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Inequality Aversion and the Environment*

Frank Venmans† and Ben Groom‡

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Abstract

Measures of inequality aversion (η) are elicited using hypothetical decision tasks. The tasks require an assessment of social 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 past/present decision). Inequality aversion is higher in the intra-temporal framing ($\eta = 3$) than in the inter-temporal framing with either negative ($\eta = 2$) or positive ($\eta = 1.4$) growth in environmental quality. Differences across environmental domains exist but are less pronounced. Similar results hold for pure time preference. The results provide empirical evidence to calibrate dual discount rates or changing relative prices for the environment, but also cast doubt on the classical Utilitarian formulation of inter-temporal social welfare. Hence, this paper is an exercise in applied social choice: we test common normative conceptions of social welfare to help operationalise the welfare evaluation of long-run environmental change.

JEL Classification: D31, D61, H43.

Keywords: Social Discount Rate, Inequality, Inequality Aversion, Cost Benefit Analysis, Ramsey Rule.

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1 Introduction

This paper uses hypothetical decision tasks to estimate the extent of societal aversion to environmental inequalities (η_{EE}). In doing so we make three main contributions. First, we provide evidence that there is substantial aversion to environmental inequalities. Second, our empirical estimates of environmental inequality aversion could be used to operationalise the "dual" Social Discount Rate (SDR) or, equivalently, the evolution of relative shadow prices for the environment. These estimates are of practical significance since the estimated inequality aversion parameters are sufficiently high for the Ramsey environmental SDR: $SDR_E = \delta + \eta_{EE} g_E$, to be negative for typical (negative) estimates of environmental growth (Baumgaertner et al., 2015).[1] This implies steeply rising relative prices for the environment in the future. Third, as an exercise in empirical social choice, our experiments provide a test of the so-called "dual-discounting" framework, the chief normative framework for inter-temporal welfare analysis which treats consumption and environmental quality separately. The results identify important exceptions to the extended Ramsey framework based on how inequalities are framed.

Specifically, we find that inequality aversion differs across intra-temporal ($\eta_{EE} = 3$) and inter-temporal settings: $\eta_{EE} = 2$ if the future is environmentally 'brown' (degraded), and η_{EE} =1.4 if the future is 'green'. We also find sensitivity to the loss/gain framing and different environmental domains (recreational forest, air quality, soil fertility), and some sensitivity in pure time preference. By testing the normative framework, the paper can be thought of as providing an important iteration towards a Rawlsian *reflective equilibrium,* through which normative ideas are iteratively tested against their outcomes and implications, and their assumptions revised accordingly. In this sense this paper helps provide a firmer basis for the welfare analysis of long-term public policy concerning natural resources and environmental quality.

A general motivation for our work stems from the growing concern about inequality. In recent years this concern has focussed on the financial dimensions of wealth (e.g. Piketty, 2014; Stiglitz, 2012). Aversion to inequality of this type, where it exists, stems from normative views surrounding fairness and equity, as well as from more positive arguments associated with concerns about economic performance or political stability (Piketty, 2014; Stiglitz, 2012). Yet an important component of wealth is natural capital, which is the source of important flows of ecosystem services. Some ecosystem services increase well-being through income generation, but natural capital itself and the vast majority of the associated ecosystem services 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 (Hamilton and Hepburn, 2017). If people are in general averse to inequality in the financial dimension, it seems reasonable to assume that there will be aversion to inequality in other dimensions also, such as

[1] δ is the pure rate of time preference, η_{EE} is environmental inequality aversion, and g_E is growth in environmental quality. Cross elasticities are assumed to be zero for now.

distributions of environmental quality and quantity. 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.

Also of concern in the environmental domain are the acceptable trade-offs that society makes over time with regard to environmental quality. Such preferences are embodied 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 their relative scarcity are also ignored in welfare analysis. This oversight, ignoring relative scarcity, has been shown to seriously underestimate the likely gains from climate change mitigation policies, for instance (see Hoel and Sterner, 2007; Drupp and Haensel, 2018 Stern, 2007; Nordhaus, 2007). 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 carefully projecting changes in relative shadow prices to reflect changes in scarcity. The two procedures are entirely 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 indeed the change in relative shadow prices, therefore requires some measure of environmental inequality aversion. Given this, our results could be a useful input to recent policy recommendations on social discounting in the UK and the Netherlands.[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 constrains inequality aversion to be the same across space and time, and, in applications, across different environmental domains (e.g. Sterner and Persson, 2008). These are the assumptions of this normative framework. An important question from this social choice perspective is, therefore, do people social decisions in

[2]The UK and Netherlands governments are considering dual discounting frameworks. (see Freeman et al., 2018, Groom and Hepburn, 2017) .

accordance with the extended Ramsey framework, with all the restrictions that this entails on social preferences over consumption and environment? The final purpose of this paper is to address this question of the acceptability and validity of the Ramsey Rule. A priori, it is not clear that individuals evaluating social decisions would behave according to the simple Ramsey Rule, for example. Anecdotally, people who are highly inequality averse when they consider inequality within society today, perhaps from the political left, could well disagree with the higher discount rate that this would imply (via the wealth effect), due to their concern for future generations. In relation to environmental inequalities, strong intra-generational inequality aversion could well be accompanied by a preference for a low SDR for the environment, or a low SDR in general. These are empirical questions.

With these questions in mind, we developed hypothetical decision tasks in the mould of those typically used in the 'empirical social choice' literature to evaluate ethical frameworks and associated parameters (e.g. Gaertner and Schokkaert, 2012). The decision tasks are organised around estimating the inequality aversion over different domains of environmental resources, and across spatial and temporal domains. This is in contrast to most research on inequality aversion which elicit preferences over monetary trade-offs (E.g. Groom and Maddison, 2019). Our respondents choose between a green project that creates a large increase of environmental quality in a green region or a smaller increase in environmental quality in a dirtier region. In some questions, the 2 projects are realized at different moments in time, with either secular growth or decline in environmental quality in the background. Our large sample of respondents (363 individuals, 40.747 answers) allows us to study the effect on inequality aversion and pure time preference of different domains of environmental quality (forests, clean air and fertility), loss aversion, altruism and habituation. This allow a rigorous test of the normative framework. We also provide exploratory evidence of associations between inequality aversion and political preferences.

Our paper contributes to a broader literature on the experimental measurement of intertemporal preferences and inequality aversion which rather focused on: individual discount rates for the environment (Hardisty and Weber 2009; Viscusi et al. 2008); different commodities (Weatherly et al. 2010); social discount rates for consumption (e.g. Howard, 2013); estimating parameters of a social welfare function including inequality aversion towards consumption (Groom and Maddison, 2019); discounting for health benefits (Robson et al., 2016; Dolan and Tsuchiya, 2011; Cropper and Raich, 2016). Organising around the Ramsey Rule, and testing multiple framings across environmental domains, compliments these revealed and stated preference studies of inequality aversion over consumption. Yet, while aversion to environmental inequality is borne out, the strict application of the extended Ramsey Rule is not. From the perspective of achieving a reflective equilibrium, more iterations will be required.

2 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: $W = \sum_i U(C_i)$, 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), $U_C(C_i)$:

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

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

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

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, p251) motivated an iso-elastic utility function: $U(C_i) = (1-\eta)^{-1} C_i^{1-\eta}$, in which case the elasticity of marginal utility, η, is a fixed parameter and the ratio of marginal welfares becomes: $(dW/dC_i)/(dW/dC_j) = (C_j/C_i)^{\eta}$. 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]

[3] With two agents $W = U(C_1) + U(C_2)$. 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 $\eta = \ln(1 - MTL)/\ln(C_{high}/C_{low})$. 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:

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

To formalize 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:

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

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.[6] Our empirical strategy for the estimation of η_{EE} does not test for dependence on E or C, but is careful to control for this possibility.

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: $W = \sum \exp(-\delta t)U(C_t)$, then rate at which marginal welfare declines from period $t = 0$ to τ, the SDR, is given by the Ramsey Rule:

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

where δ is the pure rate of time preference, η 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: $W\left(\{C_t\}, \{E_t\}\right) = \sum_{t=0}^{T} \exp\left(-\delta t\right) U\left(C_t, E_t\right)$ and the SDRs appropriate for consumption C_t and environmental quality, E_t, are then:[8]

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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).

[6] Hoel and Sterner (2007) discuss a constant elasticity of substitution, σ, utility function with inequality aversion towards both goods together α: $U(C, E,) = (1-\alpha)^{-1}\left[\left(1-\gamma\right)C^{1-\frac{1}{\sigma}} + \gamma E^{1-\frac{1}{\sigma}}\right]^{\frac{(1-\alpha)\sigma}{\sigma-1}}$. 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 $U(C, E,) = \left(1-\gamma\right)C^{1-\frac{1}{\sigma}} + \gamma E^{1-\frac{1}{\sigma}}$.

[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).

$$SDR_C = \delta + \eta_{CC} g_C + \eta_{EC} g_E \quad (5)$$

$$SDR_E = \delta + \eta_{EE} g_E + \eta_{CE} g_C \quad (6)$$

where $\eta_{ij} = -\frac{U_{ij}(x_1,x_2)}{U_i(x_1,x_2)} x_i$ 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 pure time preference, δ, a wealth effect: $\eta_{CC} g_C$ for consumption and $\eta_{EE} g_E$ for environment, and substitution effects η_{EC} and η_{CE}.[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 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. To see this more clearly, when $\eta_{EC} = \eta_{CE} = 0$ the environmental Ramsey Rule becomes:[11]

$$SDR_E = \delta + \eta_{EE} g_E \quad (7)$$

and the change in relative shadow prices becomes simply:

$$\triangle RP_{EC} = \eta_{CC} g_C - \eta_{EE} g_E \quad (8)$$

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] With growth in C_t and E_t being observable, and estimates of η_{CC} at hand (see Groom and Maddison, 2019), the remaining obstacle to estimating the change in relative prices is an estimate of inequality aversion for the environment, η_{EE}. An inter-temporal leaky-bucket type experiment can be used for this purpose.

[9]These reflect the effect of changes in environmental quality on the consumption discount rate and vice versa. Gollier and Hammit (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: $\triangle RP_{EC} = SDR_C - SDR_E = \eta_{CC} g_C + \eta_{EC} g_E - (\eta_{EE} g_E + \eta_{CE} g_C)$.

[11]Howard et al. (2018) distinguish δ_C from δ_E and assume $\eta_{EC} = \eta_{CE} = 0$: $W_0 = \sum_{t=0}^{T} \exp(-\delta_C t) \frac{C_t^{1-\eta}}{1-\eta} + \exp(-\delta_E t) \frac{E_t^{1-\xi}}{1-\xi}$.

[12]Relative price changes can also be understood in terms of the elasticity of substitutability (EOS) between E and C. $\triangle RP_{EC} = \sigma_{E,C}^{-1}(g_C - g_E)$. The EOS is defined as $\sigma_{E,C} = \frac{d\ln(C/E)}{d\ln(U_E/U_C)}$, which becomes: $\sigma_{E,C} = (g_C - g_E) / (\eta_{CC} g_C - \eta_{EE} g_E)$ 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.

The two-good framework provides guidance on how to structure the empirical approach. As discussed above, there maybe normative reasons why η_{EE} ought to be constant and invariant to levels of C and E, irrespective of the intra- or inter-temporal context. Yet whether or not individuals evaluate social welfare in this way is an empirical question. To rule out that variations in estimated η_{EE} arise due to substitution effects, in both intra- and inter-temporal contexts the background level of consumption, C, must be held constant. Therefore, the experiments present a better-off society with environmental quality that is always 50% larger than the environmentally worse-off society, while both societies have identical levels of consumption. We then use the formula $\eta_{EE} = \frac{\Delta lnU_E}{\Delta lnE}$ to calculate environmental inequality aversion. In case respondents do not display constant relative inequality aversion, this calculation approximates the geometric mean of the elasticity over the range between the higher and lower environmental quality.

Several testable hypotheses flow from the extended Ramsey framework. Under the null that individuals follow the simple Ramsey Rule when evaluating inter-temporal social welfare, all estimates of η should be identical no matter whether they are elicited over inequalities over time or space, or indeed over environmental domains. Similarly, under the null that extended Ramsey framework in equations (5) and (6) is used, pure time preference should not vary across consumption and environment, or indeed across environmental domains.[13]

3 Decision tasks and empirical experimental approach

3.1 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 formalized 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

[13]Importantly, different δ for consumption and the environment would lead to arbitrage opportunities, which is not an axiomatically desirable property.

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 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.

Finally, 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 principles 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 Rawl's principles, whereas the answers by respondents in a specific hypothetical choice situation correspond to Rawl's 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 then 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 clearly have the advantage of a better informed opinion on technical and sometimes ethical matters. On the other hand, students are a more interesting sample when it comes to testing the dominant conceptual frameworks in the field. Indeed, if one adheres to the 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.

[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' anwers. Unfortunately, such choices are easily affected by erroneous conceptions about carbon credits and credibility of researchers' promises (e.g. Cavatorta and Groom, 2018).

In sum, in addition to estimating inequality aversion for the practical business of welfare analysis and CBA, we also see our this research as a piece of empirical social choice theory, which tests the applicability of the standard ethical framework.

3.2 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 pure 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 meter in the less green region?".[15]

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. Figure 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 as the indifference point.

A second type of question is inter-temporal. A choice between a concession today in one

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

region and a concession in the future in another region in 20 years time is offered. As shown in Section 2, background growth in consumption has to be assumed to be zero in each scenario to avoid identifying cross elasticities. Figures 2-4 show how the presentation was altered for inter-temporal framings.[16]

The inter-temporal question has 3 variants, which are asked to different respondents. The first variant is a gain framing instead of a loss of forest, as explained above. In another variation, instead of two regions, the project is realized in the same region. In a 'one 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 two region question, the ethical dimension of a decision behind a veil of ignorance may have more weight. 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. If respondents decisions do not differ between a decision now and a decision in the past, they judge as if they were behind a veil of ignorance. Altruism may put more weight on both past and future generations, or inversely, self-regarding preference may put less weight both on the past and future. This effect is captured by our 'decision past' variation. Question 3 to 7 combines time with inequality. We present scenarios with no growth in the environment, which allows us to calculate the pure time preference rate (See Figure 2). If the future has more forest, we will call this a 'green future' question (see Figure 3), if the future has less forest, we will call this a 'brown future' question (see Figure 4). Gain framings were also presented. 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.

Respondents answer the same 7 questions but in a different environmental domain. Each respondent answers questions in two out of three domains: forest, air- pollution and fertility. All variants (gain/loss; one/two regions; decision now/past; green/brown future) are applied to the different environmental domains. The experimental set-up is shown in Table 1, and the exact wording of the experiment can be found in Appendix D.

Another important design feature relates to how the experiment connects with the way in which the parameter of inequality aversion is estimated. Our approach 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 Figures 1-4, our experimental design was explicit about the baselines and the marginality of the interventions. The accuracy of our estimates will in principle be greater as a consequence.

[16]The exact wording of all questions can be found in Appendix D.

A final important departure from the leaky-bucket farming was that our experiments did not require the transfer of environmental quality from one richer party to another poorer party, but rather compared additions to rich and poor regions, or green and brown futures. In this way we avoid the potentially problematic zero-sum nature of the leaky-bucket framing. The precise manner in which inequality aversion is estimated from these data is discussed in Section 4.

The questionnaires took 90 minutes to complete. The first 30 minutes 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 40747 decision tasks. Given that we discard inconsistent answers, we work with 3618 indifference points based on 29554 decision tasks.[17]

3.3 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 Appendix D.

In order to confront the cognitively 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

[17] 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. In the Autumn of 2016, students at the University of Mons took part in a larger scale pilot study in which various designs were tested. The result of these two pilot studies lead to our eventual decision task design. The results in table 3, include answers from a pilot of 86 students who responded in Autumn 2016. This represents 22% of the sample. The rubric they received was more minimal than in the final session, but the eventual questions were identical.

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 Appendix D for more detail). Again we used the extreme starting point: $1m^2$ of forest to the poor versus 10 football pitches to the rich.

In general responses to the extreme first question ($1m^2$ 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 $1\mathrm{m}^2$ in the less green region.[18] 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 1 shows that the results are robust to excluding respondents who gave even one inconsistent answer.

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 3.2., which are to be preferred to more abstract examples.[19]

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.

[18]See Table 5 in Appendix D for a complete description of discarded answers.

[19]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."

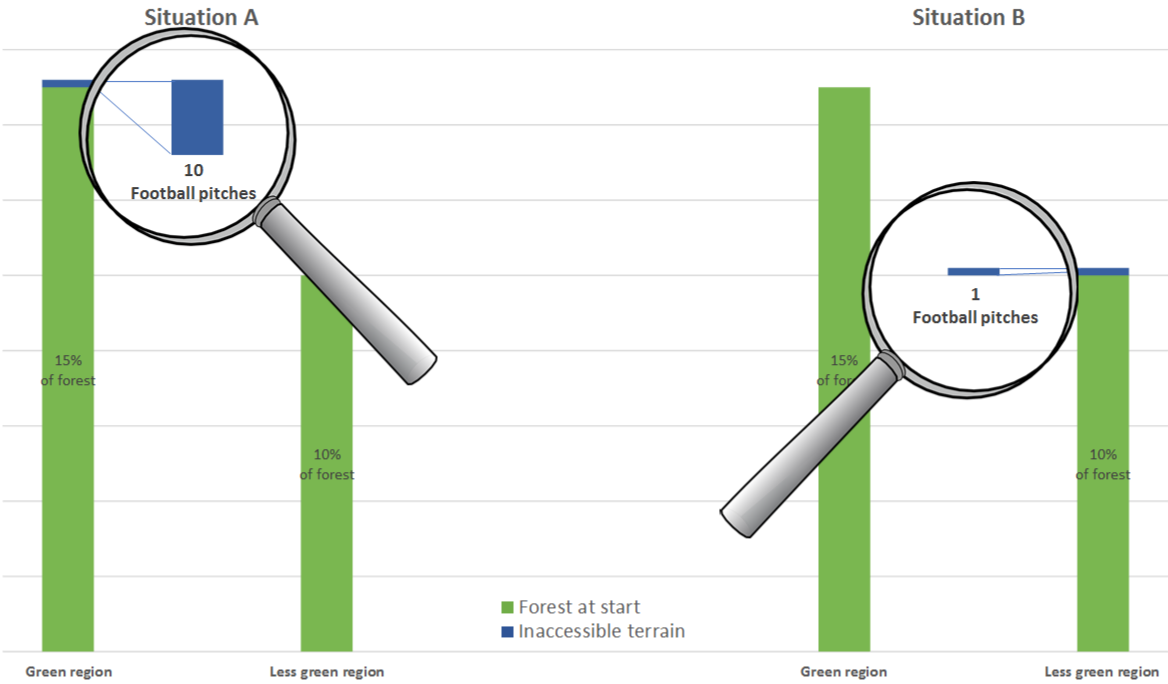

Figure 1: Example of the Decision Tasks: Forests Today

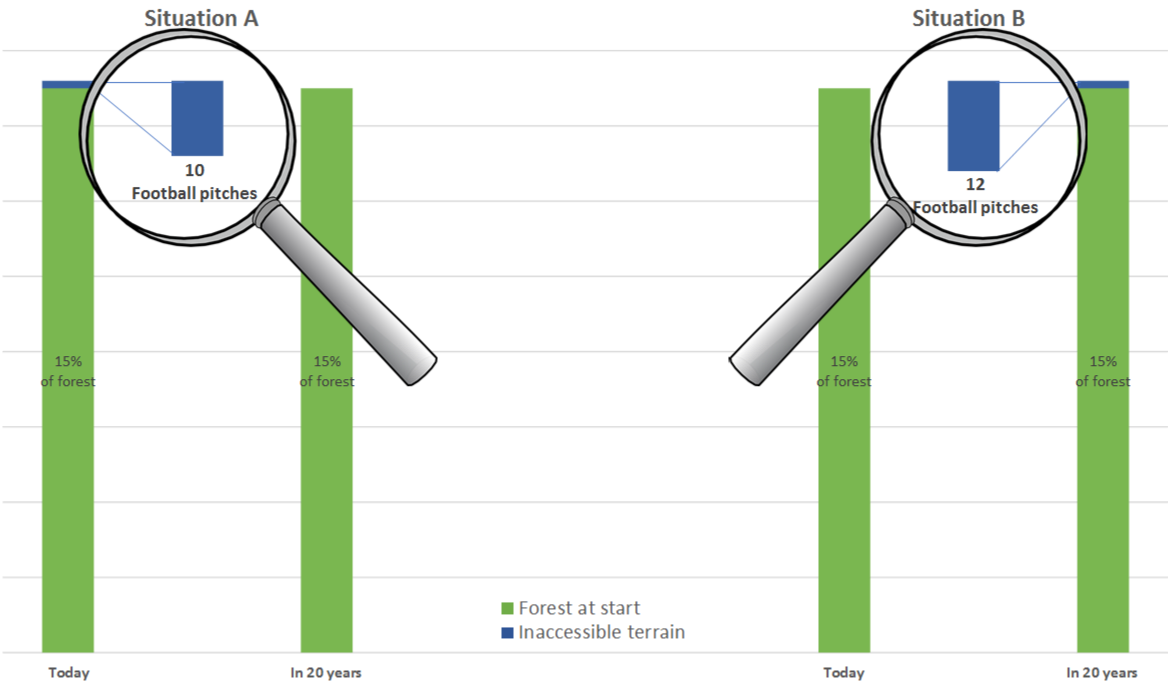

Figure 2: Example of the Decision Tasks: Forests Today

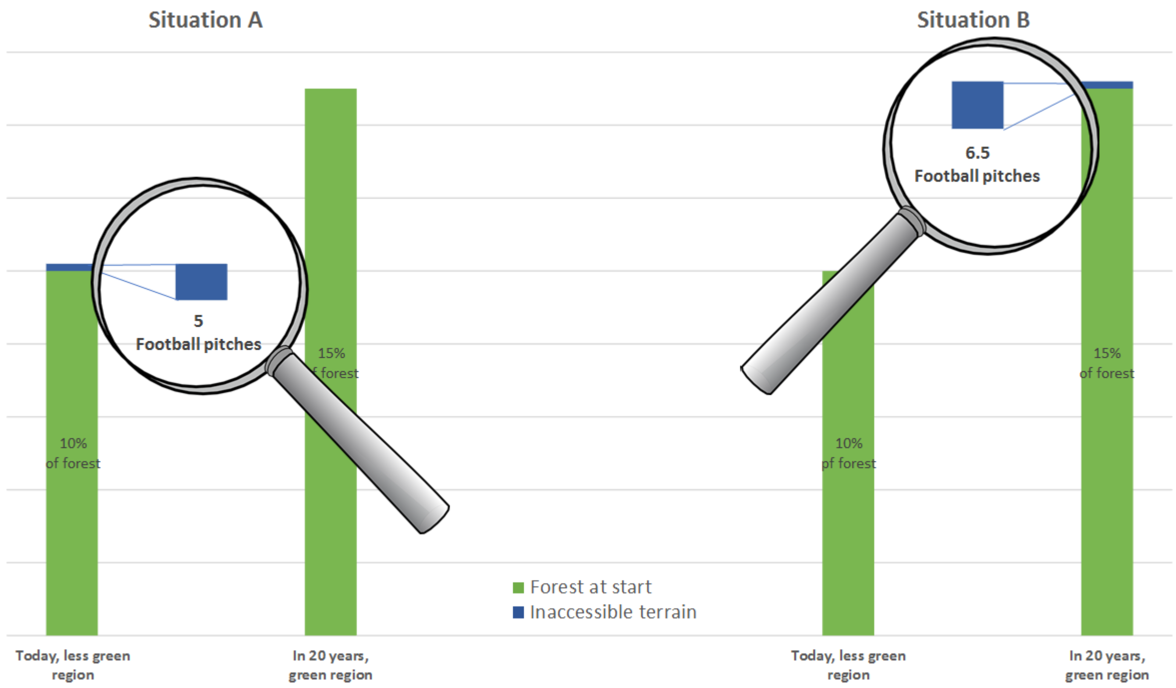

Figure 3: Example of the Decision Tasks: Forests in the Future (Green Future)

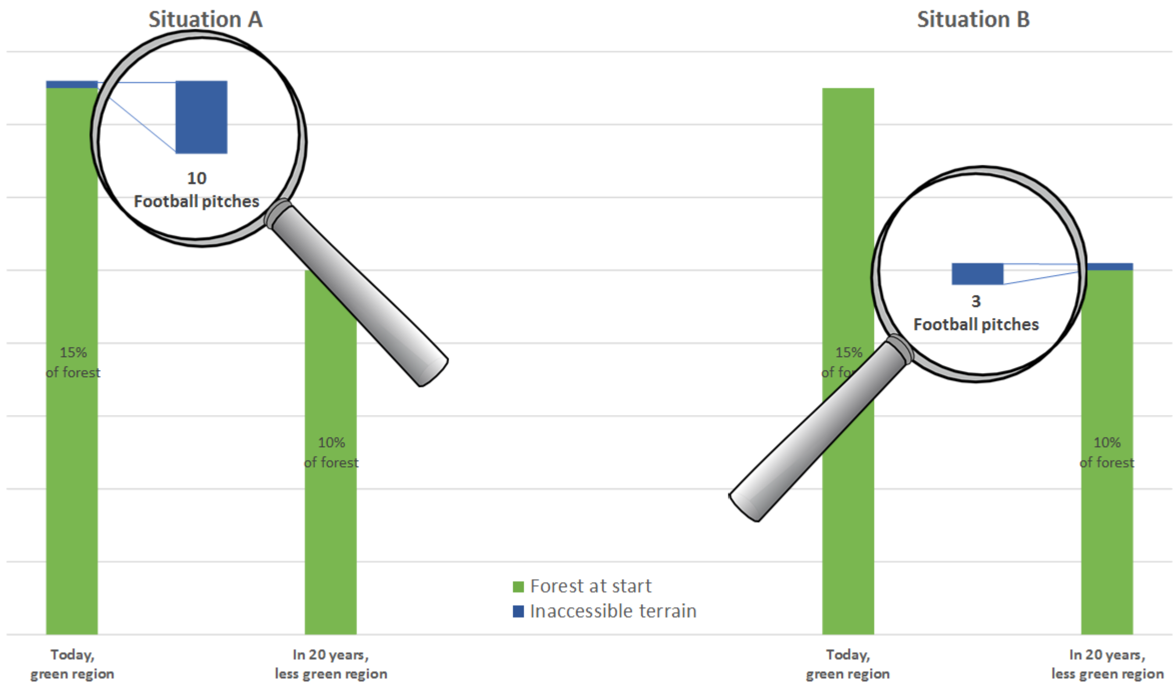

Figure 4: Example of the Decision Tasks: Forests in the Future (Brown Future)

4 Estimation of inequality aversion and pure time preference

Our hypotheses stem from the Ramsey Rule, which assumes that inequality aversion and time preferences are invariant to environmental domains or different framing (e.g. gain/loss). We draw inference from the data using OLS and Maximum likelihood procedures which estimated a model of the discount rate against which the hypotheses could be tested by simple tests of parameter equality. The maximum likelihood procedures estimated pure time preference parameters and inequality aversion parameters simultaneously following the approach taken by Andersen et al. (2008). Details of these approaches can be found in the Appendix. In this section we present the OLS results which are more easily understood and differ only marginally from the MLE approach.

The following models were estimated using OLS. Model 1 uses the responses to questions in the spatial and temporal frame to identify the generic pure rate of time preference across all environmental and monetary domains, (δ). the use of spatial and temporal frames, the latter with green and brown futures, allows the identification of 3 separate measures of 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:

$$r_i = \delta D_{Time} + \eta_{Instant} D_{Instant} + \eta_{Br.Future} D_{Br.Future} + \eta_{Gr.Future} D_{Gr.Future} + \epsilon_i \quad (9)$$

where the dependent variable, r_i, is the discount rate implied from the individual responses. In case of instantaneous questions, r_i corresponds the to elasticity of marginal utility implied from the response. D_{Time} and $D_{Instant}$ are indicator variables which are one for questions which have time difference and instantaneous questions respectively. Indicator variable $D_{Br.Future}$ is -2 for brown future question, else zero, whereas $D_{Gr.Future}$ is 2 for a green future question, else zero. The values -2 and 2 correspond to the yearly growth rate implied in our questions. As a result, δ is the (arithmetic) mean of the discount rates on 'time only' questions and $\eta_{Instant}$ $\eta_{Br.Future}$ and $\eta_{Gr.Future}$ is the mean elasticity of marginal utility reported on instantaneous brown future and green future questions.[20]

In the fifth model, the effects of the domain, gain/loss, 1/2 regions, decision past/now are estimated using the following equation:

[20]More specifically $\eta_{Br.Future} = \frac{\overline{r_{i,Br.Future}}}{2} - \overline{r_{i,TimeOnly}}$

$$r_i = \delta D_{Time} + \left(\sum_i \delta_i D_i\right) D_{Time} + \eta_{Instant} D_{Instant} + \left(\sum_i \eta_{Instant,i} D_i\right) D_{Instant}$$
$$+\eta_{Br.Future} D_{Br.Future} + \left(\sum_i \eta_{Br.Future,i} D_i\right) D_{Br.Future} + \eta_{Gr.Future} D_{Gr.Future} \quad (10)$$
$$+ \left(\sum_i \eta_{Gr.Future,i} D_i\right) D_{Gr.Future} + \epsilon_i$$

where i corresponds to air, fertility, gain, one region, decision past. As a result, δ is the mean discount rate on time-only questions for the reference category, which is a forest loss in 2 different regions for a decision taken today. The same reference category applies to $\eta_{Instant}, \eta_{Br.Future}, \eta_{Gr.Future}$.

Models 2-5 include additional indicator variables to test further Hypotheses and the robustness of Model 1. Models 2 to 4 follow a comparable approach, but assume that the effects are the same on all discount rates or are the same for $\eta_{Instant}, \eta_{Br.Future}, \eta_{Gr.Future}$. Model 2 includes additional interactions terms for the different environmental domains and agricultural productivity. These interactions allow estimation of separate inequality aversion and pure time preference parameters for each of these domains. Interactions with the Region, Gain, and Past test the spatial, gain/loss and past/future hypotheses.

Models 4 and 5 contain a more complete set of interaction terms which disentangle the estimates of inequality aversion by temporal, spatial and domain variation, thereby offering a more complete test of Hypotheses 1-4. These OLS regressions boil down to aggregating discount rates by taking arithmetic means within the cells defined by the main effects and interactions. For robustness we deploy several other methods for estimating these parameters, including geometric means, non-linear least squares and maximum likelihood methods following Andersen et al. (2008).[21]

[21] There are however different 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, therefore, this discount rate will only be reported for the pure time preference rate.The formula of Heal and Millner shows that an arithmetic mean of discount rates approaches the efficient outcome large inequality aversion and/or short time horizons.

The efficient aggregation over longer periods requires however to put lower weight on high discount rates. Therefore, appendix 2 reports non-linear regression results for the following equation

$$\beta_i = \exp\left(-\delta D_{Time} - \eta_{Instant} D_{Instant} - \eta_{Br.Future} D_{Br.Future} - \eta_{Gr.Future} D_{Gr.Future}\right) \frac{t}{100} + \epsilon_i \quad (11)$$

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.

5 Inequality Aversion and the Environment: Experimental Results

Table 2 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 of inequality aversion and the social discount rate. The results from alternative estimation procedures are outlined in the Appendix.[22] The results in Table 2 make for interesting reading and are supported by the additional analysis contained in the Appendix.

Model 1 provides a preliminary test of Hypothesis 1, whose null is that inequality aversion is not dependent upon 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 and positive for each of $\eta_{Instant}$, $\eta_{Br,Future}$ and $\eta_{Gr.Future}$. This indicates inequality aversion exists across all the environmental domains. Moreover, a Wald test shows that there are statistically significant differences between $\eta_{Instant}$ and both of the parameters estimated in the temporal domain: $\eta_{Br.Future}$ and $\eta_{Gr.Future}$. Indeed, inequality aversion is much higher when measured at an instant in time ($\eta_{Instant} = 2.9$) than when measured across time ($\eta_{Br.Future} = 2.0$ and $\eta_{Gr.Future} = 1.4$). Furthermore, inequality aversion is much larger in the temporal domain when the future is "brown" rather than "green". Since the growth in the brown scenario is the negative of the growth in the green scenario, this means that the wealth effect is larger when the future is richer (green) compared to when the future is poorer (brown). These are not equal an opposite effects due to the differences in inequality aversion in these scenarios. These results are qualitatively robust across all the models in Table 2.

Models 2 and 3 provides some tests of Hypotheses 2,3 and 4. The null in each case is that the parameters of pure time preference and inequality aversion are the same across environmental, spatial and gain/loss domains. Specifically, the null of Hypothesis 2 is: $H_0^2 : \eta_{Forest} = \eta_{air} = \eta_{Fertility}$, the null of Hypothesis 3 is: $H_0^3 : \delta_{Forest} = \delta_{air} = \delta_{Fertility}$, and the nulls of Hypothesis 4 are $H_0^{4a} : \eta_{Region} = \eta_{Gain} = \eta_{Past}$ and $H_0^{4b} : \delta_{Region} = \delta_{Gain} = \delta_{Past}$. In each case, the hypotheses are tested conditional on whether the decision tasks were intra- or inter-temporal.

The results of Model 2 show that pure time preference is positive across all domains. The forest-baseline pure time preference is $\delta = 0.7\%$ and there are no significant differences between this and the pure time preference in the "air" and "past" domains, since $\delta_{Air} = -0.01\%$ and $\delta_{Past} = -0.05\%$ and neither are statistically different from zero. Respondents have higher pure time preference rates than the baseline when presented with a gain: $\delta_{Gain} = 0.7\%$ and lower pure time preference than the baseline in the Fertility and Region

[22] In the Appendix, Table A1 shows the results for the sub sample of respondents who had lexicographic preferences or who violated the Pareto principle: they preferred outcomes in which all parties are worse off than one in which all parties are better off but slightly more unequal. Table A2 shows the equivalent results for the maximum likelihood approaches that were described in the methodology section above.

domains: $\delta_{Fertility} = -0.3\%$ and $\delta_{Region} = -0.3\%$. The null of Hypotheses 3 and 4b are rejected.

With regard to inequality aversion, the null Hypotheses 2 and 4a are also rejected since $\eta_{Fertility} = 0.12$, and is statistically different from zero at the 5% level, while $\eta_{Gain} = -0.13$, which is statistically different from zero at the 1% level. Model 3 confirms these findings and further shows that $\eta_{Past} = -0.13$ and is statistically significant at the 5% level. In conclusion, the results show that inequality aversion differs across environmental, spatial, gain/loss and past/future domains, even after conditioning on the intra- and inter-temporal dimensions in which these parameters were elicited.

Table 1: Pure Time Preference, and Elasticities of Marginal Utility: Models (1) - (5)

Variables	(1)	(2)	(3)	(4)	(5)
δ	0.877***	0.723***	0.726***	0.497***	0.544***
	(0.0740)	(0.111)	(0.111)	(0.159)	(0.166)
δ_{Air}		-0.0140	-0.0241	0.279	0.310*
		(0.104)	(0.104)	(0.182)	(0.186)
$\delta_{Fertility}$		-0.292***	-0.298***	-0.118	-0.108
		(0.101)	(0.101)	(0.182)	(0.182)
δ_{Gain}		0.713***	0.712***	0.834***	0.852***
		(0.0831)	(0.0831)	(0.150)	(0.151)
δ_{Region}		-0.291***	-0.284***	-0.295***	-0.397**
		(0.0892)	(0.0892)	(0.0894)	(0.161)
δ_{Past}		-0.0458	-0.0436	-0.0448	-0.124
		(0.0845)	(0.0845)	(0.0844)	(0.151)
$\eta_{Instant}$	2.933***	2.949***	2.948***	2.574***	2.574***
	(0.101)	(0.109)	(0.109)	(0.208)	(0.208)
$\eta_{Instant,Gain}$				0.386*	0.386*
				(0.201)	(0.201)
$\eta_{Instant,Air}$				0.0806	0.0806
				(0.239)	(0.238)
$\eta_{Instant,Fertility}$				0.418*	0.418*
				(0.252)	(0.252)
$\eta_{Br.Future}$	1.980***	1.990***	2.015***	1.850***	1.915***
	(0.0512)	(0.0667)	(0.0723)	(0.106)	(0.115)
$\eta_{Br.Future,Region}$					-0.0451
					(0.110)
$\eta_{Br.Future,Past}$					-0.193*
					(0.105)
$\eta_{Br.Future,Gain}$				-0.0703	-0.0636
				(0.103)	(0.104)
$\eta_{Br.Future,Air}$				0.264**	0.296**
				(0.124)	(0.130)
$\eta_{Br.Future,Fertility}$				0.227*	0.257**
				(0.124)	(0.125)
$\eta_{Gr.Future}$	1.405***	1.443***	1.471***	1.629***	1.617***
	(0.0512)	(0.0653)	(0.0720)	(0.105)	(0.117)
$\eta_{Gr.Future,Region}$					0.117
					(0.111)
$\eta_{Gr.Future,Past}$					-0.0683
					(0.104)
$\eta_{Gr.Future,Gain}$				-0.260**	-0.276***
				(0.103)	(0.104)
$\eta_{Gr.Future,Air}$				-0.168	-0.202
				(0.124)	(0.128)
$\eta_{Gr.Future,Fertility}$				-0.0128	0.000869
				(0.125)	(0.126)
η_{air}		0.0475	0.0426		
		(0.0584)	(0.0607)		
$\eta_{Fertility}$		0.124**	0.142**		
		(0.0583)	(0.0590)		
η_{Gain}		-0.131***	-0.135***		
		(0.0485)	(0.0486)		
η_{Region}			0.0413		
			(0.0536)		
eta_{Past}			-0.127**		
			(0.0510)		
Observations	3,618	3,618	3,618	3,618	3,618
R-squared	0.607	0.618	0.618	0.619	0.620

Finally, Models 4 and 5 test 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 they do not with two notable exceptions. First, $\eta_{Br.Future,Air} = 0.30$ and $\eta_{Br.Future,Fertility} = 0.26$, indicating that the brown future effect on inequality aversion is stronger for air pollution and fertility, compared to forests. Both are significantly different from zero at the 5% level. Second, $\eta_{Gr.Future,Gain} = -0.28$, which means that the green future effect on inequality aversion (i.e. lower than for brown future) is stronger when elicited in the gain domain.[23]

In essence, the null hypotheses 1-4 are tests of the theoretical structure of the Social Welfare Function, in particular the relationship between consumption and environmental quality.

6 Analysis of heterogeneity in inequality aversion and pure time preference

For the 14 responses of each respondent, we run a regression using equation 9, obtaining individual levels of inequality aversion and pure time preference rates. This allows us to analyse the distribution of discount rates conditional on political and social opinions. Respondents gave a score between 1 and 10 on the following questions:

- How much do you feel concerned by 1) Inequality 2)The environment in general 3) The future of the planet 4) Pollution today.
- How how much confidence do you have in :1) The government 2) Political parties 3) NGO's 4) People in general

Figure 5 shows the distribution of individual results of $\delta, \eta_{Instant}, \eta_{Br.Future}$ *and* $\eta_{Gr.Future}$ conditional on quartiles of levels of concern or confidence. In general, results do not vary much conditional on the above concerns or levels of trust. For example, among 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 among the quartile with the highest concern for inequality, the mean $\eta_{Instant}, \eta_{Br.Future}$ *and* $\eta_{Gr.Future}$ are 2.6, 1.4 and 1.8 respectively. The reason for this stable result is that equality comes at a price of lower environmental quality. Yet people which are strongly concerned by inequality tend also to be strongly concerned by the environment en general. The correlation between both questions is 0.35. Similarly, where one could expect that the people that are most concerned by the environmental are ready to trade off environmental quality against equality, this relationship is very weak. The quartile of respondents with the highest concern for the environment have mean $\eta_{Instant}, \eta_{Br.Future}$ *and* $\eta_{Gr.Future}$ of 1.7, 1.3 and 1.9, while the the quartile of respondents

[23]Standard errors clustered at the individual level.

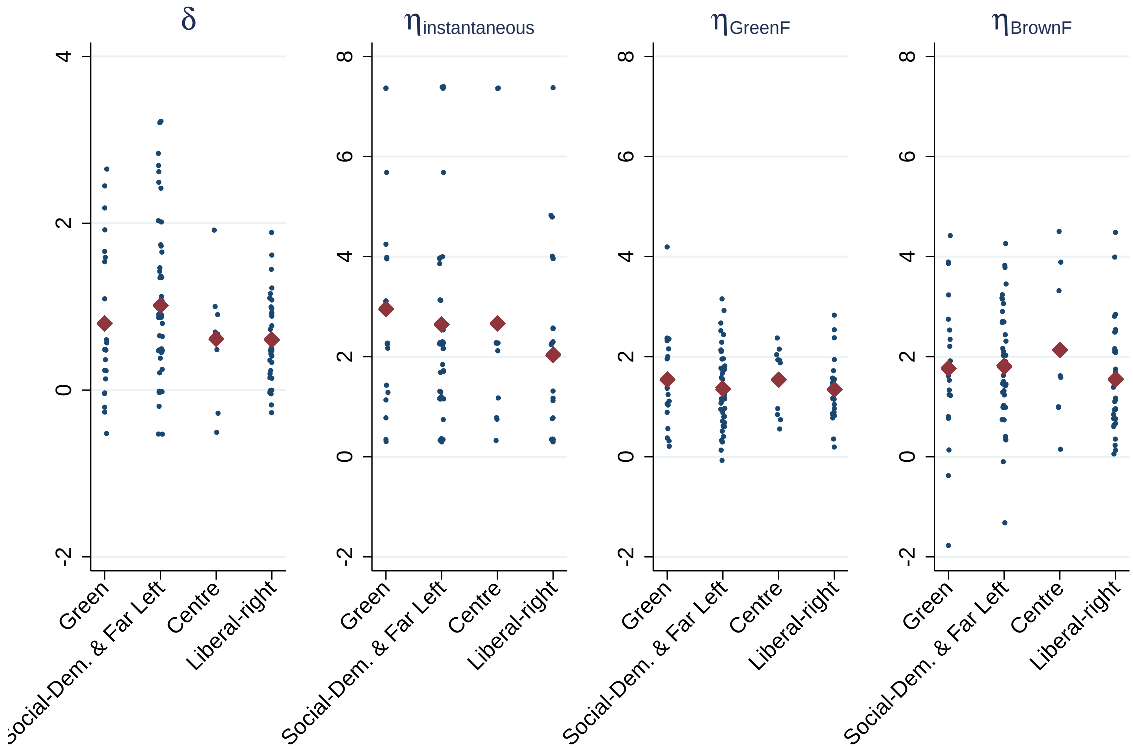

Figure 5: Pure time preference and inequality aversion by political party voted for.

with the highest concern for the environment have mean $\eta_{Instant}, \eta_{Br.Future}$ and $\eta_{Gr.Future}$of 2.6, 1.3 and 1.9.

Likewise, respondents who are highly concerned by the future of the planet do not have a lower pure time preference rate. Nor do respondents highly concerned with pollution today have a lower pure time preference rate. The obvious explanation is that both concerns are highly correlated (correlation coefficient 0.64).

Confidence levels do not tend to have a large effect on discount rates either. The pure time preference rate tends to be unrelated to confidence in the government (0.79 for lowest confidence versus 0.78 for highest confidence). This is also a consistency check that respondents preference for the present was unlikely to be driven by distrust in the government and disbelief that plans would remain unchanged in the future.

Next we also asked which party respondents had voted for during the last elections and the rates of pure time preference and inequality aversion in this political dimension. Since different political parties have distinct positions on redistribution and fairness, and long-term issues such as sustainability, intuition suggests that some patterns should exist in our data. Our exploratory analysis is summarised in Figure 5 and indeed there are some recognisable, albeit noisy patterns.

In Figure 5 the political parties are arranged from Left to Right politically as one move left to right on the x-axis. Taking instantaneous inequality aversion first, those 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, the 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 not compatible with each other in the Ramsey Framework, in they would be equal. By contrast, voters for the centre party and liberal-right party tend to have inequality aversion that is comparable in an instantaneous, green future and brown future setting. These voters therefore follow the logic and normative structure of the Ramsey rule to a larger extent. Overall, differences in inequality aversion over political parties tend to be smaller in an inter-temporal context, compared to a setting where there is no time involved. There are no obvious differences in the pure time preference parameter across different political parties.

It should be recognised that the sample sizes are rather small, and none of the differences discussed above are statistically significant at the 5% level. The analysis should be thought of as exploratory only. Appendix E shows the regression results that were used to undertake the statistical testing. Nevertheless, the intuitive nature of the results here provides some further evidence of the consistency of the responses in the data.

7 Conclusion

This paper has presented estimates of environmental inequality aversion obtained from experimental decision tasks. The purpose of obtaining these estimates was to inform CBA and welfare analysis of long-lived public projects and policies that affect environmental quality. There are two symmetric ways in which our estimates can inform the analysis of public policy. First, a measure of inequality aversion or inter-temporal substitution elasticity is a requirement for calibrating the 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 (H.M. Treasury, 2003; Groom and Hepburn, 2017; Freeman et al., 2018). Such an estimate, coupled with an estimate of the growth in environmental quality, will characterise the environmental "wealth effect" in the environmental SDR (see e.g. Baumgaertner et al., 2015). Alternatively, if the so-called dual-discounting approach is thought to mask what is essentially a valuation problem for environmental quality, the same information required to calibrate dual discount rates can inform the change in relative shadow prices for environmental quality in CBA. Just such an approach is under consideration in the UK, the Netherlands and France, while the role of relative price changes has been shown to be critical to the welfare analysis of climate change mitigation (Drupp and Haensel (2018); Groom and Hepburn (2017); Sterner and Persson (2008)). For example for a number of settings we find inequality aversion of $\eta = 2$, implying that if in the future the environmental quality is lower by say 50%, it should be valued at a price that is 4 (four) times its current value, all else (consumption) being equal.[24]

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. Firstly, our results show that the pure rate of time preference that people apply is not constraint across different environmental domains: air pollution, agricultural fertility and forests. Neither is the rate of pure time preference applied the same across gain/loss experiments, or different spatial domains. Estimates range from $\delta \approx 1.4\%$ when estimated in the gain domain, to $\delta \approx 0.4\%$ for agricultural fertility. Similar results apply for inequality aversion, which differs 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 bleak: ($\eta \approx 1.4$ in the so-called "brown 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 look backwards in time. All of these results tend to reject the typical framing of the social discount rate in discounted utilitarian mould, within which pure time preference and typically environmental inequality aversion are assumed to be invariant to context and domain.

These results are useful and insightful for policy and modelling purposes, especially given the recent interest in environmental scarcity and relative prices exhibited by governments and climate change analysts . Yet a word of caution is required in this respect. 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 are driven by both sources of inequality aversion, but we are unable to disentangle them. Future work will disentangle these different dimensions of inequality aversion, or to establish the likely cost of not doing so. So far though, our estimates are the most comprehensive empirical analysis of the question of environmental inequality aversion.

[24]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 $E_0 = 2E_t$ and $\eta = 2$, $\frac{p_t}{p_0} = 4$.

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Appendix A: Results Excluding “Irrational” Responses

Table 2: Pure Time Preference, and Elasticities of Marginal Utility: Models (1) - (5) estimated on a sub-sample

Variables	(1)	(2)	(3)	(4)	(5)
δ	1.123***	1.183***	1.185***	0.809***	0.850***
	(0.127)	(0.173)	(0.173)	(0.249)	(0.255)
δ_{air}		-0.254	-0.263	0.211	0.245
		(0.167)	(0.167)	(0.298)	(0.301)
$\delta_{Fertility}$		-0.550***	-0.550***	-0.271	-0.230
		(0.159)	(0.162)	(0.315)	(0.320)
δ_{Gain}		0.600***	0.598***	0.855***	0.877***
		(0.135)	(0.135)	(0.255)	(0.259)
δ_{Region}		-0.194	-0.188	-0.189	-0.384
		(0.143)	(0.143)	(0.144)	(0.317)
δ_{Past}		-0.383** -0.381**	-0.390***	-0.493	
		(0.151)	(0.154)	(0.151)	(0.318)
$\eta_{Instant}$	3.208***	3.213***	3.223***	2.649***	2.649***
	(0.145)	(0.157)	(0.158)	(0.293)	(0.293)
$\eta_{Instant,Gain}$				0.582*	0.582*
				(0.299)	(0.300)
$\eta_{Instant,Air}$				0.405	0.405
				(0.333)	(0.333)
$\eta_{Instant,Fertility}$				0.422	0.422
				(0.380)	(0.380)
$\eta_{Br.Future}$	2.170***	2.191***	2.163***	1.973***	1.985***
	(0.0842)	(0.108)	(0.115)	(0.166)	(0.176)
$\eta_{Br.Future,Region}$					-0.0476
					(0.195)
$\eta_{Br.Future,Past}$					-0.148
					(0.209)
$\eta_{BR.Future,Gain}$				0.0338	0.0367
				(0.171)	(0.173)
$\eta_{Br.Future,Air}$				0.399**	0.406**
				(0.202)	(0.207)
$\eta_{Br.Future,Fertility}$				0.251	0.302
				(0.203)	(0.210)
$\eta_{Gr.Future}$	1.360***	1.386***	1.353***	1.676***	1.601***
	(0.0824)	(0.105)	(0.115)	(0.162)	(0.176)
$\eta_{Gr.Future,Region}$					0.222
					(0.197)
$\eta_{Gr.Future,Past}$					0.0129
					(0.195)
$\eta_{Gr.Future,Gain}$				-0.338**	-0.362**
				(0.168)	(0.170)
$\eta_{Gr.Future,Air}$				-0.278	-0.340
				(0.203)	(0.209)
$\eta_{Gr.Future,Fertility}$				-0.109	-0.103
				(0.204)	(0.206)
ηAir		0.0826	0.0565		
		(0.0935)	(0.0967)		
$\eta_{Fertility}$		0.0878	0.104		
		(0.0894)	(0.0910)		
η_{Gain}		-0.103	-0.111		
		(0.0766)	(0.0769)		
η_{Region}			0.0845		
			(0.0814)		
η_{Past}			-0.0508		
			(0.0877)		
Observations	1,418	1,418	1,418	1,418	1,418
R-squared	0.662	0.673	0.673	0.676	0.676

Appendix B: Further Examples of Decision Tasks

In Appendix B the decision tasks involving consideration of the past versus the present are illustrated. The basic structure is the same, only respondents must evaluate hypothetical interventions that would have provided more or less environmental quality in the past, with relatively "green" or "brown" baseline scenarios in the past.

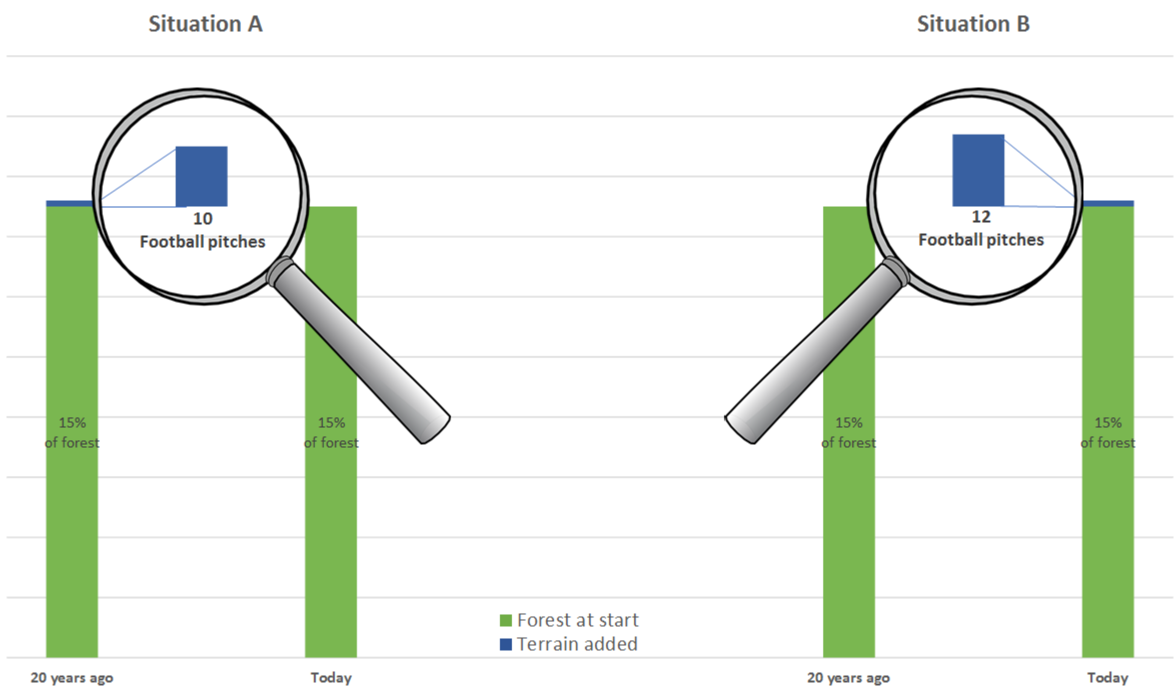

Figure 6: Example of the Decision Tasks: Forests in the Past (Green Past)

Appendix C : Maximum likelihood estimation

The maximum likelihood estimation is based on the Fechner model (Hey and Orme 1994).

If the respondent does not make an error (or has the same individual parameters as the aggregate 'best fit' parameters in the model), A is chosen if $W^A - W^B > 0$. As above, $W^{A,B} = e^{-rt_{A,B}} U^{A,B}$ with r the expression in equation 9 or 10, without the error term. If the respondent makes random errors (or has individual preference parameters that deviate from the aggregate 'best fit' parameters in the model), he chooses A if $W^A - W^B + \epsilon > 0$ and the probability that A is chosen is $P\left(W^A - W^B + \epsilon > 0\right) = P\left(\epsilon < W^A - W^B\right)$. If moreover this error is assumed to be normally distributed with mean zero and variance

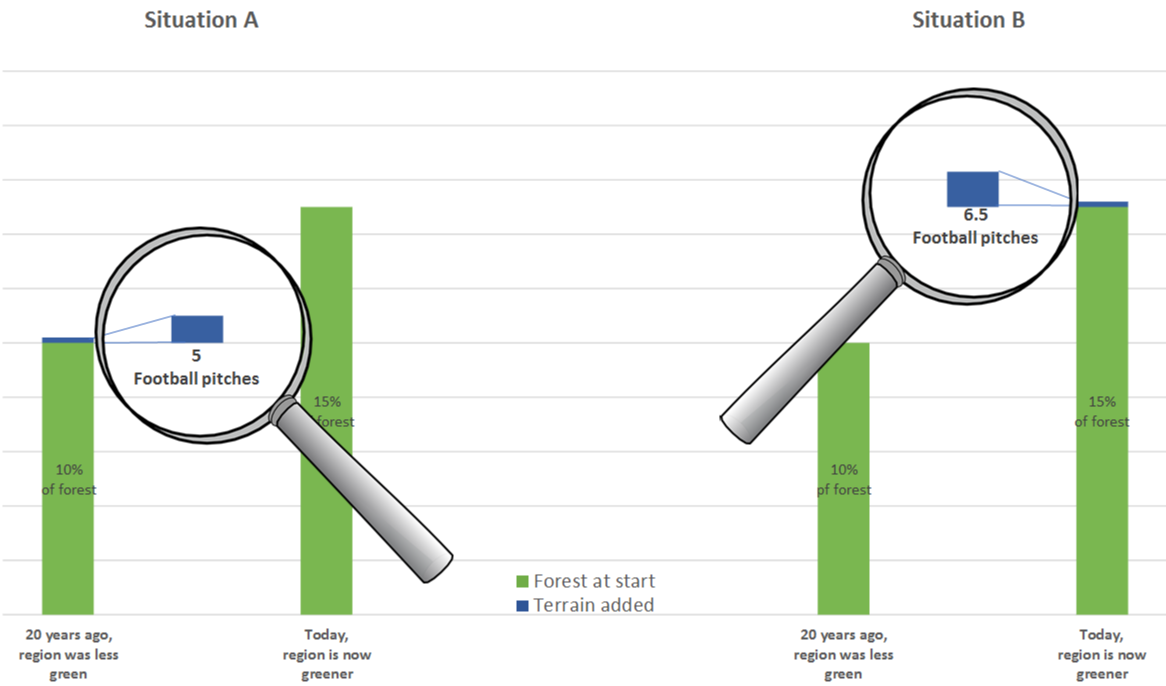

Figure 7: Example of the Decision Tasks: Forests in the Past (Brown Past)

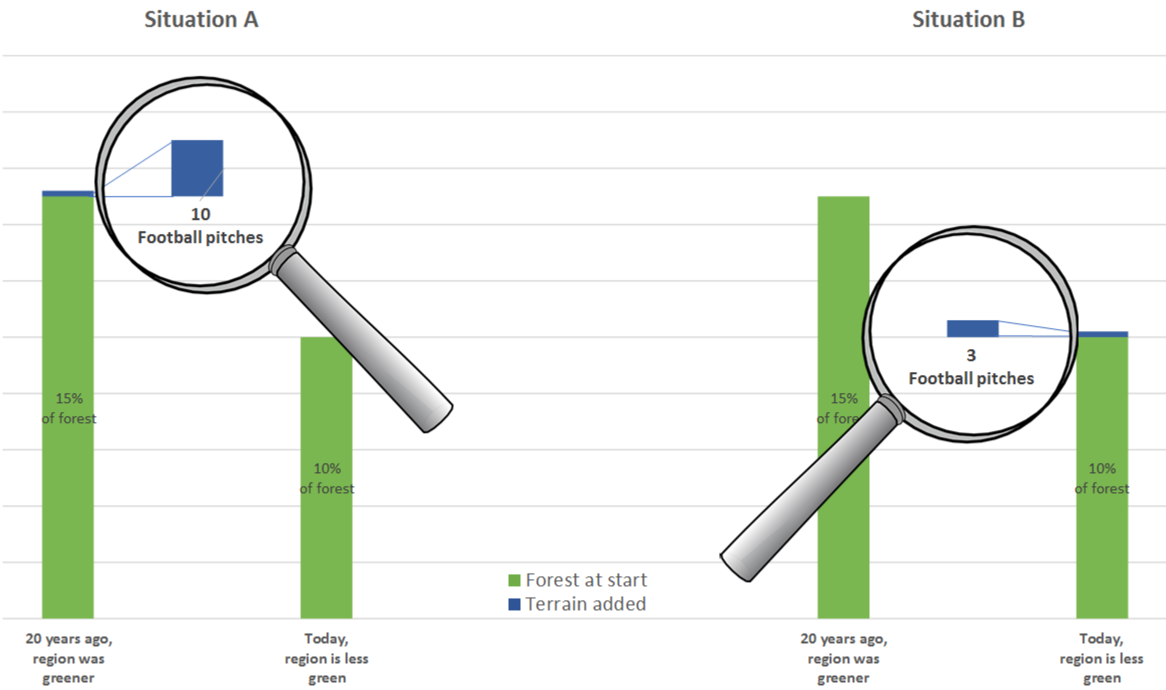

Figure 8: Example of the Decision Tasks: Forests in the Past (Green Past)

Table 3: Fechner Estimators

Variable	Fechner1	Fechner2	Fechner3	Fechner4
		Delta Equation		
air		0.16	0.05	0.05
fertility		-0.10	-0.22**	-0.23**
oneRegion		-0.28***	-0.28***	-0.09
decisionPast		-0.16**	-0.16**	-0.00
gain		0.74***	0.74***	0.70***
_cons	0.80***	0.52***	0.59***	0.50***
		Eta Equation		
brown		0.07***	0.07***	0.09***
green		-0.01	-0.01	0.01*
gain		0.01*	0.01**	0.02***
air			0.02***	0.03***
fertility			0.02***	0.02***
oneRegion				-0.04***
decisionPast				-0.03***
_cons	1.50***	1.59***	1.57***	1.56***
		Ln(mu) Equation		
_cons	-8.66***	-9.46***	-9.45***	-9.33***
Stats				
N	29557	29557	29557	29557
ll	-1.1e+04	-1.1e+04	-1.1e+04	-1.1e+04
bic	22362.40	21495.94	21481.85	21332.06
aic	22337.52	21404.71	21374.03	21207.65

Note: p < 0.1; ** p < 0.05; *** p <0.01.

μ, the probability that A is chosen is $P(A) = \Phi\left(\frac{W^A - W^B}{\mu}\right)$ with Φ the cumulative normal distribution. Similarly $P(B) = \Phi\left(\frac{W^B - W^A}{\mu}\right)$. Note that since the standard deviation of the errors is proportional to the scale that is used to measure W, the variance parameter makes the problem scale-invariant.

Appendix D : Questionnaire Rubric

Respondents were recruited in 10 groups and gathered in a classroom. This allowed us to give a long introduction and explain the different settings in an engaging way. Like in a typical course, we showed a powerpoint rather than reading a text. An online questionnaire was not possible because sessions were 90 minutes long. Respondents answered the questions individually. They received 10 euros for their participation.

The questionnaire was composed of 14 choice lists, 7 in one domain and 7 in another domain. Table 5 shows the ordering of the choice lists for different groups of respondents. Within one domain respondents always started with a choice list on instantaneous inequality (no time), followed by one choice list on time-only (no inequality) and finally four choice lists combining time and inequality. This order allowed us to go from the simplest to the most complex setting. The four choice lists on time and inequality contained two scenarios with increasing quality (green future) and two scenarios with decreasing quality (brown future). Moreover, two of these choice lists were framed as decision tasks today (decision-now) whereas two choice lists were framed as a judgement on how decision makers should have decided on the same questions 20 years ago (decision past). For each domain, there was a gain and a loss setting and a within region and between regions setting.

Domains, gain/loss and one/two regions were submitted in their 12 possible permutations. Within each of these permutations, respondents answered four questions with different features of decision-now/past and green/brown future. Ideally, to avoid ordering effects, we would have asked all orderings of decision-now/past and green/brown future within each permutation of domain, gain/loss, one/two regions. This was not possible however, given the limited number of groups. Ordering effects of green/brown future was limited because each respondent had both orderings, for example, if the question on decision-now started with green future, the question on decision in the past would start with the brown future. Ordering effects of decision-past/now were limited because the effect of the variable was insignificant to begin with. Also, half of the respondents started with decision-past questions, whereas the other half started with decision-now questions.

Table 5: Ordering of questions

Domain	Gain/loss	1/2 regions	Q1*	Decision now/past	Q2	Q3	Q4	Decision now/past	Q5	Q6	Q7	Group
Forest	Gain	2 regions	instantaneous inequality	Decision now	Time only	Green future	Brown future	Decision past	Time only	Brown Future	Green future	9 & 10 &2
Air	Loss	1 region	instantaneous inequality	Decision now	Time only	Green future	Brown future	Decision past	Time only	Brown Future	Green future	9 & 10 & 2
Fertility	Gain	2 regions	instantaneous inequality	Decision now	Time only	Green future	Brown future	Decision past	Time only	Brown Future	Green future	3
Forest	Loss	1 region	instantaneous inequality	Decision now	Time only	Brown Future	Green future	Decision past	Time only	Green future	Brown future	3 &1
Air	Gain	2 regions	instantaneous inequality	Decision now	Time only	Brown Future	Green future	Decision past	Time only	Green future	Brown future	4 & 1
Fertility	Loss	1 region	instantaneous inequality	Decision now	Time only	Brown Future	Green future	Decision past	Time only	Green future	Brown future	4
Forest	Gain	1 region	instantaneous inequality	Decision past	Time only	Green future	Brown future	Decision now	Time only	Brown Future	Green future	5
Air	Loss	2 regions	instantaneous inequality	Decision past	Time only	Green future	Brown future	Decision now	Time only	Brown Future	Green future	5 & 1
Fertility	Gain	1 region	instantaneous inequality	Decision past	Time only	Green future	Brown future	Decision now	Time only	Brown Future	Green future	6
Forest	Loss	2 regions	instantaneous inequality	Decision past	Time only	Brown Future	Green future	Decision now	Time only	Green future	Brown future	6
Air	Gain	1 region	instantaneous inequality	Decision past	Time only	Brown Future	Green future	Decision now	Time only	Green future	Brown future	7 & 8
Fertility	Loss	2 regions	instantaneous inequality	Decision past	Time only	Brown Future	Green future	Decision now	Time only	Green future	Brown future	7 & 8

* Questions on instantaneous inequality are always in 2 regions

During the preliminary test phase of the questionnaire, the main problem was the difficulty for respondents to understand the trade-offs and give meaning to the questions. Therefore, we gave an introduction with test questions, helping them to see the difficulty in inter-temporal trade-offs and inequality.[25] The powerpoint of the introduction stated the following text:

> "The results of this research will help to improve the valuation of environmental gains and losses which occur far in the future. There is a substantial level of disagreement on how to value the future in the field of environmental economics. This valuation is fundamental in any cost-benefit analysis ... If you have the impression that you have trouble understanding the meaning of the question, we prefer that you do not answer. Don't hesitate to ask me to go slower. There are no false answers, because the questions are about individual societal preferences. There are no 'unethical' answers because in each question there is a contradiction between at least two ethical values. For example: we want a lot of environmental gains, but we also want these improvements to happen quickly. We ask you not to look at previous questions when answering questions. The independence between the responses makes the analysis easier for us. We thank you for your valuable collaboration."

Test question 1

A similar image to Figure 1 is shown.

> "What follows is a test question, which allows you to get comfortable with trade-offs that are involved in the questions to follow.
>
> You can give money to one of two families. The two families are similar in every respect, the only difference is that one family is richer than the other. What is your preferred option? Give 10€ to a family that has a revenue of 2400€ per month or 3€ to a family with a revenue of 1600€ per month?
>
> What kind of reflection can help you to answer this question? You can compare the satisfaction of consuming 10 euros in a upper middle-class family with the satisfaction of a consumption of 3 euros in a lower middle-class family. Or if you accept that the additional benefit of 10 euros extra consumption corresponds to the disadvantage of 10 euros less consumption, you may wonder if you agree to take 10 € from the richer family in order to give 3€ to the other family and lose the difference in the transfer.
>
> Here is another similar question. Give 10€ to a family that has a revenue of 2400€ per month or 1€ to a family with a revenue of 1600€ per month? (a figure is shown) Note the trade-off that is implied by the question. You

[25] A training session can avoid 'learning' effects as found by Andersen et al. (2006). The revealed discount rate from their first choice list was typically lower than the following choice lists, although the order of the choice lists was randomized.

may like equality and therefore rather give to the poorer family, but as the difference between the 2 donations increases you may prefer at some point to give the 10€ to the family that is somewhat richer. Or inversely, you may say, 'I want to give as much as possible', i.e. the 10€, but on the other hand, you can imagine that the same euro will have a larger effect in a small budget than in a large budget. Note also that the difference in wealth between the 2 families is nor tiny, nor immense, which probably matters for you answer."

Test question 2

A similar image to Figure 2 is shown.

> "You can give money to one of two families. You can give 10€ now or 14€ in 20 years. In both cases the euros are expressed in euros of 2017, as if there were no inflation. Both families are similar in every respect and they live in the same context that does not change over time. Nevertheless, in one case you make a donation today, in the other you do so in 20 years. What is your preferred option?
>
> What kind of reflection can help you to answer this question? You can ask yourself what the family would chose if it was the same family that would receive the money now or in 20 years. Or you could consider the fact that a family which receives a donation today could save it with interest and get a larger amount in 20 years. This would even be a valid argument if we were thinking about transfers of environmental quality over time, because this family can use the donated money to improve its environmental quality."

A similar image to Figure 2 is shown.

> "You have to take money away from a family. You can chose to take away 10€ now of 10€ in 20 years. Euros are expressed in their value of 2017.
>
> What kind of reflection can help you answer this question? You can also think about what the family would chose if it was the same family that would lose the money now or in 20 years. Or you can take into consideration that a family could save today and earn interest to make up for the loss in 20 years. This reasoning would also apply to an environmental damage (for example a flooded house), because the family can set aside a sum of money today (and earn interest) to pay for the damage later."

The preliminary phase in which we tested our questionnaire, showed us that there is a need for training in the relatively complex inter-temporal trade-offs we ask our respondents to evaluate. We are aware that such training may also introduce framing effects. However, the bigger evil is that without training, many respondents will not grasp the meaning and implications of the questions. For example, some respondents would only see one dimension "I give always to to least well off" or "I always prefer the present over the future" or "I always prefer to give more rather than less". Although the $\frac{p_t}{p_0} = \frac{U_{E_t}}{U_{E_0}} = \left(\frac{E_0}{E_t}\right)^{\eta}$ difficulty in trading off ethical principles is interesting in itself, it was not the subject of this study.

Forest | loss | instantaneous inequality

> "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).[26] 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.[27] 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.[28] 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 pitches in the greener region or a concession of the size of one square meter in the less green region?"

A preference to lose a forest of the size of a football pitch rather than 1 square meter corresponds to $\eta > 22$, in which case we assumed the respondent did not understand the trade-off between the size of the concession and inequality, seeing only inequality. Table 6 shows that this misunderstanding is much more common (97 answers) than the opposite misunderstanding of seeing only size and not inequality ($\eta < 0$; 42 answers). Therefore, we always started with the choice between 1 football pitch and 1 m^2, to ensure that the respondents saw not only inequality but also the quantity of forest as a relevant dimension from the beginning of the choice list. The next choice was between a concession of the size of 10 football pitches in the greener region or 1 football pitch in the less green region. If a

[26]We exclude chemical pollution and biodiversity effects because they have more complicated dynamics. For example, one may argue that it does not make sense to have more forest in 20 years if a species went extinct by then. Damage may be a concave function of chemical pollution in which case increasing marginal damage combines with increasing marginal utility for larger damage. In this case our measure eta would be the sum of the concavity of the utility function and convexity of the damage function.

[27]The insistence on the 2 regions being similar in every regard allows us to avoid the effect of cross elasticities between consumption and environmental goods.

[28]The proportion of a 50% better environmental quality for the greener region was kept constant in all questions. We tried other levels of improvement in the test questionnaire. Once time is involved, a 50% improvement over 20 years corresponds to a 2% growth rate, which we consider to be a familiar growth rate for respondents.

Table 6: Estimated Parameters: Upper and Lower Bounds

Scenario	Estimate	Below lower bound	Lowest included	Highest included	Beyond upper bound	Total # answers
Instantaneous inequality	eta	eta<0	0.3	7.4	eta>22	
	# answers	42	106	101	97	751
Time only	delta	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

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.

respondent switched preference between the first and second question, we supposed that the size for which he is indifferent is half in between $1m^2$ and 1football pitch, resulting in the 'highest accepted' eta of 7.4. Lowest and highest accepted parameters are reported in Table 6. Respondents did not see on their response sheet how many choices we were going to ask in a given choice list, to avoid that they perceive switching in the middle of the choice list as the most reasonable response. The sixth choice in this choice list was between a concession of the size of 10 football pitches both in the greener region and less green region.[29] If respondents preferred the concession in the less green region we discarded the answer because we assume that they did not understand the question rather than assuming a negative eta. During the preliminary test phase, we tried to change the order of the choice list (start with 10 versus 10 football pitches), but this was confusing for some respondents. They logically started with a preference for a gain in the less green region, but only realized that they had to think carefully about the difference in quantities of forest when these differences were already extreme. This confusion would create an upward bias on η.

Forest | loss | time-only

The wording of the time-only choice list was:

> "Imagine that you have to chose between an immediate concession or a larger

[29] Andersson et al. (2006)find that respondents are not sensitive to the skewness of the choice sets of discount rates. They find no effect for the following three choice lists: A) evenly spread rates between 5% and 50% , B) 5%,10%,15%, 25%, 35%, 50% , C) 15%, 25%, 35%,40%,45%, 50%. Note that their initial price list is refined by a finer second grid around their switching point. Unlike for discount rates, they do find skewness effects for choice sets in revealed risk preferences.

concession in 20 years time (in 2037) in another region.[30] Imagine that you know with certainty that the other future region will have the same conditions (economic conditions, population density, fauna and flora, pollution...) Moreover, you know that this region will have the same forest coverage. Imagine moreover, that the recreational value of the forest will be identical before and after the concession, so you can abstract from what happens after the concession. Suppose that there is no uncertainty involved regarding the realization of the concession if you choose the future concession. In the extractive industry, long term contracts over a period of 20 years are common, because the industry needs to plan the continuity of operations a long time in advance. In both cases, the payment of the concession will happen today. Once the contract is signed, there is no doubt about the course of the operations. What is your preferred option."

In the first trade-off, respondents chose between a concession the size of 10 football pitches today or 8 football terrains in the future. If the former option is preferred ($\delta < -1.1\%$), we discard the answer, because we assume that the question was not understood. The next proposed choice was between a concession of the size of 10 football pitches today or 10 football pitches in 20 years. If they preferred losing the same quantity of forest today, [31] we assumed that they had a negative pure time preference rate of -0.5%, in line with certain sustainability criteria which prescribe non-decreasing wealth over time. In the eight and last choice of the choice list respondents chose between 10 football pitches of forest today and 25 football pitches in the future.

Again, we always used the same order of choices. During the preliminary test phase, we tried to change the order of the choice list (start with 10 football pitches now versus 25 football pitches in 20 years), but this was confusing for some respondents, because the difference in size is a more prominent feature than the timing. They logically started with a preference for a much smaller loss today, but only realized that they had to think carefully about the timing of forest when we arrived at a comparison between 10 football pitches forest now or in 20 years. This confusion would create an downward bias on δ. By starting with a preference for a future loss, respondents more naturally thought about both timing and quantity from the start. Despite the fact that we started with an 'obvious' choice in favour of postponing the loss (a concession of the size 10 football pitches forest now vs 8 football pitches in 20 years) there are much more respondents always preferring the present loss ($\delta < -1.1\%$), 167 answers) compared to respondents always preferring the future loss ($\delta > 4.5\%$, 66 answers) (see Table 6). This confirms our concern observed in the preliminary phase.

Forest | loss | brown future

[30] The concession with a contract helps respondents to assume that there is no uncertainty involved in postponing the project.

[31] We assume that the respondents had an indifference point in the middle of the 2 questions, i.e. 9 against 10 football pitches

The wording of the time-only choice list was:

> "The question is the same as the preceding question, but you know with 100% certainty that the region in the future will have less forest. So you will make a trade-off between 1) the quantity of forest, 2) the fact that when there is less forest in a region, people are more strongly affected by a decrease in forest 3) the moment of the deterioration."

The first question proposes a choice between a concession of the size of 10 football pitches today in a region with 15% forest coverage, against a concession of 1 m^2 in 20 years in a region with only 10% forest coverage. As mentioned above, inequality is more prominent than size whereas time is less prominent than size. As a result, respondents are at risk of preferring always a loss in the greener present region. Therefore we start with a setting where the extreme difference in size creates an obvious preference for a loss in the brown future. Despite this precaution in the ordering of the choice list, we had 200 answers preferring the concession of the size of 10 football pitches rather than 1 m^2 ($r < -44\%$).

Forest | loss | green future

In a green future choice list, the first choice was between a concession of the size of 5 football pitches today in a region with 15% forest coverage and a concession of the same size in 20 years time in a region with only 10% forest coverage. The ordering of the choice list is less obvious in this case, which is confirmed by the fact that we have many answers beyond both boundaries of our accepted range. In order to have a consistent approach with the other choice lists involving time, we started with a question where the obvious answer is a loss in the future.

Decision in the past

The exact wording of the choice list framed in the past, in all domains and for gain or loss settings, was:

> "Imagine that 20 years ago, somebody of the environmental administration would have needed to make a choice between an immediate concession and a concession 20 years later. We often have an opinion on what decisions should have been taken in the past. Historians make a moral judgement of decisions in the past, given knowledge regarding the decision in the past. Lawyers condemn or justify the ethics of certain decisions in the past... Imagine that the decision maker knew with certainty that the 2 regions would be identical in all regards (economic performance, population density, fauna and flora, pollution...). (the same information is given regarding identical context and uncertainty) What should have been his preferred option according to you?"

Forest | gain

> "A sand extraction company wants to stop operating one of its quarries for 5 years. In fact, they have to change their method of operation. The transition

from one method to another takes 5 years for technical reasons (drainage). They propose to give access to the public on this site and take the necessary measures if your environmental government agency pays compensation. When the site is in operation, the public cannot access it for security reasons. The sand extraction company makes two proposals to you in 2 different regions that have the same cost."

For the same reasons as above, the ordering of the choices is such that we started with a gain of 1 football pitch against $1m^2$ in the inequality-only setting and a preference for a gain today in the three other choice lists involving time.

Air quality | loss

The exact wording for the air quality context was:

> "You work for the public service of transport of your country. A road renovation needs to be realised, requiring a traffic deviation. The deviated traffic will cause supplementary air pollution along it's trajectory. Therefore, certain neighbourhoods will experience extra pollution. You have to choose between two deviations affecting two different neighbourhoods. Both neighbourhoods are identical in all regards other than the pre-existing pollution (mean income, type of houses, population density, mean age...). The effect of additional pollution is relatively small compared to the pre-existing pollution. The air quality is measured with an index. If the air quality index in the more polluted zone is 33% lower, the number of cars is 33% higher (and therefore the amount of pollutants is 33% higher too). You can interpret the index as the mean distance between 2 cars (at identical speed): 150m in the less polluted zone, 100m in the more polluted zone. Decrease the index by 10 units will decrease this mean distance between cars by 10m. For technical reasons, the index deteriorates more if the deviation goes through the less polluted neighbourhood. therefore there is a trade-off between the amount of extra air and the fact that additional pollution will be perceived more in the case that the air quality is bad to start with. What is your preferred option? decrease the air quality index by 10 in a neighbourhood that has a (better) quality of 150 or decrease the air quality index by 0.01 units in a neighbourhood that has a quality of 100."

Air quality | gain

> For a gain in air quality, the setting is slightly changed as follows:
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> "You work for your country's public infrastructure service. There is a major road renovation that needs to be carried out, which requires a road traffic diversion plan. The work requires the closure of certain roads, only accessible to local residents. Air quality will increase in some neighbourhoods that will have less traffic during construction. Traffic will be diverted to an uninhabited

area and you can ignore the decrease in air quality in this uninhabited area.

Fertility | gain

The exact wording for the fertility context was:

> "You work for your country's environment agency and you are developing a project to increase the productivity of agricultural land. The project increases productivity by applying green manure, i.e. plants ploughed into the soil that will increase the humus contained in the soil. Suppose there is no gain on biodiversity. The effect is temporary because after 10 years, the humus will have been digested. Farmers do not have to pay for this improvement. The increase in agricultural yield is very modest compared to the total harvest of farmers.
>
> There are two regions that are considered for the project. In one region farmers are richer because their soil (limonous) is more fertile with a yield of 9 tons per hectare and an average income of 2400 euros/month. In the other region farmers are less wealthy, because their soil (sand) is less fertile with a yield of 6 tons per hectare and an average income of 1800 euros/month. The two regions are identical in all other regards: farmers earn the average income of their region, they cultivate the same number of hectares, they have the same level of education, the same family situation, etc. What is your preferred option?"

Fertility | loss

For a loss in fertility, the setting is slightly changed as follows:

> "You work for your country's environment agency. The water company is applying for a permit to draw drinking water from an agricultural area. This will decrease water availability in the soil and lead to a decrease in fertility. Suppose there is no effect on biodiversity. The effect is temporary because it is a 10-year concession after which the water company will draw water elsewhere. Farmers are not compensated by the water company. The loss of agricultural yield is very modest compared to the total crop of farmers."