$ and $\eta_{CE} g_C$.[9] Intuitively, Weikard and Zhu (2005) show that the difference between (5) and (6) is equal to the change in relative shadow prices between environment and consumption.[10]

This framework provides the theoretical backdrop for our experimental approach and empirical work. Conceptually, it is clear that to inform the SDR for environmental quality or, equivalently, to estimate the evolution of shadow prices for the environment, an estimate of environmental inequality aversion, η_{EE}, is crucial. For example, in the special case when $\eta_{EC} = \eta_{CE} = 0$ the environmental Ramsey Rule becomes[11]:

$$SDR_E = \delta + \eta_{EE} g_E \tag{7}$$

and the change in relative shadow prices, $SDR_C - SDR_E$, becomes simply:

$$\vartriangle RP_{EC} = \eta_{CC} g_C - \eta_{EE} g_E \tag{8}$$

Other things equal, the relative price of environmental quality will increase (SDR smaller) if it is growing more slowly, becoming relatively more scarce, than consumption: $g_C > g_E$. The precise trajectory of relative prices will be determined by the relative values of the inequality aversion parameters η_{CC} and η_{EE}.[12] Growth in C_t and E_t is typically estimated using historical trends or forecasts, and estimates of η_{CC} are at hand (see e.g. Drupp et al., 2018). The remaining obstacle to estimating the change in relative prices

6 Hoel and Sterner (2007) discuss a constant elasticity of substitution, σ, utility function with inequality aversion towards both goods together α: $U(C,E,) = (1-\alpha)^{-1}\left[(1-\gamma)C^{1-\frac{1}{\sigma}} + \gamma E^{1-\frac{1}{\sigma}}\right]^{\frac{(1-\alpha)\sigma}{\sigma-1}}$. Here η_{EE} is constant in two special cases: (i) $\sigma = 1$, the Cobb–Douglas function $U(C,E) = \frac{1}{1-\alpha}\left[C^{1-\gamma}E^{\gamma}\right]^{1-\alpha}$; or, (ii) $\alpha\sigma = 1$, the additive power function $U(C,E,) = (1-\gamma)C^{1-\frac{1}{\sigma}} + \gamma E^{1-\frac{1}{\sigma}}$.

7 Emmerling et al. (2017) derive an SDR that combines intra- and inter-temporal inequality aversion.

8 For a detailed derivation of dual discount rates (see Traeger, 2013, p. 216).

9 These reflect the effect of changes in environmental quality on the consumption discount rate and vice versa. Gollier and Hammitt (2014) discuss the sign of these terms in the context of health and environmental quality. See e.g. Baumgaertner et al. (2015) for an application of dual discounting.

10 Taking (6) from (5) yields: $\vartriangle RP_{EC} = SDR_C - SDR_E = \eta_{CC} g_C + \eta_{EC} g_E - \left(\eta_{EE} g_E + \eta_{CE} g_C\right)$.

11 Howard (2013) discusses the possibility of distinguishing between δ_C from δ_E in a utility function that assumes $\eta_{EC} = \eta_{CE} = 0$ and takes the form: $W_0 = \sum_{t=0}^{T} \exp\left(-\delta_C t\right)\frac{C_t^{1-\eta}}{1-\eta} + \exp\left(-\delta_E t\right)\frac{E_t^{1-\xi}}{1-\xi}$.

12 Relative price changes can also be understood in terms of the elasticity of substitutability (EOS) between E and C. $\vartriangle RP_{EC} = \sigma_{E,C}^{-1}\left(g_C - g_E\right)$. The EOS is defined as $\sigma_{E,C} = \frac{d\ln(C/E)}{d\ln(U_E/U_C)}$, which becomes: $\sigma_{E,C} = \left(g_C - g_E\right)/\left(\eta_{CC} g_C - \eta_{EE} g_E\right)$ when $\eta_{EC} = \eta_{CE} = 0$. When environmental quality is becoming relatively more scarce, and the EOS is small, relative prices for the environment will rise rapidly.

in this special case is an estimate of η_{EE}. An inter-temporal leaky-bucket or multiple price list type experiment can be used for this purpose. The two-good framework provides guidance on how to structure an empirical approach, and a number of issues arise.

Firstly, to estimate η_{EE} using variations in E, we must be careful to separate out the effect of the cross elasticity, η_{EC}. Secondly, as discussed, applications of the Ramsey Rule typically assume an iso-elastic utility function, either for convenience or for normative reasons (e.g. Atkinson, 1970). There may be normative reasons why η_{EE} ought to be invariant to levels of C and E, and invariant to the intra- or inter-temporal context. Yet whether such normative principles are reflected in the way in which individuals evaluate social welfare is an empirical question. As Section 'Estimation of inequality aversion and the pure rate of time preference' explains, cross-elasticities are controlled for by holding consumption growth at zero in the experiment, while η_{EE} is estimated as a fixed parameter in each scenario or framing in a manner that accommodates any variation with levels of E.[13] The role of non-constant elasticities and cross elasticities is left for further research.

Several other testable hypotheses flow from the theory. Under the null that individuals follow the simple Ramsey Rule when evaluating inter-temporal social welfare, all estimates of η should be invariant to whether they are elicited over inequalities over time or space, or over environmental domains. Under the null that extended environmental Ramsey Rule in Eqs. (5) and (6) is used, environmental inequality aversion should also be invariant to intra- and inter-temporal contexts. Under each of these nulls, inequality aversion should be invariant to framing (e.g. gain–loss), while the pure rate of time preference is constant in all cases, reflecting the assumption that utility is treated similarly irrespective of whether it stems from consumption or environmental quality. The specific hypotheses tested are discussed in Section 'Inequality aversion, time preference and the environment: Empirical analysis'.

Decision tasks and empirical experimental approach

Epistemological underpinning

In the field of social discounting it is typical to distinguish between normative and positive approaches (e.g. Arrow et al., 1996). A normative approach asks 'what ought to be' or which arguments are valid for defining a 'what is just', often based on attractive axioms. A positive approach is concerned with how individuals make decisions in real life. It is often argued that a specific perspective on distributive justice does not become ethically acceptable just because it is supported by a majority of the population. However, the 'empirical social choice' literature confronts formalised social choice approaches with the opinions of lay respondents so as to derive normatively relevant information. It argues that there is a role for empirical work in normative research for several reasons (Gaertner and Schokkaert, 2012). First, although one may find dual Ramsey discounting very attractive from an axiomatic point of view, we still need the parameters of the model to use it in the real world. Second, testing the model allows us to describe the extent to which the model is supported by people in the real world or not. The puzzles found in empirical approaches may be a useful insight in future theoretical work. For example, our respondents show different discount rates for gains than for losses, a feature that the Ramsey model does not permit. Such findings may motivate theoretical work that allows for phenomena such as habituation (Dietz and Venmans, 2019). Third, even if experts have very strong opinions in favour of Ramsey discounting with particular parameter values, understanding how opinions in the real world depart from this framework is meaningful as a predictor of the general acceptability of the approach.

Some scholars argue that empirical work is an essential element of any ethical theory. Rawls developed the concept of a 'reflective equilibrium' whereby a theory of justice results from confronting ethical principles with considered judgements in concrete situations, and fine-tuning either the principles or the judgement until they are compatible. Though Rawls developed this concept at the individual level, a similar argument can be made on a social level (Miller, 1994). In their seminal paper, Yaari and Bar-Hillel (1984) argue that economic theories of justice can be thought of as being Rawls' ethical principles, whereas the answers by respondents in a specific hypothetical choice situation correspond to Rawls' considered judgements. In the context of this paper, economic experts' views on discounting are then ethically acceptable only if they can be endorsed by the wider public (Miller, 1994).

Contrary to much of the literature on time and risk preferences in experimental behavioural economics, which uses incentivised experiments to induce real rather than hypothetical individual behaviour, the empirical social choice literature aims to derive useful information about a wider variety of normative considerations. As such it necessarily tries to avoid self-interested, incentivised choices. Hypothetical approaches are much more frequent in this context, since they allow flexibility in the normative domains addressed, and remove self-interest.[14] Hypothetical questions may have their own bias, for example when respondents try to answer in a way that pleases the researcher. As we explain in the next section, we attempt to reduce this bias in a number of ways.

Finally, following most studies in empirical social choice, we use student samples rather then a representative sample. Students are an interesting group because they have a higher level of education and allow for more difficult questions. They are also more likely to be among future decision makers. Drupp et al. (2018) surveyed experts on social discounting, who have the advantage of an informed opinion on technical and sometimes ethical matters. On the other hand, students are a useful group when it comes to

[13] In case respondents do not display constant relative inequality aversion, this estimate approximates the arithmetic mean of the elasticity over the range between the higher and lower environmental quality. Section 'Estimation of inequality aversion and the pure rate of time preference' elaborates on this point.

[14] For example, we could have followed the approach of Grijalva et al. (2014) and used questions on time preference incentivised by committing to buy carbon credits according to the respondents' answers. Unfortunately, such choices are easily affected by erroneous conceptions about carbon credits and credibility of researchers' promises (e.g. Cavatorta and Groom, 2018). Almas et al. (2020) also have a complicated incentive scheme to test different conceptions of fairness from a spectator perspective like ours.

testing the dominant conceptual frameworks in the field. Indeed, if one adheres to the Rawlsian concept of a reflective equilibrium on a social level, any differences between experts' and lay people's opinions are an indication that the equilibrium has not been reached[15]

In sum, in addition to estimating inequality aversion with the intention of informing welfare analysis and CBA, our research can be viewed as a piece of empirical social choice theory, which tests the applicability of standard ethical frameworks.

Experimental design

We estimate inequality aversion parameters across different domains of the environment, in which respondents are asked to decide between allocations of environmental commodities, rather than for monetary evaluations. This allows empirical tests of inequality aversion and the pure rate of time preference across different domains. As a means of testing the assumptions of the Ramsey Framework we also test for differences in spatial versus inter-temporal inequality aversion, and behavioural issues like loss-aversion and stationarity of preferences. An example of a decision task is the following:

> "You work for the environmental agency of your country. A sand extraction company introduces a request for a concession in a forest. This will render a part of the forest inaccessible to the public for security reasons. The only disadvantage to be considered is of recreational order: the population will not be able to enjoy the forest during the operations. You can safely assume that there is no chemical pollution and that the effect on biodiversity is negligible (the absence of hikers compensates the presence of extraction machines). Imagine that during operations, the 2 concerned regions are identical in all regards (economic performance, population density, fauna and flora, pollution...), except for forest cover. The extraction company makes two proposals for a concession, for which it is ready to pay the same price. You choose between giving a concession in a region where there is 15% forest coverage or a concession over a smaller surface where there is only 10% forest coverage. There is therefore a trade-off between the quantity of forest that is inaccessible and the fact that when there is less forest in a region, people are more strongly affected by a decrease in forest. What is your preferred option? Attribute a concession of the size of 10 football pitch in the greener region or a concession of the size of one square metre in the less green region?".[16]

Next, respondents choose between a concession of the size of 10 football pitches in the greener region or a concession of 1 football pitch in the less green region. Fig. 1 shows how this choice was presented. The size of the concession is then gradually increased until it is 10 football pitches. The switching point allows us to calculate an instantaneous inequality aversion, using midpoints to define indifference. This procedure is explained in detail in Section 'Estimation of inequality aversion and the pure rate of time preference'.

A second type of question is inter-temporal. A choice between a concession today in one region and a concession in the future in another region in 20 years time is offered. As shown in Section 'Inequality aversion, environment and the Social Discount Rate (SDR)', background growth in consumption has to be assumed to be zero in each scenario to avoid identifying cross elasticities. Figs. 2–4 show how the presentation was altered for inter-temporal framings.[17]

The inter-temporal questions have 3 variants, which are asked to different respondents. The first variant is a gain framing. Instead of 'losing' forest to an extraction company, respondents were asked to decide on 'gaining' public access to a forest because a sand extraction company decides to interrupt operations in one of two regions over a period of 5 years. This allows us to measure differences on inequality aversion between gain and loss framings. In another variation, instead of two regions, the project is realised in the same region. In a 'within-region' framing, the same people will enjoy the forest, which may put more weight on how the affected people may have chosen themselves, whereas in a between-region question, the respondent must consider the distinct sets of people benefiting from environmental quality. Differences arising from this framing could reflect spatial or agent-relative motivations for discounting. In a final variant the question is framed as a decision 20 years in the past. This allows us to test for an 'altruism' effect whereby, if a higher discount rate is preferred when considering previous *generations* compared to future generations, it reflects a view that previous generations should have consumed more and invested less. Similarly, lower rates for the future may reflect concern for sustainability. This altruism effect is captured by our 'decision past' variation. Question 2 presents a scenarios with no growth in the environment, which allows us to calculate the pure rate of time preference rate (See Fig. 2). Questions 3 to 7 combine time with inequality. If the future has more forest, we will call this a 'green future' question (see Fig. 3), if the future has less forest, we will call this a 'brown future' question (see Fig. 4).

Next, respondents answer the same 7 questions in a different environmental domain. Each respondent answers questions in two out of three domains: forest, air-pollution and soil fertility. All variants (gain/loss; within/between regions; decision now/past; green/brown future) are applied to the different environmental domains. The experimental set-up is shown in Table 9 in the Online Appendix 1, along with the exact wording of the experiment.

15 Saelen et al. (2008) also used a sample of students in their sample. Almas et al. (2020) elicit inequality aversion parameters in non-student samples, but focussed on a more representative sample of citizens from the US and Scandinavia.

16 Many respondents have difficulty to make trade-offs between ethical principles such as minimising recreational loss and favouring the least advantageous region. By starting with an extreme difference in size, respondents realise more easily that there are 2 trade-offs going on at the same time.

17 The exact wording of all questions can be found in the Online Appendix 1.

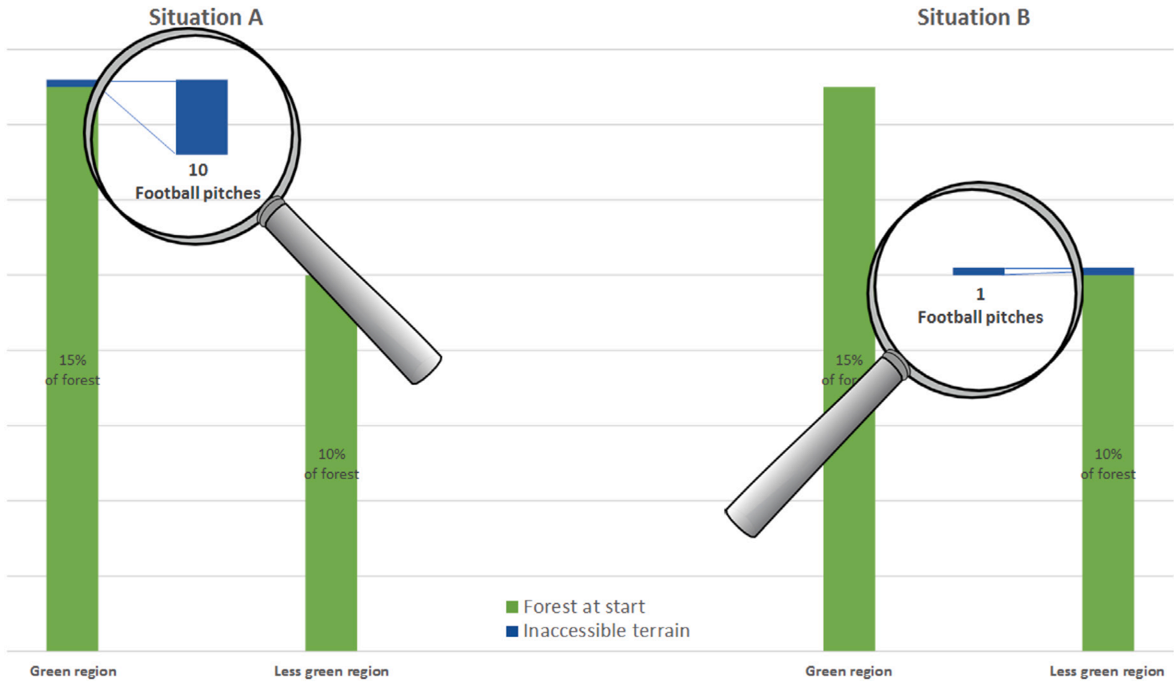

Fig. 1. Example of a Decision Task: Forest loss for a decision now between two regions (Intra-temporal inequality).

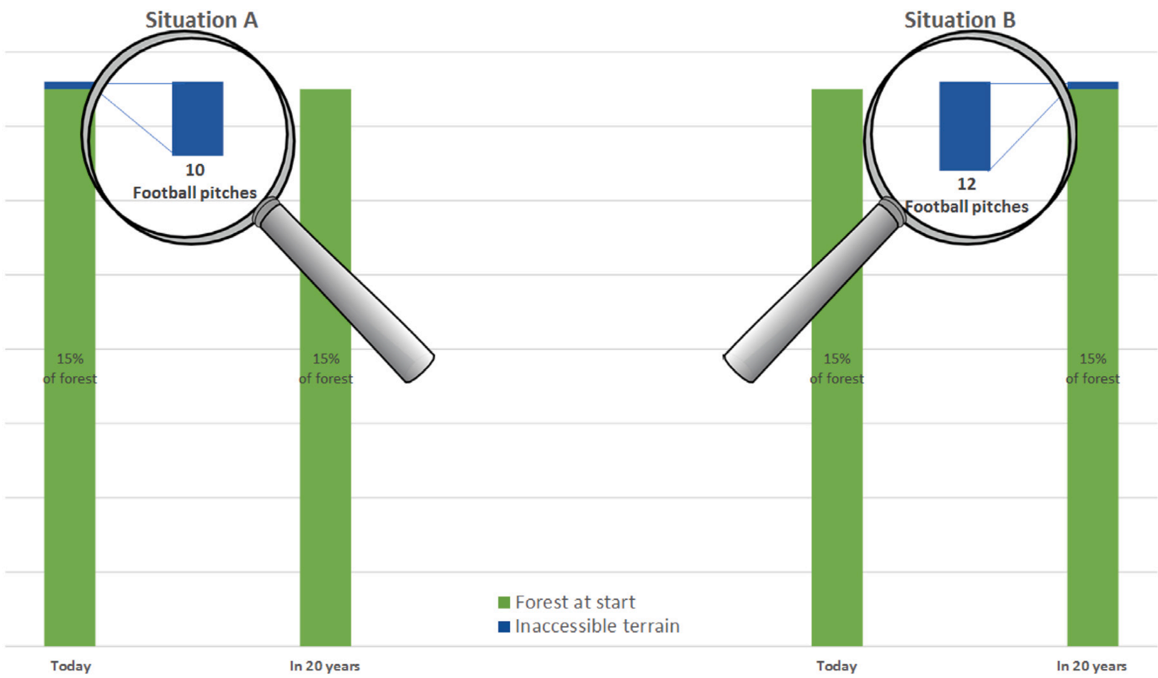

Fig. 2. Example of a Decision Task: Inter-temporal scenario (No Growth).

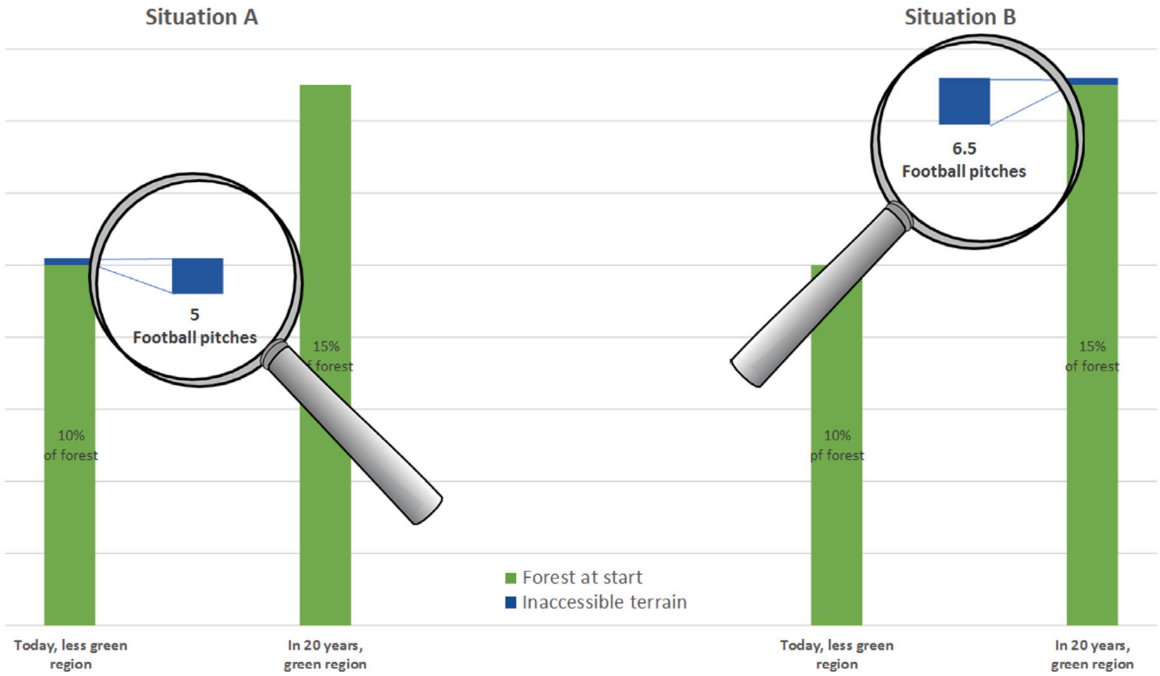

Fig. 3. Example of a Decision Task: Inter-temporal scenario (Green Future).

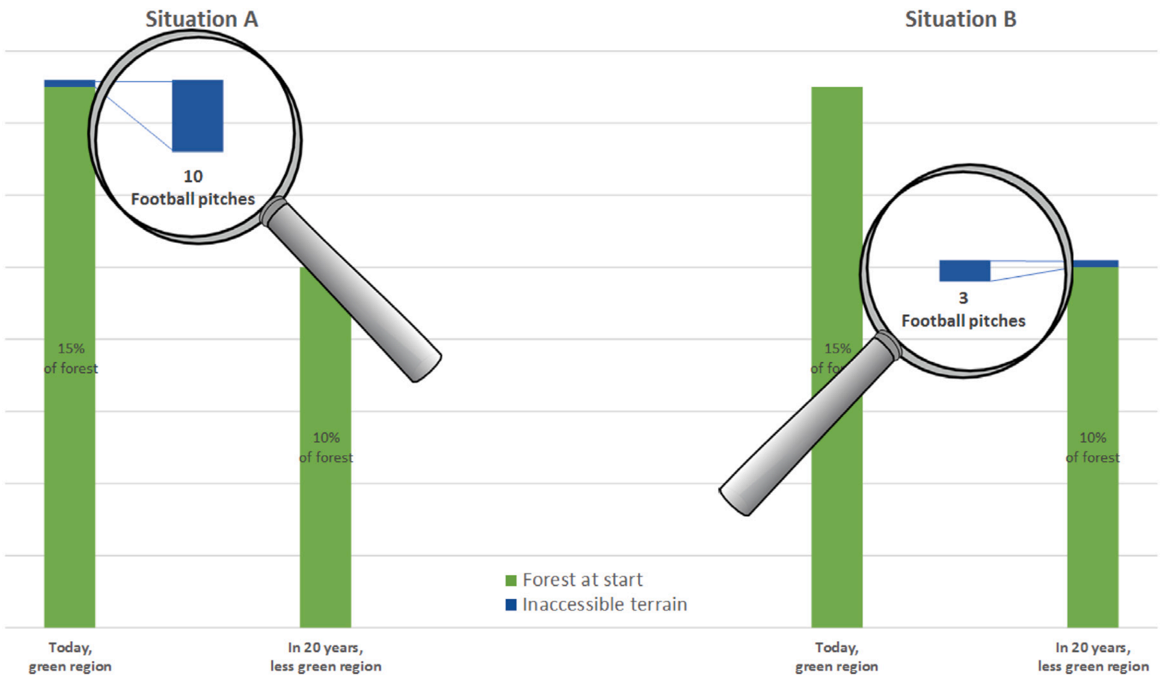

Fig. 4. Example of a Decision Task: Inter-temporal scenario (Brown Future).

An important design feature relates to how the experiment identifies and estimates the parameter of inequality aversion. Our approach is essentially a graphic multiple price list whose design is related to the "leaky-bucket" approach, but with some important exceptions. Firstly, previous studies of inequality aversion (e.g. Cropper and Raich, 2016; Groom and Maddison, 2019) were not explicit about the need for interventions (projects, redistributions, income taxes) to have only a marginal impact in order to estimate inequality aversion. Yet previous approaches have typically used non-marginal transfers to identify the inequality aversion parameter (see footnote 4 for example). As shown in Figs. 1–4, our experimental design was explicit about the baselines and the marginality of the interventions.[18]

Another important departure from the leaky-bucket type framing, where there is a cost to transfer from rich to poor or future to present, was that our experiments did not require the transfer of environmental quality from a richer party to a poorer party. Rather, respondents compared additions to rich and poor regions, or from green and brown futures. In this way we avoid the potentially problematic prospect of taking away from one party, which may introduce elements of loss-aversion, which we test for separately. The precise manner in which inequality aversion is estimated from these data is discussed in Section 'Estimation of inequality aversion and the pure rate of time preference'.

The questionnaires took 90 min to complete. The first 30 min were devoted to an introduction and test questions involving monetary decision tasks, insisting on the logic of trade-offs between ethical principles, marginal effects and saving opportunities (arbitrage opportunities). Students received €10 for participation. The sample consists of 363 respondents establishing 4974 indifference points based on 40,747 decision tasks. We discarded inconsistent answers and work with the remaining 3618 indifference points based on 29,554 decision tasks.[19] Descriptive statistics of our sample are contained in the Online Appendix 5.

Hypothetical bias

A number of response biases are possible in this necessarily hypothetical setting. The unusual and cognitively difficult nature of the scenarios means that responses could well reflect a misunderstanding of the decision-task, or the use of heuristic rules as a cognitive shortcut. We deployed a number of strategies in order to allay both of these sources of bias which are described in detail in the Online Appendix 1.

In order to confront the cognitive difficulties the survey rubric walked respondents through an example in which the essential welfare trade-offs of giving smaller amounts to a poorer party or a larger amount to a richer party were made clear. Respondents were reminded that there were no wrong answers or ethical stances. Respondents were also told of the purpose of the research and its importance for public policy. The ordering of the decision-tasks was also carefully designed to reduce cognitive loads. When comparing two areas at the same point in time, the series of tasks always started with an extreme example to exemplify the idea of trading off distributional fairness of the additional environmental quality, with its overall size: e.g. the microscopic $1m^2$ of forest to the environmentally poor versus 10 football pitches to the environmentally rich. In sequence this was followed by tasks giving ever increasing amounts to the poor. This approach, rather than the reverse sequencing, meant that the trade-off was clear from the first decision-task, rather than understood half-way through the sequence. An analogous approach was taken with the inter-temporal tasks. The intention here was to avoid unintentional heuristic responses such as 'always give to the poor or 'always give to the future', albeit without removing these possibilities altogether. For the tasks involving green or brown futures, and other framings, the ordering of the tasks took on many different permutations to avoid any biases arising due to the sequencing effect (see the Online Appendix 1 for more detail). Again we used the extreme starting point: $1m^2$ of forest to the poor versus 10 football pitches to the rich.

Responses to the extreme first question (1 m^2 to the poor versus 10 football pitches to the rich) were used as a notional rationality test. A preference for the microscopic addition to environmental inequality was used as an indication that individuals were simply unable to make trade-offs at all. Indeed, when evaluating the responses, we discarded a number of different types of response, each of which betrayed inability to understand the question. The three main types were: (1) multiple-switchers; (2) a preference to give a concession of the same size in the less green region; (3) a preference to give a concession of 10 football fields in the green region over a concession of 1 m^2 in the less green region.[20] Respondents were invited to give comments to the questions, especially if there answers were 'inconsistent'. In the main results, only a respondent's 'inconsistent' answer is discarded, not the respondent's other answers. Appendix A shows that the results are robust to excluding respondents who gave even one inconsistent answer.

[18] Further examples of the experimental instrument are shown in the Online Appendix 2.

[19] In the Autumn of 2016, 20 students and adults at the University of Mons took part in a pilot study in which various designs were tested. Similarly, in February 2017, students from the Department of Geography and Environment at the London School of Economics took part in a pilot study with the aim of fine tuning the design of the decisions tasks in the various domains of environment. The answers of these two pilot studies are not included in our results but led to our eventual decision task design. The final design started with 2 groups of students at the University of Mons in the spring of 2017 (22% of the sample), followed by 8 other groups in the Autumn of 2017. At the suggestion of the referees we undertook a replication study in Autumn of 2020 in the same situation at the University of Mons.

[20] Online Appendix A for results for 'rational' answers only, and Online Appendix 1 for a complete description of discarded answers.

Finally, the following design features are also designed to reduce hypothetical biases stemming from the fact that the exercise in empirical social choice is relatively unfamiliar. First the questions force a trade-off between ethical principles. Respondents chose between having more environmental improvement or more equality, they cannot have both. This avoids problems associated with open-ended, unconstrained elicitation, but also ensures due consideration of the ethical issues at play. In addition, concrete choice situations are used to test the ethical underpinnings of Ramsey discounting, as explained in Section 'Experimental design', which are to be preferred to more abstract examples.[21]

While there is always the possibility that our approach could introduce some anchoring or framing bias, this concern was outweighed by the need to reduce the cognitive difficulty of the tasks and engage with the essential trade-offs associated with eliciting environmental inequality aversion. We undertook a replication study and estimated a model using only between-respondent variation, partly controlling for respondent 'demand effects'. In each case the results are robust, which suggests that the responses were consistent within and between respondents (See Appendix A Tables 2, 3 and 5).

Estimation of inequality aversion and the pure rate of time preference

The simple Ramsey Rule constrains inequality aversion for the environment to be the same as for income and consumption. In applications, the simple Ramsey Rule is calibrated using evidence on intra-temporal and inter-temporal inequality aversion interchangeably, the implicit assumption being that these social preferences are the same (Groom and Maddison, 2019). The extended environmental Ramsey Rule relaxes the former restriction on inequality aversion for the environment, but in principle retains the assumptions on intra- and inter-temporal inequality aversion. While the extended Ramsey Rule can perfectly well reflect different levels of inequality aversion across environmental domains, the pure rate of time preference ought to be invariant across different domains. Whether a simple or extended Ramsey Rule is considered, the social preferences it embodies are invariant to framing effects such as gain–loss, past–future and, as we explain, green or brown growth scenarios. In this section we explain the theoretical underpinnings of the empirical model used to estimate environmental inequality aversion. In Section 'Inequality aversion, time preference and the environment: Empirical analysis' a series of empirical tests are proposed of these invariance hypotheses using OLS estimates of a linear specification of the extended environmental Ramsey Rule.[22]

The dependent variable of our linear model of the environmental Ramsey Rule, the social discount rate, is estimated as follows. The rubric of the experiment made clear that consumption is identical in options A and B, therefore the cross-elasticity (η_{EC}) in Eq. (7) is equal to zero and the equation collapses to $SDR_E = \delta + \eta_{EE} g_E$.[23] The point at which the respondent switches from option A to B determines a point of indifference. that we define as the midpoint. For instance, the respondent may prefer option A, i.e. 10ha in the brown region, over 11ha in the greener region. But in the next question, she may switch to option B, prefer 13 ha in the greener region over 10 ha in the brown region. As a result, we assume that she is indifferent between 10 ha in the brown region and 12 ha in the green region. Assume constant relative inequality aversion and define $E^{-\eta_{EE}}$ as the marginal utility in the environmental domain, where E is the background level of environmental quality, and define the marginal increment offered in option A and B as ΔE_A and ΔE_B. In the inter-temporal case indifference between option A (with benefits now) and option B (with benefits in 20 years) yields:

$$\Delta E_A * E_A^{-\eta_{EE}} = \Delta E_B * E_B^{-\eta_{EE}} e^{-\delta 20} \tag{9}$$

In the experiment the greener scenario had a background environmental quality which was always 50% larger. In the inter-temporal scenarios this corresponded to a growth rate of $g = \pm 2\%$ (+2% = green future, -2% = brown future) over a time horizon of 20 years. So, $E_B = E_A e^{g*20}$. Using this fact in Eq. (9) and rearranging yields an expression for the SDR r_i:

$$r_i = \frac{1}{20} ln \frac{\Delta E_A}{\Delta E_B} = \delta + \eta_{EE} * g_E \tag{10}$$

which is the linear Ramsey type specification of the environmental SDR in terms of parameters δ and η_{EE}.[24] The data for the dependent variable are calculated for each choice list at the individual level: $r_i = \frac{1}{20} ln \frac{\Delta E_A}{\Delta E_B}$. The data on growth, the independent variable in the intertemporal context, are captured by dummy variables $D_{Gr.Future}$ and $D_{Br.Future}$ which take values 2 or 0 and -2 or 0 respectively, reflecting the assumed secular growth of $\pm 2\%$ in the green and brown future scenarios respectively. When growth is zero the pure rate of time preference is the intercept in this linear model. Intra-temporal environmental inequality aversion is identified analogously, as the parameter on a dummy variable $D_{Instant}$ in a linear specification of Eq. (10).[25] We estimate several

[21] Gaertner and Schokkaert (2012, p. 20) point out that: "Confronting respondents with specific stories is less suggestive than formulating abstract principles, and brings us closer to their own original ethical intuitions".

[22] For robustness we also used maximum likelihood procedures to estimate the linear specification following the approach taken by Andersen et al. (2008), and the estimates only differ marginally. See Online Appendix 3.

[23] The exception is the soil fertility domain where we estimate $SDR_E = \delta + (\eta_{EE} + \eta_{EC})\, g$, where g is the growth rate of consumption.

[24] We estimate η_{EE} as a constant parameter. Footnote 6 discussed the theoretical justification for this. Our estimate can be thought of as linear approximations otherwise.

[25] The calculation for instantaneous/intra-temporal questions is slightly different. Here we have Eq. (9) except with $t = 0$. Therefore, $r_i = \eta_{EE} = ln \frac{\Delta E_A}{\Delta E_B} / ln \frac{E_A}{E_B}$, noting that ($ln \frac{E_A}{E_B} = ln(1.5) = 20 * 0.02$). The dummy variable $D_{Instant}$ takes on values 1 for instantaneous no-growth scenarios, and zero otherwise. The estimate of the parameter on this dummy variable is an estimate of η_{EE} in intra-temporal contexts, rather than a discount rate.

Table 1
Inequality Aversion and Pure Time Preference: Models (1)–(5). OLS regressions of Eqs. (11) and (12) with robust (clustered) standard errors, *** p<0.01, ** p<0.05, * p<0.1. Main sample (excluding the replication sample).

Estimated parameters	(1)	(2)	(3)	(4)	(5)
δ	0.88***	1.02***	0.37***	0.44***	0.20*
	(0.044)	(0.08)	(0.089)	(0.11)	(0.1)
δ_{Air}		−0.12		−0.027	0.28***
		(0.12)		(0.11)	(0.098)
$\delta_{SoilFertility}$		−0.30***		−0.30***	−0.11
		(0.11)		(0.10)	(0.085)
δ_{Gain}			0.72***	0.72***	0.83***
			(0.083)	(0.082)	(0.074)
δ_{Past}			−0.079	−0.045	−0.044
			(0.07)	(0.07)	(0.07)
$\delta_{TwoRegions}$			0.24***	0.29***	0.29***
			(0.084)	(0.087)	(0.087)
$\eta_{Instant}$	2.94***	2.88***	3.01***	2.95***	2.56***
	(0.12)	(0.12)	(0.12)	(0.12)	(0.2)
$\eta_{Instant,Air}$					0.086
					(0.21)
$\eta_{Instant,SoilFertility}$					0.44
					(0.27)
$\eta_{Instant,Gain}$					0.40**
					(0.19)
$\eta_{Br.Future}$	1.98***	1.92***	2.10***	2.05***	1.90***
	(0.07)	(0.077)	(0.082)	(0.089)	(0.11)
$\eta_{Br.Future,Air}$					0.27**
					(0.13)
$\eta_{Br.Future,SoilFertility}$					0.26*
					(0.13)
$\eta_{Br.Future,Gain}$					−0.081
					(0.099)
$\eta_{Gr.Future}$	1.41***	1.34***	1.55***	1.51***	1.70***
	(0.036)	(0.055)	(0.06)	(0.074)	(0.079)
$\eta_{Gr.Future,Air}$					−0.18**
					(0.086)
$\eta_{Gr.Future,SoilFertility}$					0.00098
					(0.076)
$\eta_{Gr.Future,Gain}$					−0.26***
					(0.063)
η_{air}		0.053		0.044	
		(0.079)		(0.081)	
$\eta_{SoilFertility}$		0.13		0.15*	
		(0.083)		(0.084)	
η_{Gain}			−0.13**	−0.14**	
			(0.06)	(0.059)	
η_{Past}			−0.10**	−0.12**	−0.12**
			(0.049)	(0.05)	(0.05)
$\eta_{TwoRegions}$			−0.028	−0.044	−0.039
			(0.056)	(0.062)	(0.063)
Observations	3,618	3,618	3,618	3,618	3,618
R-squared	0.608	0.609	0.617	0.619	0.621

empirical models using OLS with dummy variables to indicate different experimental treatments: growth scenarios and framings. A test of parameter equality is then used to test the assumptions of the extended Ramsey Rule.

The theory outlined above has assumed constant relative inequality aversion (Atkinson, 1970). If this is not the case for our respondents, the method identifies the arithmetic mean of the inequality aversion parameter across high and low environmental quality scenarios. Because all scenarios use the same pair of high and low background environmental quality, the estimated parameter will not differ across these scenarios if the Ramsey Rule is being followed, even if relative inequality aversion is not constant.[26] This observation, and the related restrictions that the Ramsey Rule imposes, form the basis of our testable hypotheses.

Our empirical analysis also accommodates the case where environmental quality affects production, and is hence linked to income inextricably. In our questions related to soil fertility, we explicitly specify that income grows or decreases at the same rate as the

[26] It is easy to show that if utility is not CRRA/CRIA then the Ramsey Rule we estimate is: $\bar{r} = \delta + \frac{1}{t}\int_{E_A}^{E_B} \frac{\eta(E)}{E} dE = \delta + g\ \frac{1}{t}\int_{t_A}^{t_B} \eta(t)dt$, for time periods t_A and t_B, with an analogous expression for the intra-temporal scenarios. Since E_A, E_B and g are identical in each setting, the estimate of $\bar{\eta} = \frac{1}{gt}\int_{E_A}^{E_B} \frac{\eta(E)}{E} dE = \frac{1}{t}\int_{t_A}^{t_B} \eta(t)dt$ should be identical across all of the scenarios in the experiment.

environment. In that case we estimate $r_i = \delta + (\eta_{EE} + \eta_{CE})\, g_E$ and our estimated inequality aversion parameter potentially captures both effects. This represents the relevant case in which the benefits of environmental quality stem from ecosystem services that enhance productivity, rather than directly through utility.[27]

Empirical Model 1 specifies time only (no growth), instantaneous, brown future and green future scenarios to estimate a generic pure rate of time preference across all environmental and monetary domains (δ) and three separate measures of environmental inequality aversion for: (i) instantaneous/intra-temporal inequality ($\eta_{Instant}$); (ii) inter-temporal inequality with brown future ($\eta_{Br.Future}$); and. (iii) inter-temporal inequality with a green future ($\eta_{Gr.Future}$). The following equation is estimated using OLS:

$$r_i = \delta D_{Time} + \eta_{Instant} D_{Instant} + \eta_{Br.Future} D_{Br.Future} + \eta_{Gr.Future} D_{Gr.Future} + \epsilon_i \tag{11}$$

In fact, the parameter estimates can often be understood as group arithmetic means of r_i for the different treatments. For instance, in the case of instantaneous questions, r_i corresponds to the elasticity of marginal utility for instantaneous inequality $\eta_{Instant}$, since only $D_{Instant} = 1$ in such cases. Furthermore, δ is the mean of the discount rates on 'time only' questions where only $D_{Time} = 1$. Parameter estimates $\eta_{Br.Future}$ and $\eta_{Gr.Future}$ reflect group means for the brown and green future treatments.[28]

Models 2–5 include additional indicator variables to test further Hypotheses and the robustness of Model 1. Models 2 and 3 include additional interaction terms for different environmental domains: air pollution and soil fertility. These interactions allow estimation of separate inequality aversion and pure time preference parameters for each of these domains. Interactions with indicators to distinguish the within-region / between-region , gain/loss and past/future framings allow us to test the effect of these treatments. Models 4 and 5 contain a more complete set of interaction terms which disentangle the estimates of inequality aversion in instantaneous and green/brown future scenarios by the environmental domains and the gain/loss, within-region/between-region, and decision past/future framings. Models 1–4 are nested in the more general Model 5, which is specified as follows;

$$\begin{aligned} r_i = {} & \delta D_{Time} + \left(\textstyle\sum_k \delta_k D_k\right) D_{Time} \\ & + \eta_{Instant} D_{Instant} + \left(\textstyle\sum_k \eta_{Instant,k} D_k\right) D_{Instant} \\ & + \eta_{Br.Future} D_{Br.Future} + \left(\textstyle\sum_k \eta_{Br.Future,k} D_k\right) D_{Br.Future} \\ & + \eta_{Gr.Future} D_{Gr.Future} + \left(\textstyle\sum_k \eta_{Gr.Future,k} D_k\right) D_{Gr.Future} + \epsilon_i \end{aligned} \tag{12}$$

where k = (air, soil fertility, gain, between regions, decision past). As discussed the parameter estimates reflect group means of for different experimental treatments. The reference category for all estimates is forest loss, in between regions for a decision taken today.[29]

Inequality aversion, time preference and the environment: Empirical results

Table 1 shows the results of the OLS regressions for the full sample of respondents. Columns 1 to 5 show the results from the 5 different models nested in Equation Eq. (11). The results from alternative empirical models and estimation procedures support these results and are outlined in the Online Appendix 3.[30]

Table 1 shows the estimates of environmental inequality aversion. The first observation is that there is substantial aversion to environmental inequality, across different environmental domains and framings. For instance, Model 1 shows that inequality aversion measured at an instant in time, $\eta_{Instant}$, is estimated to be 2.9. In an inter-temporal context in the brown future scenario the estimate is $\eta_{Br.Future} = 2.0$, and in the green future scenario, $\eta_{Gr.Future} = 1.4$. All of these estimates are statistically significantly different from zero (p = 0.000). These estimates can be compared to values obtained from revealed preference (Groom and Maddison, 2019) or stated preference studies Saelen et al., 2008 of income inequality aversion that lie respectively between 1 and 2 or up to 9 for a variety of spatial and temporal contexts. The evidence suggests that environmental inequality aversion varies in a similar way

27 Cost–benefit analysis of climate change typically considers the effect of the climate on productivity as its only effect on utility.

28 More specifically $\eta_{k.Future} = \frac{\overline{r_{i,k.Future}}}{2} - \overline{r_{i,TimeOnly}}$ where $k = Green, Brown$.

29 There are many ways in which heterogeneous pure time preference rates can be aggregated. Heal and Millner (2014) maximise a welfare functional of the form $\sum_i \int_\tau^\infty U(c_i(t)) e^{-\delta_i t} dt$ s.t. $\sum_i c_i(t) = C(t)$ for i individuals with discount rate δ_i consuming c_i and $C(t)$ being aggregate consumption. The aggregate pure time preference rate under a utility function with constant and identical elasticity for marginal utility η is $\delta^*(t) = \frac{\sum_i \delta_i e^{-\frac{\delta_i}{\eta} t}}{\sum_i e^{-\frac{\delta_i}{\eta} t}}$. Note that this discount rate is time dependent and converges to the lowest discount rate in the population for very long time spans. The formula only applies to homogeneous η. The formula of Heal and Millner shows that an arithmetic mean of discount rates approaches the efficient outcome for large inequality aversion and/or short time horizons.

The efficient aggregation over longer periods requires however to put lower weight on high discount rates. The Online Appendix 3 reports non-linear regression results for the following equation

$$\beta_i = \exp\left(\left(-\delta D_{Time} - \eta_{Instant} D_{Instant} - \eta_{Br.Future} D_{Br.Future} - \eta_{Gr.Future} D_{Gr.Future}\right) \frac{t}{100}\right) + \epsilon_i \tag{13}$$

where $\beta_i = \exp(-r_i t)$ is the discount factor. Results boil down to aggregating time preferences by taking arithmetic means of discount factors which corresponds to taking geometric means of discount rates.

30 In Appendix A, Table 4 shows the results for the sub sample of respondents who never gave an "irrational" answer on any price list. In the main results, an "irrational" choice list, such as a response violating transitivity by switching twice, is disregarded, but not the other choice lists of the same respondent. Online Appendix 3 shows the equivalent results for the maximum likelihood approaches that were described in the methodology section above. Figure 12 in Online Appendix 5 provides histograms of rational and irrational responses.

across spatial and temporal contexts as income inequality aversion, and is at a similar level. We do not make direct comparisons in our experiment however, leaving this for future work.

Several further hypotheses can be tested in relation to the extended environmental Ramsey Rule. Hypothesis 1 concerns the invariance of inequality aversion irrespective of whether inequality occurs within time periods or over time: H_0^1 : $\eta_{Instant} = \eta_{Br,Future} = \eta_{Gr.Future}$. Model 1 shows that the inequality aversion parameters are statistically different from zero, but a Wald test of H_0^1 rejects the null hypothesis of parameter equality (p-value 0.000), and all pairwise comparisons show statistically significant differences also (p-value 0.000). The fact that $\eta_{instant}$, $\eta_{Br,Future}$ and $\eta_{Gr.Future}$ differ significantly from one another is a violation of the assumptions of the Ramsey Rule. As discussed in Section 'Estimation of inequality aversion and the pure rate of time preference', even if social preferences do not obey constant relative inequality aversion, our estimates of inequality aversion ought to be identical in scenarios with inequality. That they are statistically different from one another is a signal that on average our respondents do not use the Ramsey Rule/Utilitarian social welfare function for environmental quality. The wealth effect is larger in absolute terms when the future is poorer (brown) compared to when the future is richer (green). These results are robust across all the models in Table 2, which control for other experimental treatments. We comprehensively reject H_0^1.[31]

Hypotheses 2–5 offer further tests of the extended Ramsey framework. H_0^2 : $\eta_{air} = \eta_{SoilFertility} = 0$, which is a test of inequality aversion across environmental domains against the baseline: forests. Rejection of the null here is not a rejection of the extended Ramsey Rule, but rather an indication that relative prices evolve according to environmental domain. Hypothesis 3 is a test of the pure rate of time preference across environmental domain against the baseline: H_0^3 : $\delta_{air} = \delta_{SoilFertility} = 0$. Rejection of this null would be a violation of the extended Ramsey Rule. Finally, Hypotheses 4 and 5 concern the framing effects: within/between-regions, gain/loss, past/future, for the pure rate of time preference and inequality aversion: H_0^4 : $\delta_{TwoRegions} = \delta_{Gain} = \delta_{Past} = 0$ and H_0^5 : $\eta_{TwoRegions} = \eta_{Gain} = \eta_{Past} = 0$. Rejection of H_0^4 and H_0^5 would be a violation of the extended Ramsey Rule. Hypotheses 2–5 are tested by Models 2–5 in Table 1.

The results of Model 2 allow us to test H_0^2 and H_0^3. The parameters $\eta_{Fertility}$ and η_{Air} are interactions which measure the extent to which inequality aversion differs from the reference/baseline category: domain is forest, framing is loss, within region, present (not past), when inequality aversion is measured in these environmental domains. The estimates are: $\eta_{Fertility} = 0.13$ and $\eta_{Air} = 0.05$. These differences are both small in magnitude and statistically insignificant. A joint Wald test fails to reject H_0^2 (p-value 0.30).[32] Inequality aversion does not vary across environmental domains in our experiment.[33]

H_0^3 tests the pure rate of time preference across environmental domains. The pure rate of time preference for the reference category (forest) is $\delta = 1.02\%$. However, respondents discount at a lower rate in the fertility domain $\delta_{Fertility} = -0.3\%$, meaning a discount rate of 0.72%. A joint Wald test rejects H_0^3 (p-value = 0.02).[34] Model 4 confirms this finding when controlling for both framing and domain differences. This result is a violation of the Ramsey framework.

H_0^4 and H_0^5 test parameter equality across within/between-region, gain/loss and past/future framings for pure time preference and inequality aversion respectively. Model 3 shows that the within/between-region framing affects the pure rate of time preference: $\delta_{TwoRegions} = 0.24\%$ meaning that respondents have a higher pure rate of time preference when choosing between two regions, rather than within one. The gain/loss framing leads to a pure rate of time preference that is 0.72% higher in the gain framing than in the loss framing: $\delta_{Gain} = 0.7\%$, meaning respondents are more impatient for gains than losses and are more reluctant to postpone losses, perhaps because this contradicts sustainability motives. Respondents are not influenced by the past/future framing in relation to pure time preference: $\delta_{Past} = -0.08\%$. Nevertheless, a Wald test of H_0^4 ($\delta_{TwoRegions} = \delta_{Gain} = \delta_{Past} = 0$) rejects the null hypothesis of parameter equality (p-value 0.000). These results hold in Model 4 also.

H_0^5 ($\eta_{TwoRegions} = \eta_{Gain} = \eta_{Past} = 0$) concerns framing and inequality aversion. Model 3 shows that inequality aversion is not affected by the regional framing since $\eta_{TwoRegions} = -0.03$ and is statistically insignificant. However, $\eta_{Gain} = -0.13$, and $\eta_{Past} = -0.10$, and both are statistically significant. Model 4, which controls for domain and framing, confirms these findings. In both cases a Wald test of H_0^5 rejects the null of parameter equality (p-value 0.02): Inequality aversion depends on the how inequality is framed, and this is a violation of the extended environmental Ramsey framework.

Model 5 undertakes additional tests of whether measures of intra- and inter-temporal inequality aversion vary across the environmental, spatial, gain–loss and past–future domains. The results seem to suggest that there is some variation in these sub-subcategories. First, $\eta_{Instant.Gain} = 0.40$, meaning that instantaneous inequality aversion is higher by 0.40 in the gain domain. Second, $\eta_{Br.Future,Air} = 0.27$ and $\eta_{Br.Future,Fertility} = 0.26$, indicating that the brown future effect on inequality aversion is stronger for air pollution and soil fertility, compared to forests. Finally, $\eta_{Gr.Future,Gain} = -0.26$: the Green Future effect is lower in the gain domain. While intuitive and interesting, these effects are significant at the 5% level only, and are potentially under-powered.

Any experiment runs the risk of reporting large and significant results purely by chance, with conclusions that are under-powered and not replicable. To address this risk we ran a replication of the experiment in September 2020, in the same location with a different cohort of students. Descriptive statistics in Online Appendix 5 show the similarity of the replication sample. The replication

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31 In models 2 to 5, H_0^1 is again rejected with p-value 0.000. Individual comparisons are also rejected with p-value 0.000.

32 When we include the replication sample, the p-value decreases to 0.03. This indicates that small differences may exist.

33 Recall from Section 'Estimation of inequality aversion and the pure rate of time preference' that estimate on soil fertility includes a cross-elasticity due to consumption growth, which appears to have negligible effect on the estimate.

34 If we enlarge the sample including the replication sample, the absolute magnitude of $\delta_{Fertility}$ decreases, but H_0^3 is rejected with the same p-value (0.02).

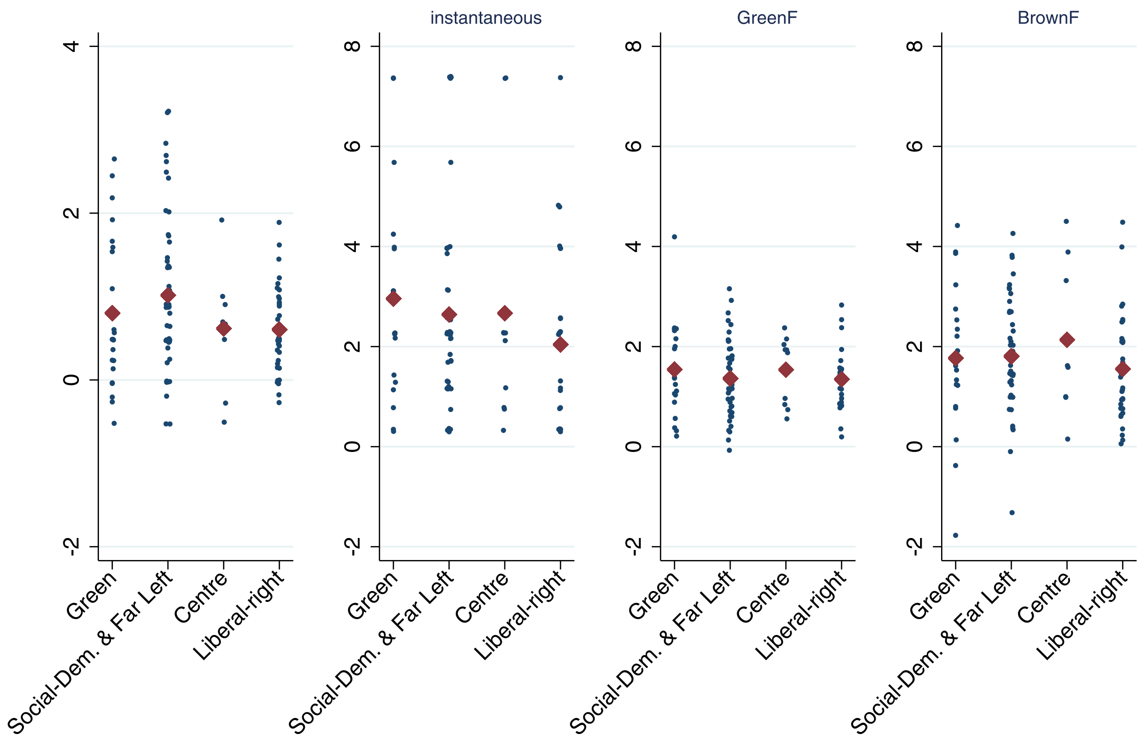

Fig. 5. Pure time preference and inequality aversion by political party voted for.

study was sufficiently powered to identify those coefficients with the smallest effect size from the 2017 experiment.[35] The results indicate that with a only few exceptions in the gain treatments, the estimated parameters are very similar in magnitude for the replication experiment, differing by less than a tenth of a percentage point in most cases (See Tables 2 and 3 in Appendix A).[36] Another concern is that Table 1 used within- respondent variation to identify the social preference parameters. The results are also largely robust to using only between respondent variation, rather than within. This test also indicates the absence of experimental demand effects.[37] Finally, the results are robust to the sub-sample of respondents who never repeatedly switched in the multiple price list (See Table 4 in Appendix A).

In sum, aversion to environmental inequality is substantial, differs across temporal and spatial framings, but is largely constant across environmental domains in our experiments. The pure rate of time preference varies when decisions are between regions rather than within, perhaps reflecting their uncertainty about which region they would reside in, or even agent relative ethical tendencies (Beckerman and Hepburn, 2007). Taken together, a cautious conclusion is that the extended Ramsey model does not describe well our respondents' social preferences for the environment over time, space and other domains.

Heterogeneous social preferences

Since different political parties have distinct positions on redistribution and fairness, and long-term issues such as sustainability, the political dimension allows a discussion of how heterogeneous positions may or may not be reconciled with the normative framework. We explore heterogeneity by political affiliation according to "Party voted for in last election". To analyse the heterogeneity of discount rates and inequality aversion we calculate individual level parameters, and then investigate the correlation with political and social opinions. Fig. 5 shows the distribution of individual results of $\delta, \eta_{Instant}, \eta_{Br.Future}$ and $\eta_{Gr.Future}$. The political parties are arranged from Left (left) to Right (right) politically on the x-axis. Taking instantaneous inequality aversion first, those

[35] We used the GPower software to calculate the power required in a multiple linear regression to identify the effect size of the original delta parameter which explained 0.025% of the variance of the discount_rate in the 2017 main effects regression with an effect size (f^2) of 0.03. For a power of 95% the sample size of responses required was 540. Our replication sample has 2562 additional observations, and so our results are sufficiently powered to identify this effect size and smaller.

[36] The effect sizes (Cohen's d) of the differences in the estimated coefficients for the important main and interaction effects are rarely significant in magnitude of statistical significance.We used the esize command in STATA to calculate Cohen's d statistic, and its significance (Cohen 1988).

[37] Table 5 shows the results of a model that relies on responses from the first 4 questions on time only, instantaneous, green future and brown future, which excludes repeated 'within' individual responses in these domains, and hence relies only on between variation. We thank the two anonymous referees for proposing these robustness tests.

who voted for the Green Party or the Social Democrats/'Far-Left' have larger instantaneous inequality aversion than other voters in the centre and the right of the political spectrum. Inversely for these two groups, in an inter-temporal green future context, inequality aversion is less important, leading to lower discount rates. This pattern accords with these Partys' typical concern with current income inequalities and their and ambitious climate, or other environmental, policies. These two ethical concerns, one instantaneous and one inter-temporal, are difficult to reconcile in the simple Ramsey framework because high inequality aversion for current inequalities is in tension with preferences for sustainability, which would dictate a lower level of inequality aversion for inter-temporal problems. By contrast, voters for the centre party and liberal-right party tend to have inequality aversion that is comparable in instantaneous, green future and brown future settings. These voters therefore follow the logic and normative structure of the Ramsey rule to a larger extent. Overall, differences in inequality aversion among respondents with different political party affiliations tend to be smaller in an inter-temporal context than an intra-temporal one. There are no obvious differences in the pure time preference parameter across different political parties.

In addition to voting behaviour, respondents gave a score between 1 and 10 on the following questions on *political concerns*: How much do you feel concerned by: (1) inequality; (2) the environment in general; (3) the future of the planet; and, (4) pollution today?, and *confidence*: How much confidence do you have in: (1) the government; (2) political parties; (3) NGO's; and (4) people in general? The results are fairly homogeneous across these political opinions. Figure 9 in Online Appendix 4 shows that for the quartile with lowest concern for inequality, the mean $\eta_{Instant}$, $\eta_{Br.Future}$ and $\eta_{Gr.Future}$ are 2.5, 1.3 and 1.6, whereas for the quartile with the highest concern for inequality the figures are 2.6, 1.4 and 1.8 respectively. The latter displays no real increase in inequality aversion despite stated concerns about this issue. One reason for these preferences being unresponsive to attitudes could be that people who are concerned about inequality are also concerned about environmental issues. Strong concerns about inequality per se, are outweighed by concerns for future environmental quality/sustainability. Indeed, in our data the correlation between both questions is relatively strong (0.35). The results are similarly homogeneous across levels of *confidence* (see Figure 10 in Online Appendix 4).

This analysis of heterogeneous responses is obviously highly exploratory.[38] The sample sizes are small, and none of the differences discussed above are statistically significant at the 5% level. Nevertheless, the results reflect some of the possible tensions that the Ramsey Rule may introduce, and provides some evidence of the consistency of the responses in the data.[39]

Conclusion

This paper has presented estimates of environmental inequality aversion obtained from experimental decision tasks showing that aversion to environmental inequality is as pronounced a social preference as aversion to income inequality, if not more so. A measure of inequality aversion, or the elasticity of marginal utility more generally, is required to calibrate a normative social discount rate (SDR) for environmental quality, just as an estimate of income inequality aversion has been used to help calibrate the SDR for consumption in policy circles (Treasury, 2003; Groom and Hepburn, 2017; Freeman et al., 2018). Multiplied by an estimate of the growth in environmental quality, and the estimate yields the environmental "wealth effect" in the environmental SDR (see e.g. Baumgaertner et al., 2015). Equivalently, if the so-called dual-discounting approach is thought to mask what is essentially a valuation problem for environmental quality, the same information can be used to estimate the change in relative shadow prices for environmental quality. Relative price effects have been discussed in government guidance documents in the UK, the Netherlands and France, and have been shown to be critical to the welfare analysis of climate change mitigation (Groom and Hepburn, 2017; Sterner and Persson, 2008; Drupp and Hänsel, 2021). In our study, for example, in a number of experimental framings we find inequality aversion for inter-temporal settings of between 1.4 and 2, implying that if future environmental quality is lower by 50%, it should be valued at a price that is up to four times its current value, all else (consumption) being equal. For intra-temporal comparisons inequality aversion is estimated to be approximately 3, meaning that for someone with half the environmental quality should receive up to eight times the weight in an equity weighted welfare analysis.[40]

In testing the typical theoretical structure used in social discounting the paper has been able to provide some empirical insights on how people think about social discounting and inequality aversion in different domains. Our results show that the pure rate of time preference that people apply is not constant across different environmental domains: air pollution, agricultural (soil) fertility and forests. Neither is the rate of pure time preference the same across gain/loss experiments, or different spatial domains. Estimates range from $\delta \approx 1.1\%$ when estimated in the gain domain, to $\delta \approx 0.7\%$ for soil fertility. For inequality aversion, the results differ when inequality exists between agents intra-temporally ($\eta \approx 3$), to when inequality exists inter-temporally ($\eta \approx 2$). Inter-temporal inequality aversion is lower still if the future of the environment looks positive: ($\eta \approx 1.4$ in the so-called "green future" scenario). Inequality aversion also differs across other dimensions such as when gains rather than losses are used to elicit responses, and when people are asked to consider their position compared to previous generations. Our estimates of environmental inequality aversion allow the calibration of a simple dual discount rate or the trajectory of relative prices that could better reflect the welfare effects of environmental inequality and environmental change. Yet, our estimates of both the pure time preference and inequality aversion

38 The sample size per party is small, green 25, far-left 17, , social democrat 43, centre 13, Liberal-right 39. Some differences in instantaneous inequality aversion, e.g. between Centre and Green, are statistically significant at the 10% level.

39 In the Online Appendix 4 Figure 11 shows the same results using the total sample including the replication sample, which has the same pattern to the original experiment, again without statistical significance.

40 With the relative price $p = \frac{U_E}{U_C}$, for constant U_C we have $\frac{p_t}{p_0} = \frac{U_{E_t}}{U_{E_0}} = \left(\frac{E_0}{E_t}\right)^{\eta}$, hence with $E_0 = 2E$ and $\eta = 3$, $\frac{p_t}{p_0} = 8$.

are sensitive to framing and are different for intra and inter-temporal contexts, which requires a more complex welfare function than discounted utilitarianism.

In addition, while the results are potentially useful for welfare analysis, and give us insights into perceptions of environmental fairness and justice, two further words of caution are required. First, stated preference and experimental approaches to eliciting these normative parameters for social discounting and welfare analysis tend to embody two theoretical sources of inequality aversion, one stemming from the treatment of unequal utilities in the social welfare function, and one from the curvature of the individual utility function. Our results reflect both sources of inequality aversion, and we are unable to disentangle them. Second, a full characterisation of social preferences would also identify cross elasticities between consumption and environmental quality, alongside any systematic differences between income and environmental inequality aversion. The estimation of a full 'social demand system' for environmental quality remains for future work. From the perspective of achieving a reflective equilibrium therefore, more iterations will be required.

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Appendix A. Replication results and other robustness

See Tables 2–6.

Table 2
Results for the 2017 experiment, the replication sample in 2020 and the pooled sample: The 2017 results are identical to Table 1. Otherwise, OLS regressions of Eqs. (11) and (12) with robust (clustered) standard errors, *** p<0.01, ** p<0.05, * p<0.1.

Estimated parameters	(1) Both Samples	(2) 2017	(3) 2020	(4) Both Samples	(5) 2017	(6) 2020	(7) Both Samples	(8) 2017	(9) 2020	(10) Both Samples	(11) 2017	(12) 2020
δ	0.89***	0.88***	0.92***	1.03***	1.02***	1.03***	0.43***	0.37***	0.51***	0.56***	0.44***	0.62***
	(0.035)	(0.044)	(0.055)	(0.063)	(0.080)	(0.097)	(0.064)	(0.089)	(0.088)	(0.082)	(0.11)	(0.12)
δ_{Air}				−0.19**	−0.12	−0.28*				−0.14	−0.027	−0.22
				(0.094)	(0.12)	(0.16)				(0.091)	(0.11)	(0.15)
$\delta_{Fertility}$				−0.24***	−0.30***	−0.10				−0.26***	−0.30***	−0.15
				(0.090)	(0.11)	(0.15)				(0.085)	(0.10)	(0.16)
δ_{Gain}							0.67***	0.72***	0.59***	0.68***	0.72***	0.58***
							(0.065)	(0.083)	(0.11)	(0.064)	(0.082)	(0.11)
δ_{Past}							−0.013	−0.079	0.11	0.0017	−0.045	0.096
							(0.055)	(0.070)	(0.088)	(0.054)	(0.070)	(0.087)
$\delta_{TwoRegions}$							0.17***	0.24***	0.097	0.16**	0.29***	0.11
							(0.065)	(0.084)	(0.11)	(0.067)	(0.087)	(0.12)
$\eta_{Instant}$	2.92***	2.94***	2.88***	2.83***	2.88***	2.74***	3.03***	3.01***	3.08***	2.94***	2.95***	2.92***
	(0.095)	(0.12)	(0.15)	(0.098)	(0.12)	(0.16)	(0.098)	(0.12)	(0.17)	(0.100)	(0.12)	(0.17)
$\eta_{Br.Future}$	1.96***	1.98***	1.94***	1.88***	1.92***	1.79***	2.16***	2.10***	2.23***	2.06***	2.05***	2.10***
	(0.056)	(0.070)	(0.095)	(0.061)	(0.077)	(0.100)	(0.068)	(0.082)	(0.12)	(0.071)	(0.089)	(0.12)
$\eta_{Gr.Future}$	1.32***	1.41***	1.15***	1.23***	1.34***	1.01***	1.52***	1.55***	1.44***	1.43***	1.51***	1.32***
	(0.030)	(0.036)	(0.051)	(0.044)	(0.055)	(0.072)	(0.050)	(0.060)	(0.088)	(0.059)	(0.074)	(0.098)
η_{air}				0.17***	0.053	0.40***				0.16**	0.044	0.36***
				(0.066)	(0.079)	(0.12)				(0.066)	(0.081)	(0.12)
$\eta_{Fertility}$				0.100	0.13	0.045				0.12*	0.15*	0.043
				(0.066)	(0.083)	(0.11)				(0.065)	(0.084)	(0.12)
η_{Gain}							−0.21***	−0.13**	−0.38***	−0.21***	−0.14**	−0.32***
							(0.050)	(0.060)	(0.084)	(0.048)	(0.059)	(0.081)
η_{Past}							−0.13***	−0.10**	−0.13**	−0.13***	−0.12**	−0.12*
							(0.039)	(0.049)	(0.063)	(0.039)	(0.050)	(0.063)
$\eta_{TwoRegions}$							−0.053	−0.028	−0.063	−0.033	−0.044	−0.14
							(0.048)	(0.056)	(0.085)	(0.048)	(0.062)	(0.098)
Observations	5,568	3,618	1,950	5,568	3,618	1,950	5,568	3,618	1,950	5,568	3,618	1,950
R-squared	0.589	0.608	0.555	0.591	0.609	0.562	0.600	0.617	0.570	0.602	0.619	0.576

Table 3
Tests on differences between the main sample and the replication sample. Column 1 reports responses on time only questions and corresponds to pure time preference rates. Column 2 reports the inequality aversion on inequality only questions. Column 3 and 4 report the implied discount rate on brown and green future questions (a combination of inequality aversion and time preferences). The first 2 lines in each panel show mean discount rates (or η) for the main (2017) sample and the replication sample. Line 3 reports Cohen's d statistic (Cohen (1954), and line 4 reports the p-value of a t-test of the difference in means.

		Time only	Inequality only	Brown future	Green future
Aggregate	Mean main sample	0.88	2.94	−3.08	3.69
	Mean replication sample	0.92	2.88	−2.95	3.21
	Cohen's d	−0.04	0.02	−0.04	0.27
	ttest p-value	0.41	0.75	0.46	0.00
Forest	Mean main sample	0.86	2.80	−2.77	3.77
	Mean replication sample	0.88	3.08	−2.44	3.11
	Cohen's d	−0.01	−0.12	−0.10	**0.42**
	ttest p-value	0.89	0.32	0.22	0.00
Air	Mean main sample	1.12	2.83	−3.17	3.59
	Mean replication sample	1.07	2.65	−3.82	3.48
	Cohen's d	0.04	0.08	0.19	0.06
	ttest p-value	0.65	0.55	0.04	0.56
Soil Fertility	Mean main sample	0.64	3.23	−3.32	3.67
	Mean replication sample	0.85	2.85	−2.70	3.09
	Cohen's d	−0.19	0.14	−0.18	**0.32**
	ttest p-value	0.04	0.32	0.04	0.00
Gain	Mean main sample	1.25	3.13	−2.66	3.83
	Mean replication sample	1.24	2.94	−2.30	3.08
	Cohen's d	0.01	0.07	−0.11	**0.42**
	ttest p-value	0.92	0.48	0.12	0.00
Loss	Mean main sample	0.42	2.72	−3.62	3.52
	Mean replication sample	0.56	2.81	−3.67	3.36
	Cohen's d	−0.14	−0.04	0.02	0.09
	ttest p-value	0.07	0.72	0.83	0.23
DecisionNow	Mean main sample	0.95	.	−3.13	3.80
	Mean replication sample	0.90	.	−3.15	3.26
	Cohen's d	0.05	.	0.00	0.29
	ttest p-value	0.51	.	0.95	0.00
DecisionPast	Mean main sample	0.76	.	−2.98	3.53
	Mean replication sample	0.94	.	−2.73	3.16
	Cohen's d	−0.17	.	−0.08	0.22
	ttest p-value	0.03	.	0.31	0.01
Betweenregions	Mean main sample	0.92	.	−2.96	3.78
	Mean replication sample	0.95	.	−2.80	3.21
	Cohen's d	−0.03	.	−0.05	0.31
	ttest p-value	0.70	.	0.49	0.00
WithinRegion	Mean main sample	0.81	.	−3.19	3.62
	Mean replication sample	0.89	.	−3.11	3.22
	Cohen's d	−0.08	.	−0.02	0.23
	ttest p-value	0.30	.	0.77	0.00

Table 4

Results for respondents who never gave "irrational" answers: "Irrational" answers are choice lists in which respondents switch more than once (violate transitivity), never switch (see Table 6 for upper and lower bounds of the parameters) or switch in the wrong way (preferring inequality over equality or the future over the present). Each respondent answers 14 choice lists. If at least one choice list is answered in an "irrational" way the remaining answers are disregarded. In the main analysis, only the "irrational" price list is disregarded. OLS regressions of Eqs. (11) and (12) with robust (clustered) standard errors, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Estimated parameters	(1)	(2)	(3)	(4)	(5)
δ	1.12***	1.42***	0.80***	1.00***	0.63***
	(0.075)	(0.12)	(0.15)	(0.17)	(0.17)
δ_{Air}		−0.42**		−0.27	0.21
		(0.18)		(0.17)	(0.14)
$\delta_{Fertility}$		−0.55***		−0.54***	−0.27**
		(0.17)		(0.16)	(0.12)
δ_{Gain}			0.58***	0.60***	0.85***
			(0.13)	(0.13)	(0.11)
δ_{Past}			−0.51***	−0.40***	−0.41***
			(0.13)	(0.13)	(0.13)
$\delta_{TwoRegions}$			0.18	0.19	0.18
			(0.14)	(0.14)	(0.14)
$\eta_{Instant}$	3.21***	3.15***	3.27***	3.23***	2.64***
	(0.18)	(0.18)	(0.19)	(0.19)	(0.28)
$\eta_{Instant,Air}$					0.41
					(0.31)
$\eta_{Instant,Fertility}$					0.45
					(0.44)
$\eta_{Instant,Gain}$					0.59**
					(0.29)
$\eta_{Br.Future}$	2.17***	2.13***	2.26***	2.24***	2.03***
	(0.10)	(0.10)	(0.11)	(0.11)	(0.13)
$\eta_{Br.Future,Air}$					0.37*
					(0.20)
$\eta_{Br.Future,Fertility}$					0.26
					(0.22)
$\eta_{Br.Future,Gain}$					0.026
					(0.14)
$\eta_{Gr.Future}$	1.36***	1.27***	1.48***	1.43***	1.73***
	(0.054)	(0.071)	(0.098)	(0.11)	(0.12)
$\eta_{Gr.Future,Air}$					−0.32**
					(0.12)
$\eta_{Gr.Future,Fertility}$					−0.086
					(0.10)
$\eta_{Gr.Future,Gain}$					−0.34***
					(0.090)
η_{Air}		0.11		0.054	
		(0.12)		(0.12)	
$\eta_{SoilFertility}$		0.11		0.10	
		(0.13)		(0.13)	
η_{Gain}			−0.096	−0.11	
			(0.087)	(0.085)	
$\eta_{DecisionPast}$			0.021	−0.038	−0.046
			(0.093)	(0.092)	(0.093)
$\eta_{TwoRegions}$			−0.095	−0.084	−0.088
			(0.074)	(0.074)	(0.075)
Observations	1,418	1,418	1,418	1,418	1,418
R-squared	0.661	0.665	0.670	0.673	0.676

Table 5

Results for the first 4 answers of each respondent, compared to results for all answers: This implies that effects on domain and framing are only driven by between-respondent variation, excluding within-respondent variation. Sample includes both the main sample and the replication sample. The reference category is now gains instead of losses, because only a small group of respondents started with losses, since starting with losses turned out to be more difficult to understand in our test phase. OLS regressions of Eqs. (11) and (12) with robust (clustered) standard errors, *** p < 0.01, ** p < 0.05, * p < 0.1.

Estimated parameters	(1) All questions	(2) 4 first questions	(3) All questions	(4) 4 first questions	(5) All questions	(6) 4 first questions	(7) All questions	(8) 4 first questions
δ	0.89***	1.19***	1.03***	1.31***	1.11***	1.01***	1.24***	1.13***
	(0.035)	(0.051)	(0.063)	(0.092)	(0.064)	(0.074)	(0.086)	(0.14)
δ_{Air}			−0.19**	−0.18			−0.14	−0.10
			(0.094)	(0.16)			(0.091)	(0.18)
$\delta_{Fertility}$			−0.24***	−0.28*			−0.26***	−0.24
			(0.090)	(0.16)			(0.085)	(0.17)
δ_{Loss}					−0.67***	−1.05***	−0.68***	−1.12***
					(0.065)	(0.23)	(0.064)	(0.24)
δ_{Past}					−0.013	−0.27	0.0017	−0.27
					(0.055)	(0.19)	(0.054)	(0.19)
$\delta_{TwoRegions}$					0.17***	0.43***	0.16**	0.37***
					(0.065)	(0.10)	(0.067)	(0.12)
$\eta_{Instant}$	2.92***	2.87***	2.83***	2.90***	2.82***	2.86***	2.73***	2.86***
	(0.095)	(0.12)	(0.098)	(0.13)	(0.099)	(0.13)	(0.10)	(0.14)
$\eta_{Br.Future}$	1.96***	1.78***	1.88***	1.80***	1.94***	1.72***	1.85***	1.72***
	(0.056)	(0.080)	(0.061)	(0.096)	(0.070)	(0.10)	(0.075)	(0.11)
$\eta_{Gr.Future}$	1.32***	1.17***	1.23***	1.18***	1.31***	1.21***	1.22***	1.21***
	(0.030)	(0.049)	(0.044)	(0.071)	(0.049)	(0.070)	(0.061)	(0.085)
η_{air}			0.17***	0.13			0.16**	0.18
			(0.066)	(0.12)			(0.066)	(0.13)
$\eta_{Fertility}$			0.100	−0.18*			0.12*	−0.14
			(0.066)	(0.11)			(0.065)	(0.11)
η_{Loss}					0.21***	0.27	0.21***	0.27
					(0.050)	(0.18)	(0.048)	(0.19)
η_{Past}					−0.13***	−0.013	−0.13***	−0.027
					(0.039)	(0.098)	(0.039)	(0.10)
$\eta_{TwoRegions}$					−0.053		−0.033	
					(0.048)		(0.048)	
Observations	5,568	1,683	5,568	1,683	5,568	1,683	5,568	1,683
R-squared	0.589	0.555	0.591	0.558	0.600	0.563	0.602	0.566

Table 6

Estimated parameters: Upper and Lower Bounds: Note: Parameter bounds in choice lists for η, δ and discount rates for four types of questions. Answers having more extreme preferences than these bounds are excluded because we suppose that they disregard the trade-off between different ethical dimensions. The lowest included and highest included parameter values correspond to respondents who switch preference between the first and second or between the penultimate and ultimate choice in the choice list.

Scenario	Estimate	Below lower bound	Lowest included	Highest included	Beyond upper bound	Total # answers
Instantaneous inequality	η	$\eta < 0$	0.3	7.4	$\eta > 22$	
	# answers	42	106	101	97	751
Time only	δ	$\delta < -1.1\%$	−0.5%	4.0%	$\delta > 4.6\%$	
	# answers	167	217	10	66	1305
Green future	r= $\delta + \eta$*2%	r < 0%	0.7%	9.0%	r > 9.7%	
	# answers	126	109	13	210	1477
Brown future	r=$\delta - \eta$*2%	r < −44%	−9.5%	2.9%	r > 4.6%	
	# answers	200	74	23	51	1441

Appendix B. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jeem.2021.102479.

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