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Heterogeneous Substitutability Preferences

Abstract

We study the heterogeneity of preferences regarding the limited substitutability of environmental public goods vis-a-vis private consumption goods and how it affects the economic valuation of environmental public goods. We show theoretically that mean marginal willingness to pay for an environmental public good decreases in society's mean substitutability preference and increases in the heterogeneity of individual-level substitutability preferences. We then introduce an experimental framework to elicit individual-level substitutability preferences for the first time directly, which we apply to study general population preferences concerning the trade-off between market goods and forest ecosystem services. We estimate preference parameters for almost 1,500 individuals and document substantial preference heterogeneity. The majority of individual preferences imply a complementary relationship, with a median elasticity of substitution (complementarity) of around 0.4 (2.5). We show that accounting for heterogeneity in substitutability preferences may considerably increase the societal value attached to environmental public goods. These findings are relevant for environmental cost-benefit analysis and for the comprehensive accounting of public natural capital.

JEL-Codes: Q510, Q560, H410, D640, C990.

Keywords: substitutability, complementarity, heterogeneous preferences, non-market valuation, experiment, donations, public goods, policy appraisal.

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1 Introduction

Limited substitutability is at the heart of sustainability debate and a key determinant for the economic valuation of goods and services provided by nature (e.g., Gerlagh and van der Zwaan 2002, Neumayer 2010, Traeger 2011, Drupp et al. 2024a,b). If a person or society can easily substitute an environmental public good, ecosystem service, or biodiversity with a market-traded consumption good, then the economic valuation of this environmental public good is typically low (e.g. Meya et al. 2020). Conversely, when an environmental public good is difficult to substitute, its economic value tends to be very high so that it makes up a large share of the comprehensive consumption value. So far, however, the theoretical literature has focused on implications of limited substitutability in equal-preference or representative agent models, neglecting the role of preference heterogeneity. Relatedly, indirect empirical estimates of substitution preferences have so far relied on aggregate-level data or between-subject variation (e.g., Drupp 2018, Drupp et al. 2024a) and no study to date has elicited the elasticity of substitution between market and non-market goods directly and studied its heterogeneity across individuals.

In this paper, we aim to fill these gaps by theoretically and empirically studying heterogeneous substitutability preferences between environmental public goods and private consumption goods and how they affect the economic value society attaches to environmental public goods. We start by exploring theoretically how heterogeneous preferences affect society's aggregate marginal willingness to pay (WTP) for environmental public goods. We then estimate individual substitutability preferences—for the first time directly—with an online experiment that posits trade-offs between market goods or income and forest ecosystem services across four treatments that contrast incentivized versus hypothetical as well as private versus public settings. Using empirical preference estimates from almost 1,500 participants from the general population in Germany, we illustrate our theoretical results for how the heterogeneity in substitutability preferences affects the economic value of nature in society.

In the first part of this paper, we extend the theoretical equal-preference model that has been applied to non-market valuation, for instance, by Ebert (2003) and Baumgärtner et al. (2017a). Specifically, we consider a continuum of individuals that derive utility from a pure-public good and a private consumption good in a constant elasticity of substitution (CES) form. We assume that individuals differ in their perception of how well environmental public goods are substitutable by or complementary to private consumption goods. For reasons of analytical tractability, we derive results for the inverse of the elasticity of substitution, which we refer to as the 'elasticity of complementarity', as it measures the individual's complementarity preference.[1] We find that an increase in the *mean* complementarity preferences *increases* mean marginal WTP for environmental public goods. Furthermore, an increase in the *heterogeneity* of complementarity preferences (through an increase in the mean-preserving spread) also *increases* mean marginal WTP for environmental public goods (except for the special case in which the availability of environmental goods and market goods is the same). Thus, an environmental public good is more valuable from a societal perspective—holding the average degree of complementarity fixed—the stronger individuals differ in their complementarity preferences. By assuming that complementarity preferences are normally distributed within society, we then find that—compared to the standard case of homogeneous preferences—considering a heterogeneous distribution exponentially increases the societal value of environmental public goods.

In the second part of this paper, we introduce an experimental framework to study individual's complementarity preference given by the elasticity of complementarity (or its inverse, the elasticity of substitution) between market goods and non-market environ-

[1]Our modeling approach is related to Gollier (2019), who studies the effect of uncertain substitutability of environmental goods on the ecological discount rate in a dynamic context and shows that an increase in risk concerning substitutability decreases the ecological discount rate. While uncertainty of the average substitutability preferences may resolve over time as knowledge improves, such as through investments into knowledge that targets the degree of substitutability (e.g., Fenichel and Zhao 2015), the heterogeneity of substitutability preferences may remain considerable within society and, importantly, is also relevant in a static and deterministic context.

mental goods for the first time directly. While substantial heterogeneity in preferences across individuals has been documented for other key preference parameters, such as risk, time or fairness preferences (e.g. Andersen et al. 2008, Barsky et al. 1997, Falk et al. 2018, Fisman et al. 2015, Von Gaudecker et al. 2011), we are not aware of empirical studies directly eliciting individual preferences for the limited substituability between market consumption goods and environmental public goods. The prior literature has so far drawn on an indirect relationship between the income elasticity of WTP and the elasticity of complemtenarity (or substitution) to estimate the latter from variation of WTP and income across individuals (e.g., Barbier et al. 2017, Drupp 2018, Martini and Tiezzi 2014) or across non-market valuation studies (e.g., Jacobsen and Hanley 2009, Drupp et al. 2024a, Heckenhahn and Drupp 2024). Besides a few exceptions, this literature has found income elasticities of WTP, and thus elasticities of complementarity, between zero and unity, implying that the goods are perceived as substitutes.

With our experiment, we seek to estimate substitutability preference directly at the individual level. To this end, we consider trade-offs between (private or public) income and donations to plant forest trees, either real or hypothetical. Our design is informed by the literature on on the elicitation of fairness preferences (e.g., Andreoni and Miller 2002, Fisman et al. 2007, 2015) and on drivers of donations in giving behavior (e.g., Bartels et al. 2024, Huck et al. 2015, Karlan and List 2007, Kesternich et al. 2016). While studies employing modified dictator games have so far focused on monetary trade-offs across individuals, estimating preferences for balancing equity and efficiency between a giver and a receiver, the donations literature has explored the effect of varying prices of giving using between-subject designs, but without estimating heterogeneous elasticities of substitution between keeping and giving at the individual level.

We elicit heterogeneous substitutability preferences between environmental goods and income empirically in an online experiment drawing on a large general population sample. Specifically, we employ a modified, generalized dictator game and ask more than

2,000 Germans to repeatedly choose their preferred consumption allocation between a public environmental good and income. Through variations in the relative prices across decision tasks we then estimate preferences of a CES utility function for around 1,500 individuals with well-behaved preferences. We allocate participants to four treatment arms to assess the sensitivity of our estimates with respect to the experimental setting. Treatments differ in whether the choices are incentivized or hypothetical and whether the chosen income is paid out to the individuals themselves or to the public. We document substantial heterogeneity in substitutability preferences. The majority of individual preferences imply a complementary relationship, with a median elasticity of substitution (complementarity) of around 0.4 (2.5), and an interquartile range from around 0.1 to 1 (1 to 12). Substitutability preferences vary only mildly across treatments and do not systematically differ along income or measures of environmental preferences.

In the final step of the paper, we bring our theoretical insights and empirical estimates together and illustrate how accounting for heterogeneity in substitutability preferences increases mean marginal WTP for environmental public goods in society as compared to the standard case of equal preferences. This quantification indicates large effect sizes, if the measured complementarity preferences heterogeneity is observed in a situation where the environmental good is more scarce than human-made consumption goods. Thus, our results imply that accounting for heterogeneous substitutability preferences may have important implications for future non-market valuation, policy appraisal and accounting (e.g., Bastien-Olvera and Moore 2021, Bastien-Olvera et al. 2024, Drupp and Hänsel 2021, Drupp et al. 2024b, Sterner and Persson 2008).

The rest of this paper is structured as follows. In Section 2, we present a simple stylized model, where individuals have heterogeneous substitutability preferences and present theoretical results. We first consider the impact of a mean preserving spread and then specify the elasticity of complementarity to be normally distributed to obtain closed-form solutions to explore their impact on the societal mean marginal WTP. In

Section 3, we introduce our experimental design, the preference parameter estimation strategy as well as its application in an online experiment with a large general population sample. Finally, in Section 4, we bring our theory and empirical data together. Sections 6 and 5 close by discussing some limitations of our analyses and by drawing conclusions.

2 Theory

2.1 Model

We consider a society that consists of a continuum of individuals, labeled $i = 1, \ldots, n$, and a single time period. An individual derives utility from consuming a private, market-traded good, C, and an environmental public good, E, which is non-rival and non-excludable in consumption, so that all households benefit from the same quantity.

Households differ in their preferences regarding the substitutability of an environmental public good by a manufactured consumption good. Utility is ordinal and preferences are represented by a constant-elasticity-of-substitution (CES) utility function:

$$U_i(C, E; \eta_i) = \left(\alpha C^{1-\eta_i} + (1-\alpha)\, E^{1-\eta_i}\right)^{\frac{1}{1-\eta_i}}, \tag{1}$$

where $\alpha \in (0, 1)$ is the utility share of the market-traded good and $\eta_i \in (0, \infty)$ is individual i's inverse of the elasticity of substitution between the environmental public good and the private consumption good. The parameter η_i captures the limited degree of substitutability or the increasing degree of complementarity. We thus refer to it as the *elasticity of complementarity*. For $\eta < 1$ the two goods are considered substitutes; for $\eta > 1$ they are complements.[2] The utility function is strictly concave, preferences are homothetic, and both goods are assumed to be normal goods.

[2]We formally study the model with the elasticity of complementarity, η, instead of the elasticity of substitution throughout for reasons of analytical tractability (cf., Gollier 2019).

To focus our analysis, we consider a setting in which all individuals are endowed with identical levels of income, $Y > 0$, and identical levels (or exposure) of the environmental public good, $E > 0$. This means that all differences in the evaluation of the environmental public good, E, are due to differences in substitutability preferences and not by an unequal endowment with income or inequalities in the exposure of the environmental public good.[3] As we consider a single private consumption good, all income is spent on it. Hence, $C = Y/P$, which further simplifies to $C = Y$ with private consumption good as numeraire, that is $P = 1$.

The marginal willingness to pay (WTP), $\omega_i(Y, E; \eta_i)$ for one unit of E is the marginal rate of substitution between the public good and private consumption:[4]

$$\omega_i(Y, E; \eta_i) := \frac{\partial U_i(Y, E; \eta_i)/\partial E}{\partial U_i(Y, E; \eta_i)/\partial Y} \overset{(1)}{=} \frac{1-\alpha}{\alpha} \left(\frac{Y}{E}\right)^{\eta_i}. \tag{2}$$

Thus, the individual marginal WTP for the environmental public good is a simple function of the ratio of income and the environmental public good to the power of the individual-specific elasticity of complementarity, weighted by the relative utility share parameters for the private and public good consumption.[5] Observe from Eq. (2) that the elasticity of complementarity equals the income elasticity of WTP for the environmental public good, which is defined as $\eta_i := \frac{\partial \omega_i}{\partial Y} \frac{Y}{\omega_i}$ (cf. Ebert 2003, Kovenock and Sadka 1981).

[3]See Baumgärtner et al. (2017a) for an examination of unequal income and Meya (2020) for a treatment of unequal endowment with an environmental (local) public good.

[4]Marginal WTP (sometimes referred to as 'virtual' or 'Lindahl price'), ω, can be interpreted as the price the individual would have been willing to pay if the level of the public good, E, had been freely chosen on a hypothetical market (e.g. Flores and Carson 1997, Ebert 2003).

[5]Note that this represents a first-order approximation of WTP, as discussed in detail in Smith (2023).

2.2 Theoretical results

2.2.1 Heterogeneous substitutability

We now turn to the societal value of the environmental good. This is motivated by a key result of public economics (Lindahl-Samuelson-condition): Pareto-efficiency requires that public goods are supplied to the extent that the sum of individuals' marginal WTPs equals the marginal (opportunity) cost of supplying the public good (Lindahl 1928, Samuelson 1954). Thus aggregate marginal WTP is meaningful without interpersonal comparison in utility or the specification of a welfare function.

For the remainder η is a distributed variable that describes the continuous distribution of the inverse of the elasticity of substitution in the population of individuals. Society's mean marginal WTP (or 'societal marginal WTP') is the expected value for a given distribution of η:

$$\overline{\omega}(Y, E; \eta) := \mathbb{E}\left[\omega(Y, E; \eta) | \, \eta\right] \overset{(2)}{=} \mathbb{E}\left[\frac{1-\alpha}{\alpha} \left(\frac{Y}{E}\right)^{\eta} | \, \eta\right] = \frac{1-\alpha}{\alpha} \, \mathbb{E}\left[\left(\frac{Y}{E}\right)^{\eta} | \, \eta\right]. \quad (3)$$

This mean marginal WTP is a measure for societal WTP, as aggregate WTP is the sum of individual WTPs, which is the mean multiplied by the number of individuals.[6]

Proposition 1

Let η denote the inverse of the elasticity of substitution (i.e., the elasticity of complementarity) between a public and private good. Then any mean preserving spread in η, i.e. substitutability preference heterogeneity, increases the economic value of the public good. The only exception is the case where the level of income and the environmental public good are identical.

[6]Note that, as substitutability preferences are the only source of heterogeneity in our model, in the special case where all individuals have the same substitutability preferences, i.e. $\forall i : \eta_i = \eta$, society's mean marginal WTP, $\overline{\omega}$, equals individual marginal WTP, ω_i (Eq. 2).

Proof. For $Y \neq E$ it holds that $k(Y) := (Y/E)^{\eta}$ is a convex function in η, for positive levels of income and the environmental good, $Y > 0$ and $E > 0$. Therefore, by Jensen's inequality, $\mathbb{E}\left[(Y/E)^{\eta}\right]$ increases by any mean-preserving spread of η. As $\alpha \in (0,1)$, Eq. (3) is a positive function of $\mathbb{E}\left[(Y/E)^{\eta}\right]$. Hence, $\overline{\omega_i}(Y,E;\eta)$ also increases by any mean-preserving spread of η. For $Y = E$, however, $k(Y) = 1$ is constant, as is $\mathbb{E}\left[(Y/E)^{\eta}\right]$, and thus remains unaffected by a mean-preserving spread of η. □

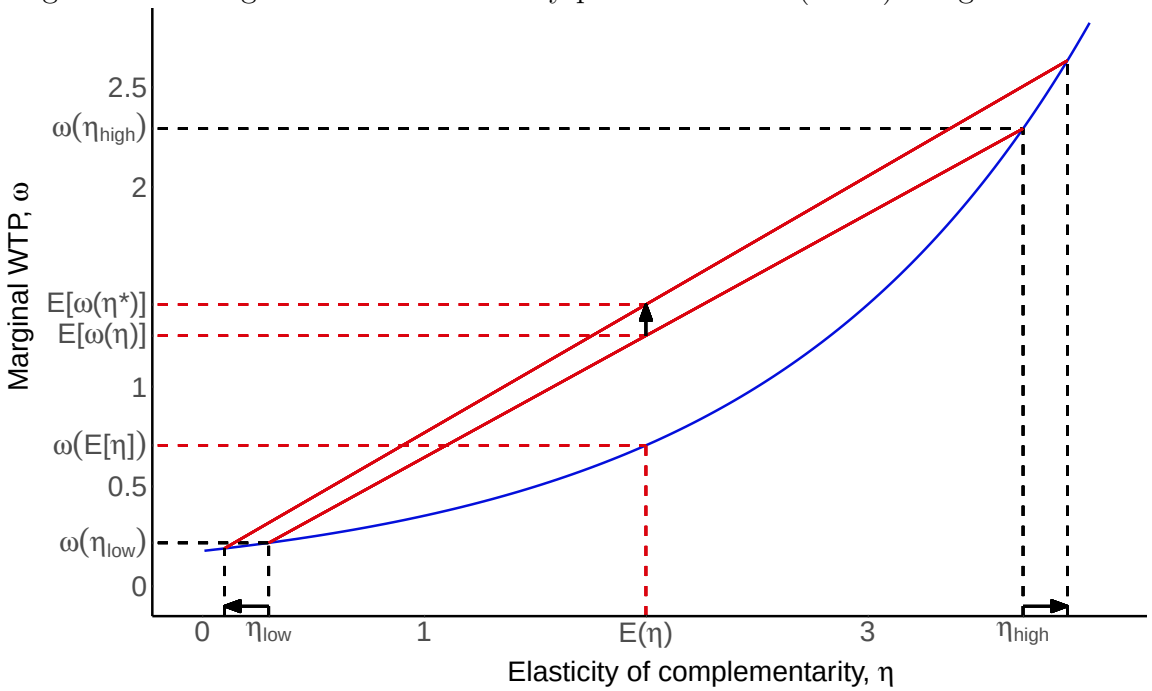
In Figure 1 we illustrate Proposition 1 for a simple case with two individuals that exhibit a low elasticity of complementarity (i.e. a high elasticity of substitutability), η_{low}, and a high elasticity of complementarity, η_{high}. Figure 1 shows that mean marginal WTP when the two individuals have heterogeneous preferences regarding the limited substitutability of environmental public goods vis-a-vis private consumption goods or income, $\overline{\omega}(Y,E;\eta)$, is higher than the marginal WTP at mean elasticity of complementarity, $\omega_i(Y,E;\mu_\eta)$. Mean marginal WTP, $\overline{\omega}(Y,E;\eta) = \mathbb{E}\left[\omega(Y,E;\eta)|\,\eta\right]$, increases with a mean-preserving spread in the elasticity of complementarity.[7]

2.2.2 Normally distributed substitutability

We now study a special case of $\eta \sim \mathcal{N}(\mu_\eta, \sigma_\eta^2)$, where μ_η is the mean of the elasticity of substitution between a public and private good in society and σ_η the corresponding standard deviation. The assumption of a normally distributed η has been previously taken to study uncertainty about the degree of substitutability (Gollier 2019) as well as to show that the effect of income inequality on WTP for environmental public goods can extend to heterogeneous preference (Baumgärtner et al. 2017a, Appendix 11).

[7] Technically, the effect of preference heterogeneity in the elasticity of complementarity, η, on the mean marginal WTP is analogue to the effect of uncertainty about substitutability on the ecological discount rate, as analyzed by Gollier (2019) in an intertemporal context.

Figure 1: Heterogeneous substitutability preferences and (mean) marginal WTP.



Notes: Illustration with two individuals with a low elasticity of complementarity (i.e. a high elasticity of substitutability), η_{low}, and a high elasticity of complementarity, η_{high}. If marginal WTP (blue) is a convex function of the elasticity of complementarity and preferences are heterogeneous, then Jensen's inequality implies that mean marginal WTP based on heterogeneous complementarity preferences, $\mathbb{E}[\omega(\eta)]$, is higher than marginal WTP at the mean elasticity of complementarity, $\omega(\mathbb{E}[\eta])$. Mean marginal WTP based on heterogeneous preferences increases with a mean-preserving spead in the elasticity of complementarity from $\mathbb{E}[\omega(\eta)]$ to $\mathbb{E}[\omega(\eta^*)]$.

Mean marginal WTP is the expected value of individual WTP's (see Appendix A.1)

$$\begin{aligned}\overline{\omega}(\mu_\eta, \sigma_\eta) =& \frac{1-\alpha}{\alpha} (Y/E)^{\mu_\eta + \frac{\sigma_\eta^2}{2} \ln(Y/E)} \\ =& \frac{1-\alpha}{\alpha} \exp\left[\mu_\eta \ln(Y/E)\right] \exp\left[\frac{\sigma_\eta^2}{2} \ln(Y/E)^2\right],\end{aligned} \tag{4}$$

which is strictly positive for $Y > 0$ and $E > 0$. Eq. (4) shows that $\overline{\omega}$ exponentially increases in both the spread and the mean of the elasticity of complementarity. Conducting comparative statics with respect to μ_η or σ_η establishes Proposition 2.

Proposition 2

Consider the elasticity of complementarity, η, to be normally distributed with mean, μ_η, and standard deviation, σ_η. It holds:

1. Mean marginal WTP, $\overline{\omega}$, increases (decreases) in μ_η if and only if the endowment with income is higher (lower) than with the public good

$$\frac{\partial \overline{\omega}}{\partial \mu_\eta} \gtreqless 0 \iff Y \gtreqless E; \tag{5}$$

2. Mean marginal WTP, $\overline{\omega}$, increases in σ_η, except if endowment with income equals endowment with the public good

$$\frac{\partial \overline{\omega}}{\partial \sigma_\eta} \begin{cases} = 0, & \text{if} \quad Y = E \\ > 0, & \text{otherwise} \end{cases}; \tag{6}$$

3. The positive effect of σ_η on mean marginal WTP, $\overline{\omega}$, increases (decreases) in μ_η if and only if the level of income is higher (lower) than that of the public good

$$\frac{\partial^2 \overline{\omega}}{\partial \sigma_\eta \partial \mu_\eta} \gtreqless 0 \iff Y \gtreqless E; \tag{7}$$

4. The positive effect of σ_η on mean marginal WTP, $\overline{\omega}$, increases with income, Y, if income is more abundant than the public good

$$\frac{\partial^2 \overline{\omega}}{\partial \sigma_\eta \partial Y} > 0 \quad \text{if} \quad Y > E. \tag{8}$$

Proof. See Appendix A.2. □

Proposition 2.1 shows that the effect of mean substitutability on mean marginal WTP for the environmental public good depends on its relative scarcity vis-a-vis private

consumption goods or income. If the environmental public good E is scarcer than income Y, mean WTP for the environmental public good increases as the degree of mean complementarity increases (or, equivalently, as mean substitutability decreases), that is the larger μ_η (Proposition 2.1).

Proposition 2.2 is a special case of Proposition 1 for a specific probability density function featuring a mean-preserving spread. We illustrate the effect of heterogeneity in complementarity preferences, σ_η on societal WTP for the environmental public good below in Figure 6.

Proposition 2.3 shows that the extent to which mean marginal WTP, $\overline{\omega}$, increases with preference heterogeneity, σ_η, is amplified (reduced) in the mean degree of complementarity, if the environmental public good is relatively more (less) scarce than income.

To compare the cases of heterogeneous and homogeneous substitutability preferences, one can consider the ratio between $\overline{\omega}$ with σ_η-heterogeneous preferences and $\overline{\omega}$ without heterogeneous preferences, that is with $\sigma_\eta = 0$, while holding everything else constant. This *heterogeneity factor*

$$h(\sigma_\eta) := \frac{\overline{\omega}(\mu_\eta, \sigma_\eta)}{\overline{\omega}(\mu_\eta, 0)} \overset{(4)}{=} (Y/E)^{\frac{\sigma_\eta^2}{2}\ln(Y/E)} = \exp\left[\frac{\sigma_\eta^2}{2}\ln(Y/E)^2\right], \tag{9}$$

is independent of μ_η and strictly positive, given our assumptions of $Y > 0$ and $E > 0$ (cf. Propositions 1 and 2.2). The heterogeneity factor equals unity in the special cases of $E = Y$ or $\sigma_\eta = 0$. Thus, when substitutability preferences are heterogeneous (and private and public goods are supplied in different amounts), mean WTP increases—relative to the standard homogeneous preference case—by a factor that is an exponential function of the heterogeneity of substitutability preferences, σ_η.

Alternatively, one can ask how high the mean elasticity of complementarity with homogeneous preferences needs to be to give the same mean marginal WTP as in a situation with preference heterogeneity. This *heterogeneity equivalent*, μ_η^*, is implicitly

defined as $\overline{\omega}(\mu_\eta^*, 0) = \overline{\omega}(\mu_\eta, \sigma_\eta)$. Inserting Eq. (4) and rearranging we have

$$\mu_\eta^* = \frac{\sigma_\eta^2}{2}\ln(Y/E) + \mu_\eta, \tag{10}$$

where the heterogeneity equivalent mean degree of limited substitutability, μ_η^*, is larger (lower) than the mean degree of limited substitutability with homogeneous substitutability preferences, μ_η, if and only if there are more (less) private goods Y than public goods E. Note, in the case of $E = Y$ the heterogeneity equivalent is equal to mean η. Eq. (10) shows how representative agent models can account for heterogeneity in the underlying preferences data in their parametrization of CES-preferences.

Since both the heterogeneity and mean of substitutability preferences affect mean marginal WTP, it is interesting to study which is the stronger effect. Comparing the elasticity of mean marginal WTP with respect to heterogeneity in substitutability preferences, $\left|\psi_{\overline{\omega},\sigma_\eta}\right|$, with the elasticity of mean marginal WTP with respect to the mean substitutability preference, $\left|\psi_{\overline{\omega},\mu_\eta}\right|$, establishes Proposition 3.

Proposition 3

Mean marginal WTP changes more elastically with σ_η than with μ_η if and only if σ_η is larger (lower) than income weighted absolute μ_η:

$$\left|\psi_{\overline{\omega},\sigma_\eta}\right| \gtreqless \left|\psi_{\overline{\omega},\mu_\eta}\right| \quad \text{if and only if} \quad \sigma_\eta \gtreqless \frac{2}{\left|\ln(Y/E)\right|}\left|\mu_\eta\right|. \tag{11}$$

Proof. See Appendix A.3. □

We can observe from Proposition 3 that $l(Y/E) := \frac{2}{|\ln(Y/E)|}$ is increasing in the income-environmental-good-ratio (Y/E) for $Y/E \in (0,1)$ and decreasing for $Y/E \in (1,+\infty)$. Thus, the scarcer the evironmental good is relative to income, the more likely it is that mean marginal WTP reacts more elastically to preference heterogeneity vis-a-vis the mean level of complementarity preferences.

3 Estimation of substitutability preferences

In the previous Section 2, we have established how preference heterogeneity regarding the limited substitutability of environmental public goods conceptually matters for the valuation of environmental public goods. Here, we now empirically estimate the heterogeneity of individual substitutability preferences. To measure substitutability preferences in the first place, we need observations on how people solve trade-offs between private market goods (or income) and environmental public goods. We collect such observations through an online experiment with more than 2,000 participants from Germany. This allows us to measure substitutability preferences at the individual level in a general population sample. In Subsection 3.1, we introduce our experimental design, in Subsection 3.2, we explain how we estimate the preference parameters with the experimental data and in Subsection 3.3 we summarize our results from the experiment.

3.1 Experimental design

To examine how individuals substitute private market goods with an environmental public good, we conduct an online experiment in which we confront participants repeatedly with a modified dictator game. The setup we employ has previously been used to study equity-efficiency trade-offs in the allocation of income between a giver and a receiver and to estimate an isoelastic measure of fairness preferences (e.g., Andreoni and Miller 2002, Fisman et al. 2007, 2015). Here we apply this game, for the first time, to estimate substitutability preferences between market goods and an environmental public good.

In our experiment, we present participants 30 choice tasks in which they have to trade off donations to plant forest trees against income, with one randomly selected decision being realized (in our incentivized treatments). In line with our theoretical model, we simplify the choice set to a single market good, so that all income is spent on it, hence $C = Y$. We use forest ecosystem services derived from planting forest trees

as the environmental public good E. Donations to plant trees are a familiar setting for participants, as evidenced by recent studies (e.g., Bartels et al. 2024, Vlasceanu et al. 2024) and the non-negligible fraction of participants who have previously donated to plant trees (see Panel D of Figure 5). To generate variation in the trade-off between income and forest trees, we match the donations from participants to plant forest trees.[8] The 30 choice tasks generate rich decision data at the individual level on how the trade-off between income and forest trees is solved along a set of relative prices. We use this data to estimate the elasticity of complementarity (η_i) as well as the utility share parameter regarding income (α_i), and thus regarding forest ecosystem services ($1-\alpha_i$), of an ordinary CES utility function for each participant i.

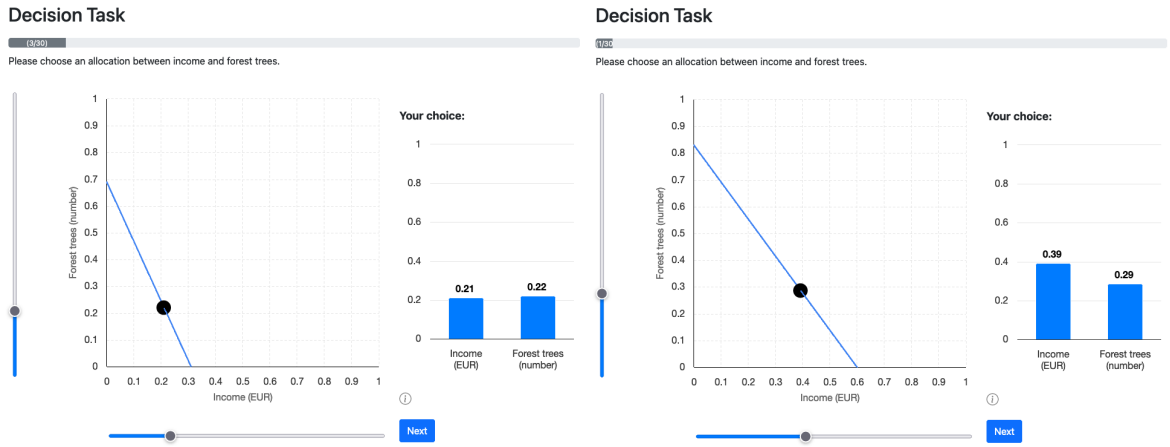
Figure 2 shows two exemplary decision tasks, in which participants have to choose allocations of additional forest trees, E, and/or additional market goods, Y. We illustrate all possible allocations that exhaust the normalized budget $m = 1$ by a blue linear budget line, which is given by the constraint $p_Y\pi_Y + p_E\pi_E = m$.[9] Participants can choose their preferred allocation by either clicking on their desired allocation on the budget line or by using one of the interactive sliders. Across these 30 decisions, we vary the price ratio in such a way that $p_E/p_Y \in [0.3; 3]$.[10] We can then reconstruct participants' preferences by examining how they react to these changes in relative prices.

[8]Specifically, planting a forest tree via an official state forestry in Germany costs 5 EUR per tree. We match donations upwards to ensure that it would not be worthwhile for participants to take the full income at relative prices that are unfavorable for tree donations in the experiment to then donate them outside of the experiment. While the use of matching donations for the provision of environmental public goods has been previously explored in the literature, most studies so far only rely on a limited set of salient variations and examine effects on participation or giving in situations with a 1:1 matching or close variants, such as a 1/3:1 or 3:1 matching (e.g., Kesternich et al. 2016). To the best of our knowledge, no study used such variations to estimate substitution elasticities.

[9]Please note that participants can actually spend a part of their budget —in two of our four treatments, see below— on a donation to the environmental public good, while in our theoretical set-up this choice is only virtual as common in theoretical and empirical non-market valuation literature.

[10]The budget lines are randomly generated prior to the experiment and fixed across participants. Participants see them, however, in a random order. We randomly draw budget lines in a way that one axis intercept is between 0.5 and 1 and the other between 0.1 and 1 (hence, $p_E/p_Y \in [0.1; 10]$ could have been theoretically possible). This process generates normally distributed logarithmic price ratios, which we visualize in Figure A1 in the Appendix.

Figure 2: Illustrations of the experimental tasks.



Notes: This figure shows two exemplary decision tasks where participants choose between private income and forest trees as a public environmental good. The budget line (in blue) represents all available allocations. Participants can either click on the budget line directly or use one of the sliders to make their decision. The bar chart on the right visualizes the chosen allocation. In total, participants must complete 30 decision tasks.

We employ a 2×2 treatment design to vary incentives and the income recipient: Participants are randomly allocated either to an incentivized or hypothetical treatment arm. In the incentivized treatment arm, one random decision out of all 30 decisions is realized and the chosen number of forest trees from that decision will be planted and the chosen income will be payed out. We add up the quantity of trees that participants have chosen for and plant them on behalf of participants through a donation to a German state forestry.[11] In the hypothetical treatment arm, no decision is realized. With this treatment, we want to examine by how much results change when participants have no direct 'skin in the game'. To mitigate hypothetical or elicitation bias (e.g., Vossler and Evans 2009, Bishop et al. 2017), we highlight in the instructions that responses may be consequential insofar as the results will be communicated to the Federal Environment

[11]Participants were not informed ex-ante about the specific state and location where trees will be planted within Germany to avoid that local preferences affect their choices. We ex-post donated according to individual choices in the two incentivized treatments (1,690 EUR in total to plant 338 trees) to HessenForst on the participants' behalf, as the state of Hessen is located centrally within Germany.

Agency, who are in charge of setting the German environmental cost-benefit guidelines and informing environmental policy design.[12] In addition, participants are randomly allocated to either the private or public treatment arm. In the private income treatment arm, participants must choose between forest trees and private income for themselves. In the public income treatment arm, participants must choose between forest trees and public income for all, which is donated to the German finance ministry ('Bundeskasse'). In comparison to the private income treatment, the public income treatment serves to mitigate public good provision free-riding considerations in influencing substitutability preferences. While we interpret the private income setting to be relevant for decisions concerning a voluntary provision of public goods, the latter might better serve as a yardstick when informing public policy. Participants are assigned to a treatment group at the beginning of the experiment and remain in them for the rest of the experiment.[13]

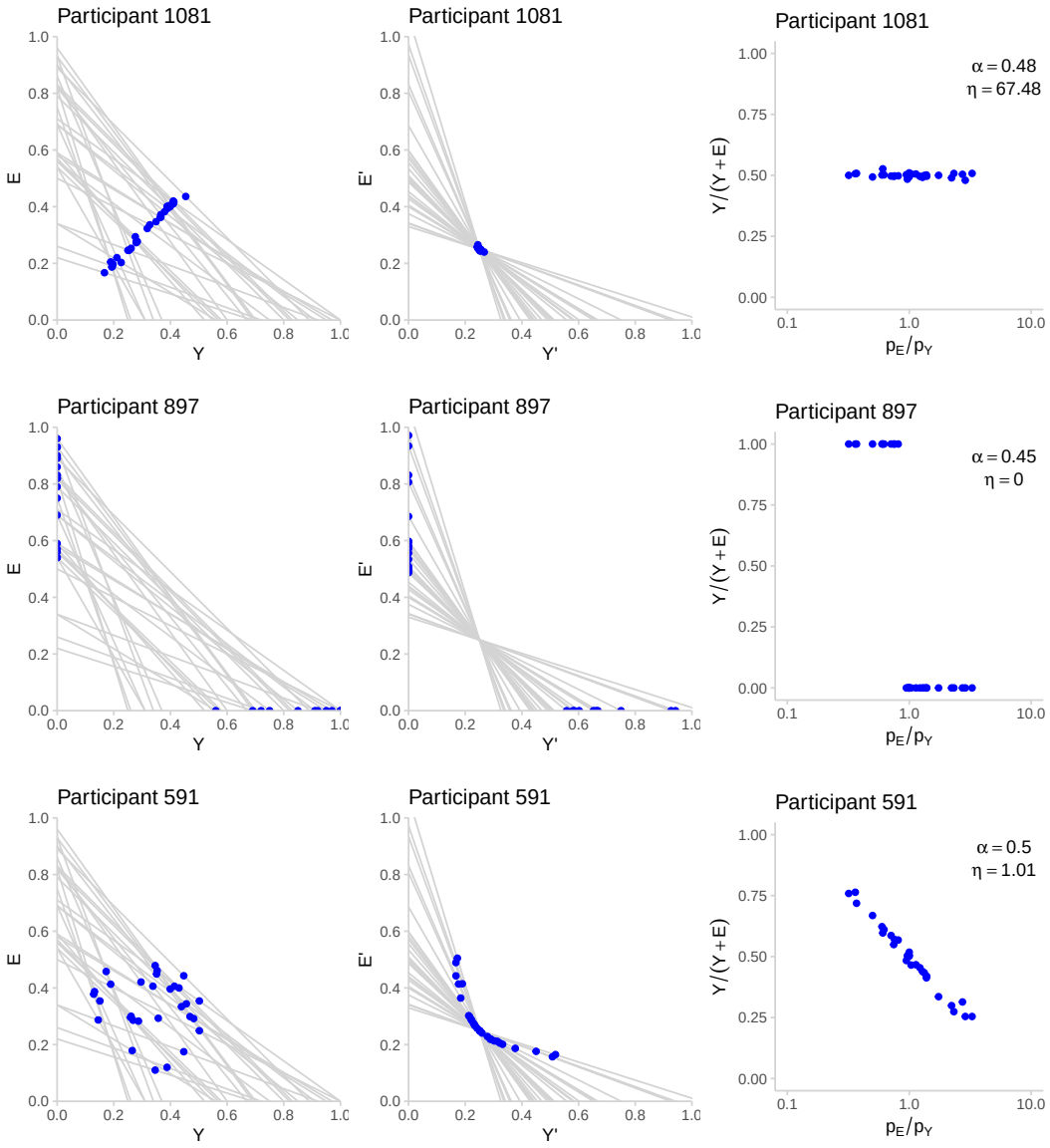
Before the main decision task, participants receive instructions about the task and get familiar with the interface in three training rounds. To ensure that participants pay attention and carefully read and understand the task, we also include an attention check and a comprehension check that participants must pass. After the main decision task the experiment closes with a short survey. We developed the experiment in oTree (Chen et al. 2016), ran the online experiment in January and February 2024, and recruited participants through the market research firm Kantar.

Before proceeding with the estimation strategy, and to facilitate a more intuitive understanding, we illustrate the choices for three selected participants who exhibit archetypal preference structures in Figure 3. The three preference structures represent near perfect subsitutability ($\eta \approx 0$), near perfect complementarity ($\eta \to \infty$), or intermediate substitutability preferences close to the Cobb-Douglas case ($\eta \approx 1$).

[12] Appendix A.4 includes a translation of the full experimental instructions.

[13] In Table A2 in the Appendix, we compare the summary statistics of participants between all four treatments and find, except for slight differences in the average age, balance between treatment groups. The age differences depend on the baseline treatment group with whom other treatment groups are compared to and disappear when using the private hypothetical treatment group, for example.

Figure 3: Exemplary choices of three selected participants.



Notes: This figure shows the choices of selected participants with three archetypal substitutability preferences, all with an approximately equal preference for market goods (or income) versus the environmental public good ($\alpha \approx 0.5$). The left panels are equivalent to the screens that participants faced in each decision task. For the middle panels, we have standardized the budget lines to cross the consumption bundle (0.25, 0.25) to facilitate comparisons between choices. In the right panels, we then show the corresponding consumption shares depending on the relative price p_E/p_Y. Participant 1081 prefers a complementary consumption of market and environmental goods, with a high estimated elasticity of complementarity, η, of more than 60, and always chooses an almost equal share between income and the environmental good. Participant 897 has consumption preferences that reflect perfect substitutability between income and the environmental good ($\eta = 0$). She always chooses the good that maximizes the consumption level. Participant 591 has preferences close to Cobb-Douglas preferences ($\eta \approx 1$): She reacts to price changes and consumes more of the relatively cheaper good.

Participant 1081 presented in the top row of panels in Figure 3, for example, prefers a strongly complementary consumption of market goods (or income) and environmental public goods, as she always chose an almost equal allocation between the two. Irrespective of the relative price (p_E/p_Y), the consumption share was always around 50 percent for each good. Participant 897, in contrast, has consumption preferences that reflect perfect substitutability between income and the environmental good, as she always chose the option that maximized the sum of consumption levels. Therefore, she selected corner solutions for relative prices differing from unity meaning that she preferred to consume only income when income was relatively cheap ($p_E/p_Y < 1$), only the environmental good when the environmental good was relatively cheap ($p_E/p_Y > 1$), and she preferred equal consumption levels when the respective prices of the goods where the same ($p_E/p_Y = 1$). Finally, participant 591 has intermediate substitutability preferences, close to the Cobb-Douglas case. She reacts to changes in relative prices and prefers a higher share of income when income is relatively cheap, and a higher share of the environmental good when that is relatively cheap, whereby she avoids corner solutions.[14]

3.2 Estimation Strategy

The experiment generates rich individual-level data about the choices of a general population sample and the context in which these choices have been made. We first check whether subjects make consistent and rational choices and subsequently estimate individual-level preference parameters of the CES utility function described in Eq. (1): the elasticity of complementarity (η_i) and the utility weight for income (α_i).

[14]Apart from these three archetypal preference types, and those with other intermediate substitution preferences, our data also features participants who do not react to price changes and always allocate the whole budget to income or to the environmental good. We exclude these participants from our main analysis, as we cannot separately identify their subsitutability preferences. Specifically, we exclude participants with *uniform preferences* if they allocated, on average, at least 98% of their budget to a single good: $E[Y/(Y+E)] \geq 0.98$ or $E[E/(Y+E)] \geq 0.98$. We vary this threshold and explore sensitivity in Figure A9 in the Appendix. We find that changing the cut-off threshold has no discernable effect on the median estimated elasticity of complementarity, but tends to lead to slightly higher mean estimates.

We start by examining whether participants make consistent and rational choices, i.e. whether their preferences can be recovered by a well-behaved utility function such as the CES utility function we seek to calibrate. Following Fisman et al. (2007), we therefore test for compliance of the participants' choices with the generalized axiom of revealed preferences (GARP). To this end, we calculate the critical cost efficiency index (CCEI) suggested by Afriat (1972). The CCEI ranges between 0 and 1 and informs by how much the budget lines would need to be adjusted to remove all GARP violations. For fully rational participants, no adjustments are necessary and $CCEI = 1$. For participants with GARP violations, however, one would need to adjust the budget lines to make their choices consistent and rational (hence, $CCEI < 1$).[15] Overall, a majority of participants makes very consistent and rational choices as we show in Figure A2 in the Appendix. While there is no formal threshold that distinguishes rational from irrational choice, we follow Fisman et al. (2007) and choose a threshold of 0.8 which leads to the exclusion of 394 participants for our main sample.

Among the remaining participants, 110 have uniform preferences and allocate, on average, more than 98% of their budget to only a single good. While we can derive an income utility weight for those (either $\alpha_i = 0$ or $\alpha_i = 1$), we are unable to jointly estimate their elasticity of complementarity (η_i) as this would require at least one choice away from the choice set boundary.[16] For the remaining 1,428 participants, we observe consistent and rational choices and are able to estimate both preference parameters, and crucially, the elasticity of complementarity.[17]

[15] In Figure A3 in the Appendix we visualize the choices of some subjects that are excluded due to low CCEI scores.

[16] It may well be that a considerable fraction of these subjects will become price sensitive at more extreme relative prices than features here in our experiment, which would then allow for capturing their substitutability preferences. We leave an investigation of this to future work.

[17] Table A1 in the Appendix shows descriptive statistics on individuals characteristics in our initial sample (N=2,181) and our main sample (N=1,428) for the estimation of substitutability preferences.

To retrieve the individual-level preference parameters we follow the estimation approach outlined in previous work, e.g. by Andreoni and Miller (2002) and Fisman et al. (2007). We assume that individuals maximize utility according to a CES utility function from consuming a private, market-traded consumption good ($C = Y$) and an environmental public good (E) and are restricted by a normalized budget $p_Y Y + p_E E = 1$. Hence, the optimal share of income for the private consumption good ($p_Y Y_i^*$) for participant i is:

$$p_Y Y_i^* = \frac{\left(\frac{\alpha_i}{1-\alpha_i}\right)^{\frac{1}{\eta_i}}}{\left(\frac{p_Y}{p_E}\right)^{-\frac{1-\eta_i}{\eta_i}} + \left(\frac{\alpha_i}{1-\alpha_i}\right)^{\frac{1}{\eta_i}}} \tag{12}$$

Thus, the optimal income share for the consumption of the private good depends on the elasticity of complementarity η_i, the utility weight for income α_i, and the price ratio p_Y/p_E. We allow for some imprecisions and measurement error in the observed choices from our experiment and thus assume that the observed income shares ($\widehat{p_Y Y_i}$) are the sum of the optimal income share for the consumption good and an error term, ϵ_i, that is normally distributed with an expected value of zero. Hence, our econometric specification is:

$$\widehat{p_Y Y_i} = \frac{\left(\frac{\alpha_i}{1-\alpha_i}\right)^{\frac{1}{\eta_i}}}{\left(\frac{p_Y}{p_E}\right)^{-\frac{1-\eta_i}{\eta_i}} + \left(\frac{\alpha_i}{1-\alpha_i}\right)^{\frac{1}{\eta_i}}} + \epsilon_i \tag{13}$$

With our experiment, we observe various income shares for the consumption ($\widehat{p_Y Y_i}$) over different price ratios (p_Y/p_E), which allow us to estimate the parameters η_i and α_i for each participant i. As the observed income share is bounded between 0 and 1, we employ a two-limit maximum likelihood model, in line with the prior literature (e.g., Maddala 1983, Andreoni and Miller 2002, Fisman et al. 2007), to estimate both parameters from Eq. (13).

3.3 Results of the experiment

Table 1 shows a summary of the estimated preference parameters for our main sample of 1,428 participants.[18] We report both the full raw distribution and a version in which elasticity of complementarity estimates are winsorized at the upper 90th percentile. We use this (one-sided) winsorization for our main analysis, as η_i goes towards ∞ for near-perfect complements, thereby making the mean elasticity of complementarity hypersensitive to these near-perfect complementarity preferences.

Table 1: Estimated preference parameters.

	Elasticity of complementarity, η		Income utility weight, α
	Wins. p90	Raw	Raw
Median	2.48	2.48	0.47
Mean	12.87	1788.17	0.47
SD	20.70	47831.55	0.35
Min	0	0	0
Max	65.34	1,782,196	1.00
Observations	1,428	1,428	1,428

Notes: This table shows summary statistics of the estimates of the elasticity of complementarity, η, and for the utility share given to income, α, for the raw sample and our main estimation sample that is winsorized at the upper 90th percentile of the elasticity of complementarity.

We show the distribution of the individual-level estimated parameters for the elasticity of complementarity (η_i) and the utility share parameter for income (α_i) in Figure 4. Panel (A) depicts the empirical cumulative distribution of substitutability preferences, which we categorize in seven preference domains in Panel (B). Panels (C) and (D) illustrate similar analyses for the utility share parameter. We document four main results:

[18] We exclude participants from our main analysis that either fail quality checks or display uniform preferences. Specifically, we exclude 17 participants that failed a comprehension at least 10 times, 232 participants that completed the experiment in less than 5 or more than 60 minutes, 394 participants with irrational choices as measured by their degree of GARP violations, and 110 participants that allocated, on average, at least 98% of their budget to only a single good. In Figure A4 in the Appendix, we visualize these exclusions and the final composition of our main sample.

Result 1: Substitutability preferences are similar across treatments, but environmental quality receives a larger utility weight in public settings.

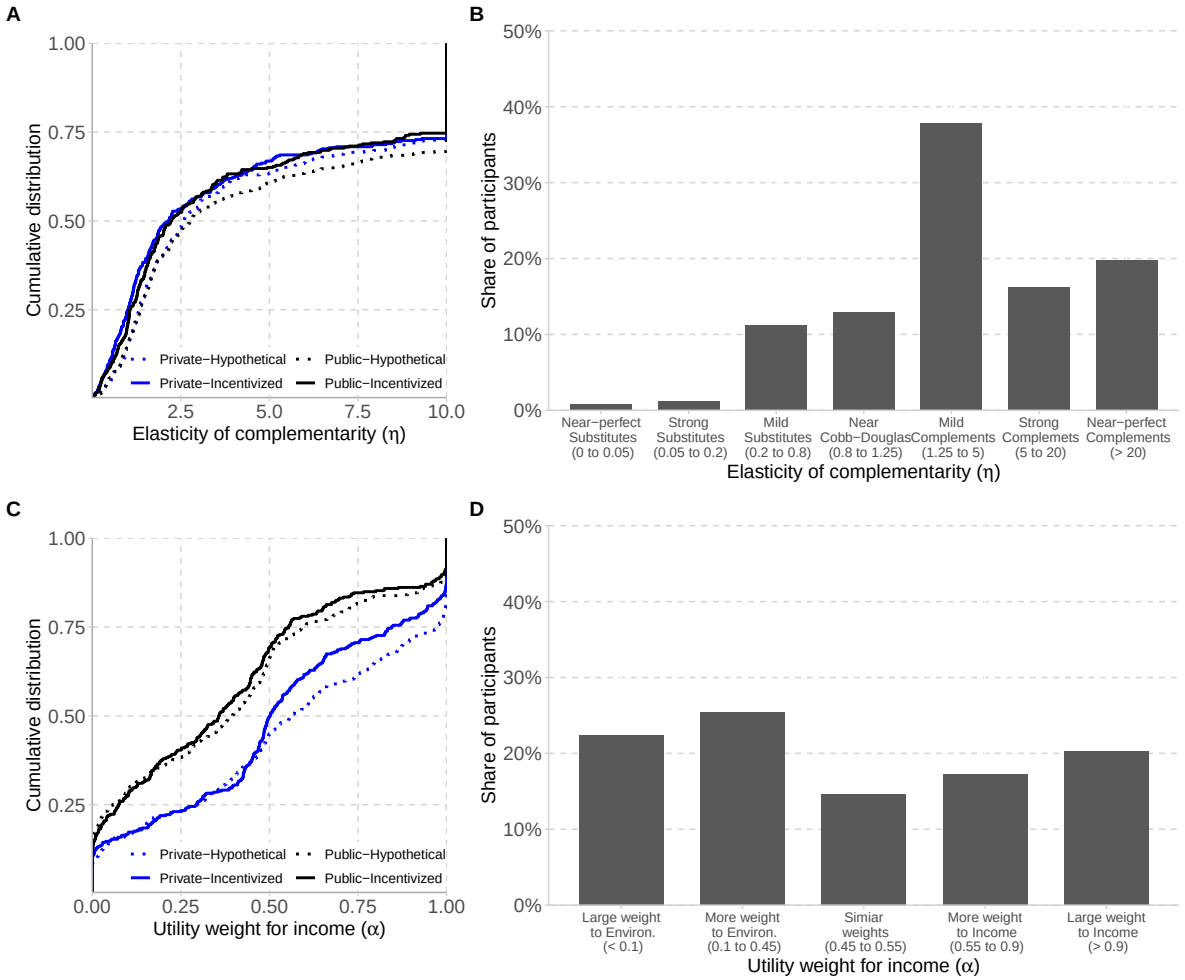
Panel A of Figure 4 shows the cumulative distribution of individual elasticities of complementarity across the four treatments, which highlights no sizable differences in the distribution of individual elasticities of complementarity. We test for differences in the mean and median elasticity of complementarity between our four treatment arms in Table A3 in Appendix A.4 with an OLS regression and Fisher's exact test for the equality of the medians, but detect only minor differences, almost all of which are insignificant.[19] These findings suggest that our estimation of substitutability preferences largely tends to carry through across settings that are incentivized or hypothetical as well as between settings where income is a private or public good. In Figure 4*C*, by contrast, we observe a level-shift on the utility share given to income between private and public setting. When participants can allocate part of the budget to private instead of public income, they put a significantly larger weight on income (see Tables A3 and A4 as well as Figures A6 and A7 in the Appendix for the corresponding statistical tests).

Result 2: The majority of preferences lie in the complementarity domain.

The majority of participants treat income and the environmental public good as complements (see Figure 4*B*). We find a median value for the elasticity of complementarity, η_i, of 2.48, which is close to but slightly higher than the value used in a prominent application of limited substitutability in the integrated assessment of climate change policies by Sterner and Persson (2008). The choices of almost 40 percent of participants imply mild complementarity (here denoted as such when $\eta \in [1.25, 5]$), while choices of 20 percent of the participants even imply near-perfect complementarity ($\eta > 20$).

[19]The two exception are a marginally significant difference for η at the 10 percent level between the Private-Incentivized and Public-Hypothetical treatments, as displayed in Figure A6 in the Appendix, and a significant difference between Private versus Hypothetical with a ranksum test (see Figure A7), which is insignificant when comparing means with a standard t-test (see Table A4).

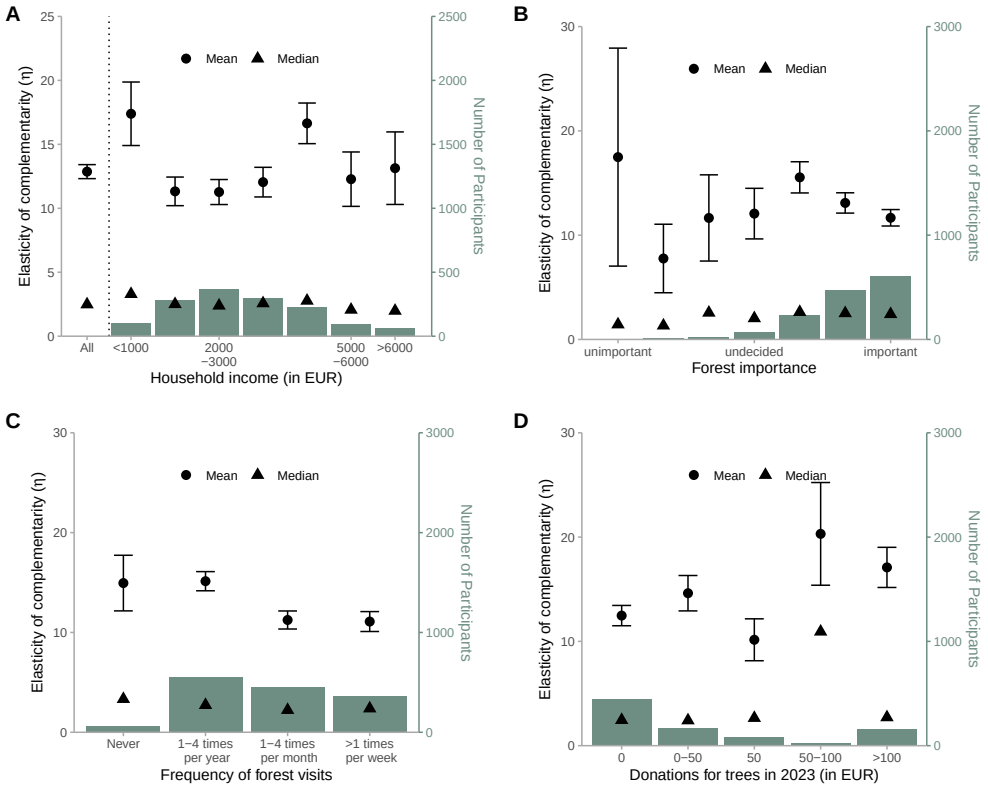
Figure 4: Distribution of estimated preference parameters.



Notes: This figure shows empirical cumulative distributions in Panels (A) and (C) and categorized histograms in Panels (B) and (D) of the individual-level estimates of α and η, where the elasticity of complementarity, η is the inverse of the common Hicksian constant elasticity of substitution (CES). In Panels (A) and (C), we also differentiate the empirical cumulative distributions by treatment group. As an alternative for the empirical cumulative distributions, we also provide histograms for α and η by treatment group in Figure A5 in the Appendix.

Overall, we find that less than a quarter of estimated elasticities of complementarity fall below unity, indicating a substitutive relationship between goods that has been indirectly estimated in the non-market valuation literature based on the income elasticity of WTP (c.f., Drupp 2018, Drupp et al. 2024a).

Figure 5: Elasticity of complementarity along income and environmental preferences.



Notes: This figure shows the mean and median elasticity of complementarity (η) for all participants (N=1,428) along income and environmental preferences. In particular, it shows the elasticity of complementarity for different household income groups (Panel A) and for different measures of environmental preferences, such as the perceived importance of forests (Panel B), the frequency participants visit forests (Panel C), and donations made for trees in the past year (Panel D). Error bars around the mean values represent one standard error.

Result 3: Preference heterogeneity for substitutability is substantial.

We observe that individuals' preferences range across the whole spectrum, from (near) perfect substitutability to Cobb-Douglas substitutability and (near) perfect complementarity. Panels A and B in Figure 4 visualize this variation in preferences. The extent of preference heterogeneity also becomes apparent by observing that the interquartile range of η_i estimates stretches from 1.19 to 12.23. Note, in this regard, that the mean estimate of 12.87 for the elasticity of complementarity lies above its 75^{th} percentile value.

Result 4: Substitutability preferences do not differ systematically across income levels or measures of environmental preferences.

Finally, we explore how substitutability preferences differ along income or the concern about the environmental public good that we assessed via three proxies in our experiment: survey measures on the perceived importance of forests and on the frequency of forest visits as well as self-reported donations made to plant trees in the past year.

In Panel *A* of Figure 5, we show the elasticity of complementarity, η, across different income levels. We find no systematic relationship between the elasticity of complementarity and income levels, which is confirmed by regression analyses reported in Table A5 in the Appendix. In contrast, Barbier et al. (2017) find that the income elasticity of WTP—which is observationally equivalent to the elasticity of complementarity, η, in our setting —increases with income levels in a multi-country contingent valuation study of eutrophication reduction in the Baltic Sea. Our result is instead in line with Drupp et al. (2024a), who do not find a systematic relationship between income levels and estimates of the income elasticity of WTP in a large-scale meta-analysis. Similarly, across our three measures (Panels *B* to *D*), we do not observe a systematic relationship between the elasticity of complementarity and our three proxies of environmental preferences. We confirm this observation by regression analyses in Table A5 in the Appendix.

4 Illustration of theoretical results

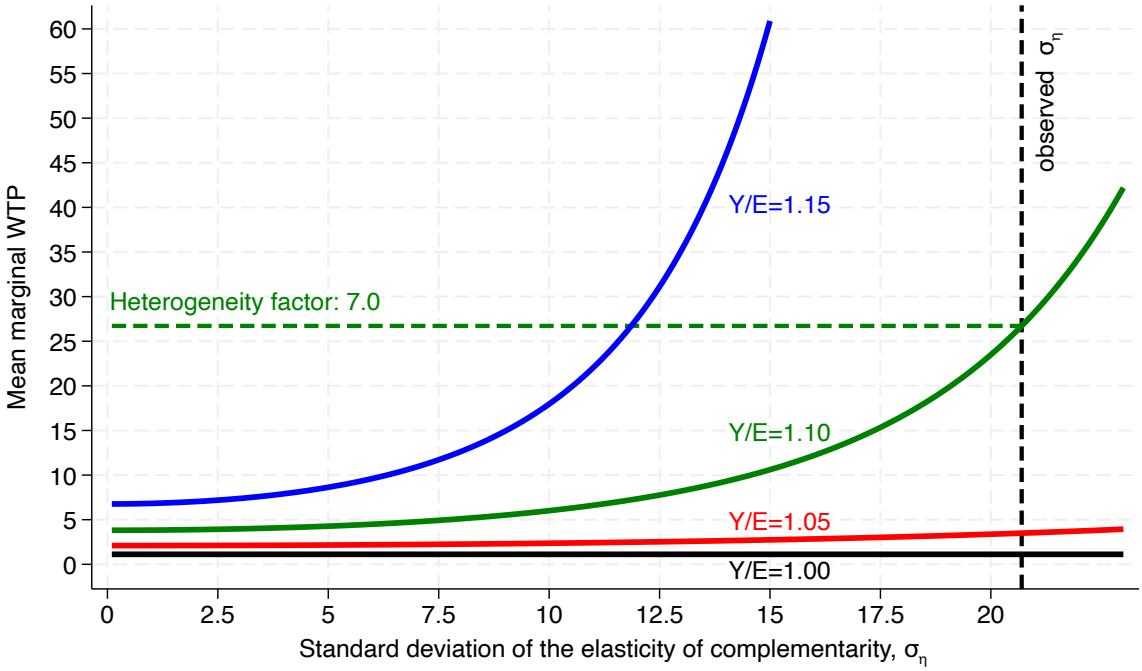
Finally, we bring our theoretical results and empirical estimates together to illustrate how accounting for heterogeneity in substitutability preferences may affect the economic value of environmental public goods. To this end, we solve Eq. (2) and (4) with our estimated parameters from the previous section. In particular, we use the utility weights for income from all participants, α_i, as well as individual estimates of the the elasticity of complementarity, η_i, the inverse of the elasticity of substitution between the environ-

mental public good and income. Besides the individual-level estimates, we also use the population mean, μ_η, and standard deviation, σ_η, of the elasticity of complementarity, η_i, where applicable. In addition, we also need to set the ratio between the environmental public good and income, Y/E, for which we—given the lack of solid guidance on magnitudes—consider small variations where $Y > E$ for illustrative purposes.[20]

In Figure 6 we illustrate how mean marginal WTP, $\overline{\omega}(\mu_\eta, \sigma_\eta)$, depends on the heterogeneity of substitutability preferences as measured by the standard deviation of the elasticity of complementarity (or income elasticity of WTP), η_i, assuming that the elasticity of complementarity follows a normal distribution. The Figure shows how the mean marginal WTP increases in the standard deviation of the elasticity of complementarity, σ_η for the mean elasticity of $\mu_\eta = 12.87$ that we observe in our experiment. The higher the ratio between income and environmental public goods is, the stronger is this relationship. In our empirical data, for example, we observe a standard deviation for the elasticity of substitution of $\sigma_\eta = 20.70$, which can imply substantial differences in the mean marginal WTP depending on the ratio between environmental public goods and income. For example, we would obtain a mean marginal WTP that is 7.0 times higher when considering preference heterogeneity than under the assumption of homogeneous preferences. This *heterogeneity factor* (see Eq. (9)) depends on the ratio between environmental public goods and market goods (or income) but will lead to much higher valuations of environmental public goods.

[20]Determining and quantifying the ratio between the environmental public good, E, and income, Y, is difficult. At the macro-scale, Elhacham et al. (2020) compare the weight of anthropogenic mass with the weight of the global living, natural biomass. They find that both were equal in 2020, suggesting $Y/E = 1$ (given $C = Y$). Moreover, they find that the anthropogenic mass has increased massively and doubles approximately every 20 years. Even if natural biomass stays constant, this suggests that the relative abundance of private goods was much lower in the recent past and will be much higher in the near future such that $Y/E > 1$ is likely. While this indicates how environmental goods tend to become more scarce relative to manufactured goods over time, the estimated anthropogenic mass does not translate into market traded goods (or income) very well, and an individual only holds a small fraction of global anthropogenic mass or income. Hence, given our ignorance about this ratio, we will illustrate how the heterogeneity in substitutability preferences affects WTP for various ratios between income and environmental public goods. This implies that the magnitudes we present here concerning WTP adjustments are solely illustrative and should not be mistaken as being quantitatively informative.

Figure 6: Illustration of the effect of preference heterogeneity on mean marginal WTP assuming normally distributed substitutability preferences.



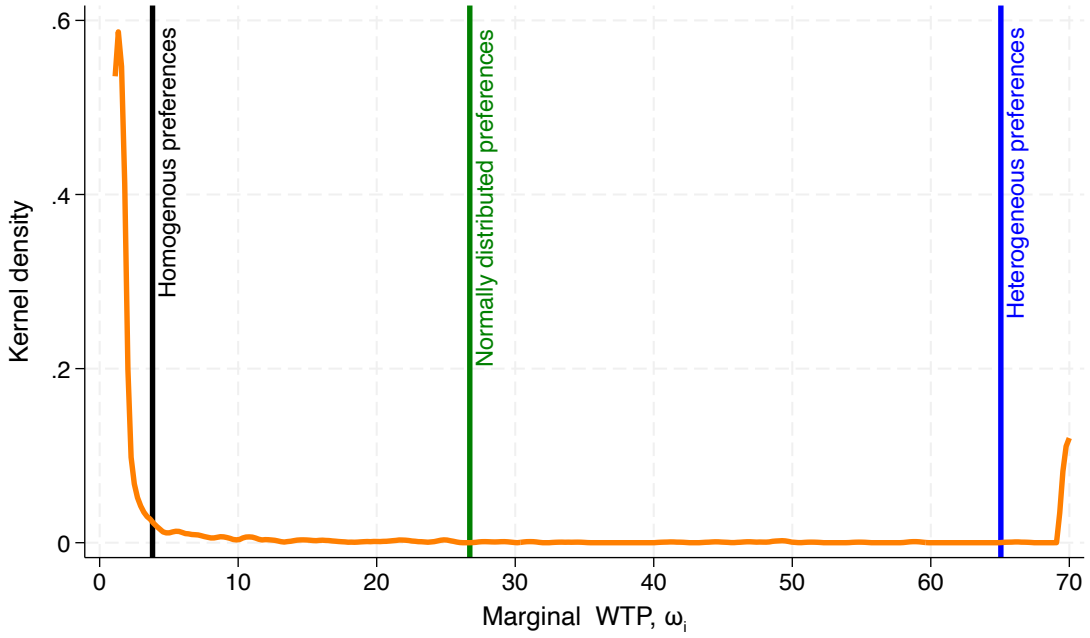
Notes: This figure shows mean marginal WTP, $\overline{\omega}(\mu_\eta, \sigma_\eta)$, (Eq. (4)) as a function of the standard deviation of the elasticity of complementarity, σ_η, for different ratios between income and the environmental public good under the assumption of normally distributed substitutability preferences. The dashed vertical black line depicts the standard deviation of the elasticity of complementarity for the upper 90th percentile winsorization. If the relation between income and the environmental public good were 1.1, this would lead to a mean marginal WTP that is 7.0 times higher with normally distributed substitutability preferences compared to the case of homogeneous preferences.

Similarly, we can quantify a *heterogeneity equivalent* estimate of the elasticity of complementarity, which allows representative agent models to account for heterogeneity in the underlying preferences data. This *heterogeneity equivalent* adds a factor that depends on preference heterogeneity, using $(\frac{\sigma_\eta^2}{2}\ln(Y/E))$, to the mean estimate of the elasticity of complementarity (see Eq. (10)). For our illustration with $Y/E = 1.1$, the *heterogeneity equivalent* elasticity, μ_η^*, would amount to 33.29 instead of the sample mean of 12.87, and thus be considerably more shifted towards complementarity. To reiterate, these examples rely on the assumption of normally distributed preferences and a ratio of market goods to the environmental public good of 1.1, solely for illustrative purposes.

Finally, we explore how mean marginal WTP unfolds with our actual empirical distribution. Unfortunately, we can only derive closed form heterogeneity factors assuming that the elasticity of complementarity is normally distributed. We can, however, reject that this is the case empirically (Shapiro-Wilk test; $z = 14.641; p < 0.001$). Therefore, we contrast the result illustrated above, which entails the assumption of normally distributed preferences, with the fully flexible empirical distribution. For this, we calculate the individual marginal WTP flexibly for each participant, using Eq. (2), again with a ratio of income to environmental public goods of 1.1. We then aggregate these marginal WTP estimates without assuming any specific distribution for the elasticity of complementarity to contrast this with our previous illustrations above that assume either homogeneous or normally distributed substitutability preferences. In Figure 7, we show the resulting distribution of the individual marginal WTPs as a kernel density plot. The distribution of marginal WTPs is highly skewed towards high WTP values, due to a high share of participants that prefer a complementary consumption of income and environmental public goods. The mean WTP for the distribution of individual WTPs is 17.5 times higher than in the homogeneous preference case and thus leads to a much higher upward adjustment as when assuming that preference heterogeneity regarding limited substitutability follows a normal distribution. Figure 7 illustrates how adjustments using normally distributed substitutability preferences already leads to a sizeable adjustment of mean WTP, which still falls considerably short of the mean WTP derived using our (winsorized) empirical distribution for the elasticity of complementarity.

While illustrative, our results underscore the importance of accounting for the heterogeneity in preferences concerning limited substitutability for environmental valuation and the application of preference parameters in environmental cost-benefit analysis and environmental-economic accounting.

Figure 7: Distribution of individual marginal WTPs.



Notes: This figure shows a kernel density plot of individual marginal WTPs, capped at a value of 70 for visual purposes, for $Y/E = 1.1$. The black line depicts the mean marginal WTP under homogeneous preferences, and the green line when assuming a normally distributed elasticity of complementarity (η). Finally, the blue line depicts the mean marginal WTP under our observed heterogeneous preferences and when we winsorize η at the upper 90th percentile.

5 Discussion

Both our theoretical and experimental approaches are subject to a number of underlying assumptions and limitations, a number of which we discuss in this section.

First, to focus our analysis on the effect of heterogeneous substitutability preferences, we considered a stylized model that is static, deterministic and solely features a homogeneous private market-traded consumption good, without income inequality, and an environmental public good, which all individuals are considered to consume to the same extent. A number of extensions of this or related valuation frameworks in other directions, but without consideration of preference heterogeneity, already exist. Baumgärtner et al. (2017a), for instance, study effects of income inequality in a static deterministic setting, extended by Smith (2023) to a more general approximation of

WTP, while Meya (2020) considers an unequal distribution of environmental quality. Meya et al. (2020) consider a deterministic dynamic context concerning the valuation of ecosystem services derived from natural capital, while Gollier (2019) studies the effects of uncertain substitutability preferences on natural capital valuation in a dynamic context. Relateldy, the literature on discounting has considered the aggregation of heterogeneous time preferences or recommendations on discount rates (e.g., Freeman and Groom 2015, Gollier and Zeckhauser 2005, Heal and Millner 2023, Millner 2020). It would be interesting to study heterogeneous preferences in a dynamic setting to examine effects on good-specific discount rates or relative price changes (e.g. Drupp et al. 2024b, Gollier 2010, 2019, Hoel and Sterner 2007, Traeger 2011, Weikard and Zhu 2005).

Second, our theoretical and empirical analyses consider a standard constant elasticity of substitution (CES) utility function and focus on the constant elasticity of complementarity (i.e. the inverse of the CES), which is equivalent in our setting to the income elasticity of WTP (Baumgärtner et al. 2017a, Ebert 2003). Preferences, however, need not be well-described by a CES utility function, and elasticities need not be constant (e.g., Barbier et al. 2017). While there is some theoretical research on non-constant elasticities of substitution (e.g., Baumgärtner et al. 2017b, Drupp 2018), examining how elasticities vary in the presence of basic needs thresholds, little is known empirically about how well the CES assumption approximates actual preferences. Future work should consider more general preference formulations and empirically examine how well CES—as compared to other utility specifications—can rationalize revealed preferences.

Third, while we found that the scarcity of E relative to Y (or C) is a decisive factor for the effect of how heterogeneous substitutability preferences affect the economic value of nature, we did not measure this ratio in our experimental setting. The comparison of the quantity of C to the quantity of E in the agents utility function relates to fundamental questions in applied microeconomic theory. We leave the development of appropriate empirical settings to determine this relation to future research.

Fourth, our main empirical analysis only includes individuals that make relatively consistent and rational choices, as measured by their violations of GARP. While we can vary the allowable threshold for GARP violations, the choices of a number of subjects are simply not well rationalizable. Our analysis, following the experimental literature on fairness preferences (e.g., Andreoni and Miller 2002, Fisman et al. 2007, 2015), thus excludes boundedly rational participants whose preferences violate utility maximization too strongly. Such participants may change their preferences during the experiment or may not experience any additional utility when going beyond a certain threshold of a given good. While such choices could still be relevant and informative for decision-makers, it becomes more questionable whether such preference can be accommodated in a CES utility function framework or related preference structures.[21] Again, we leave an examination of more complex decision-rules and preference structures to future work.

Finally, we restrict our experiment to a single environmental good: forest ecosystem services. We chose donations to plant forest trees, as this represents a relatively common 'good' for participants. Yet, the elasticity of complementarity may be very different for other environmental public goods. Akin to explorations for how the income elasticity of WTP derived in meta-analyses differs across ecosystem service types (e.g., Drupp et al. 2024a), we seek to examine how elasticities may differ across (proxies for) various environmental public goods in future work. The same holds for potential variation across countries, incentive levels and donation mechanisms.[22]

[21] In fact, we observe in Figure A8 in the Appendix that participants with a low CCEI score tend to have a higher elasticity of complementarity (η), which could either suggest that boundedly rational participants may tend to perceive both goods more often as complements, or—plausibly—that increased noise in choices drives up the estimated elasticities.

[22] One of our key findings is that substitutability preferences are more tilted towards complementarity (Result 2) than previously suggested by indirect empirical evidence derived from income elasticites of WTP below unity (e.g., Jacobsen and Hanley 2009, Drupp et al. 2024a). An exception so far in this literature is a recent study by Heckenhahn and Drupp (2024), who find income elasticities of WTP of around 3 in a meta-analysis of German WTP studies, which is close to our median estimate of the elasticity of complementarity of 2.5. Conducting our experiment to elicit substitutability preferences in other countries is therefore an important next step, not least to exclude the possibility that sizable preferences for complementarity are not just a peculiarity of the German population.

6 Conclusion

In this paper we study the heterogeneity of substitutability preferences between environmental public goods and private consumption goods both theoretically and empirically.

Drawing on a stylized model, we first show that more heterogeneity in substitutability preferences increases mean marginal WTP for environmental public goods. Moreover, whether a higher mean level of the elasticity of complementarity increases (decreases) the mean marginal WTP depends on whether environmental goods are relatively more (less) scarce than human-made consumption goods.

We then present an experimental framework to elicit individual preferences for the elasticity of complementarity (or substitution) for the first time directly. We apply it to elicit general population preferences of around 1,500 Germans in an online experiment concerning the trade-off between private market goods and public forest ecosystem services. We document substantial preference heterogeneity and find that a majority of individual preferences implies a complementary relationship, with a median estimate of the elasticity of complementarity of 2.5. This is considerably higher than most prior estimates derived indirectly from the income elasticity of WTP from non-market valuation studies, which tended to lie in the substitutes domain with values between zero and unity (e.g., Drupp 2018, Drupp et al. 2024a), and close to a prominent assumption in the integrated assessment literature studying the implication of limited substitutability on optimal climate policy (cf. Sterner and Persson 2008).

Finally, we bring together our theory and empirical estimates and illustrate how accounting for heterogeneity in substitutability preferences increases mean marginal WTP for environmental public goods in society as compared to the standard case of equal preferences. As the effect of preference heterogeneity on mean WTP is moderated by the relative abundance of private market consumption goods relative to environmental public goods, which is difficult to measure, the potentially substantial magnitude we highlight remains illustrative.

Notwithstanding the caveats that we have outlined above, our results highlight that accounting for the heterogeneity of substitutability preferences may considerably affect the societal value attached to environmental public goods. Furthermore, our experiment yields the first direct estimates of the elasticity of substitution—or its inverse, the elasticity of complementarity—and suggests that preferences may be more tilted towards complementarity than previously thought. As such, our results have both conceptual and quantitative implications for non-market valuation, cost-benefit analysis, and the comprehensive accounting of of public natural capital.

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A Appendix

A.1 Derivation of mean marginal WTP

The density function for normally distributed η, with mean μ_η and standard deviation σ_η, is

$$f_{\text{norm}}(\eta; \mu_\eta, \sigma_\eta) = \frac{1}{\sqrt{2\pi\sigma_\eta^2}} \exp\left(-\frac{(\eta-\mu_\eta)^2}{2\sigma_\eta^2}\right). \tag{A.14}$$

Mean marginal WTP is then given as the expected value

$$\begin{aligned}
\overline{\omega}(\mu_\eta, \sigma_\eta) &= \mathbb{E}\left[\omega(Y,E;\eta)\right] \\
&= \int_{-\infty}^{+\infty} f_{\text{norm}}(\eta; \mu_\eta, \sigma_\eta)\, \omega(Y,E;\eta)\, d\eta \\
&\overset{(2),(A.14)}{=} \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi\sigma_\eta^2}} \exp\left(-\frac{(\eta-\mu_\eta)^2}{2\sigma_\eta^2}\right) \frac{1-\alpha}{\alpha} (Y/E)^\eta \, d\eta \\
&= \frac{1-\alpha}{\alpha} \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi\sigma_\eta^2}} \exp\left(-\frac{(\eta-\mu_\eta)^2}{2\sigma_\eta^2}\right) \exp\left(\ln\left((Y/E)^\eta\right)\right) d\eta \\
&= \frac{1-\alpha}{\alpha} \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi\sigma_\eta^2}} \exp\left(-\frac{(\eta-\mu_\eta)^2}{2\sigma_\eta^2} + \eta \ln(Y/E)\right) d\eta \\
&= \frac{1-\alpha}{\alpha} \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi\sigma_\eta^2}} \exp\left(\frac{-(\eta-\mu_\eta)^2 + 2\sigma_\eta^2 \eta \ln(Y/E)}{2\sigma_\eta^2}\right) d\eta \\
&= \frac{1-\alpha}{\alpha} \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi\sigma_\eta^2}} \exp\left(\frac{-\left[\eta-(\mu_\eta+\sigma_\eta^2\ln(Y/E))\right]^2}{2\sigma^2} + \ln(Y)\left[\mu_\eta + \frac{\sigma_\eta^2}{2}\ln(Y/E)\right]\right) d\eta \\
&= \frac{1-\alpha}{\alpha} \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi\sigma_\eta^2}} \exp\left(\frac{-\left[\eta-(\mu_\eta+\sigma_\eta^2\ln(Y/E))\right]^2}{2\sigma^2}\right) \exp\left(\ln(Y/E)\left[\mu_\eta + \frac{\sigma_\eta^2}{2}\ln(Y/E)\right]\right) d\eta \\
&= \frac{1-\alpha}{\alpha} \exp\left(\ln(Y/E)\left[\mu_\eta + \frac{\sigma_\eta^2}{2}\ln(Y/E)\right]\right) \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi\sigma_\eta^2}} \exp\left(\frac{-\left[\eta-(\mu_\eta+\sigma_\eta^2\ln(Y/E))\right]^2}{2\sigma^2}\right) d\eta \\
&\overset{\mu'_\eta := \mu_\eta + \sigma_\eta^2 \ln(Y/E)}{=} \frac{1-\alpha}{\alpha} \exp\left(\ln\left((Y/E)^{\mu_\eta + \frac{\sigma_\eta^2}{2}\ln(Y/E)}\right)\right) \underbrace{\int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\pi\sigma_\eta^2}} \exp\left(\frac{-\left[\eta-\mu'_\eta\right]^2}{2\sigma^2}\right) d\eta}_{=1} \\
&= \frac{1-\alpha}{\alpha} \exp\left(\ln\left((Y/E)^{\mu_\eta + \frac{\sigma_\eta^2}{2}\ln(Y/E)}\right)\right) \\
&= \frac{1-\alpha}{\alpha} (Y/E)^{\mu_\eta + \frac{\sigma_\eta^2}{2}\ln(Y/E)}.
\end{aligned} \tag{A.15}$$

A.2 Proof of Proposition 2

1. Differentiating mean marginal WTP (Eq. (4)) with respect to μ_η yields

$$\frac{\partial \overline{\omega}}{\partial \mu_\eta} = \ln(Y/E)\frac{1-\alpha}{\alpha}\,(Y/E)^{\mu_\eta + \frac{\sigma_\eta^2}{2}\ln(Y/E)} \overset{(4)}{=} \ln(Y)\,\overline{\omega}, \tag{A.16}$$

for which the sign is fully determined by $\ln(Y/E)$, since $\alpha \in (0,1)$ and $Y, E > 0$. It thus holds:

$$\frac{\partial \overline{\omega}}{\partial \mu_\eta} \gtreqless 0 \iff \ln(Y/E) \gtreqless 0 \iff Y/E \gtreqless 1 \iff Y \gtreqless E. \tag{A.17}$$

2. Rearranging Eq. (4) to $\overline{\omega} = \frac{1-\alpha}{\alpha}(Y/E)^{\mu_\eta}\,\exp\left[\frac{\sigma_\eta}{2}\ln(Y/E)^2\right]$ and taking the derivative with respect to σ_η gives

$$\frac{\partial \overline{\omega}}{\partial \sigma_\eta} = \frac{1-\alpha}{\alpha}(Y/E)^{\mu_\eta}\,\exp\left[\frac{\sigma_\eta}{2}\ln(Y/E)^2\right]\,\frac{\ln(Y/E)^2}{2} \overset{(4)}{=} \frac{\ln(Y/E)^2}{2}\,\overline{\omega}, \tag{A.18}$$

which is non-negative as $Y, E, \overline{\omega} > 0$. $\frac{\partial \overline{\omega}}{\partial \sigma_\eta}$ is zero for the special case of $Y = E$, and strictly positive otherwise.

3. Differentiating Eq. (A.18) with respect to μ_η gives

$$\frac{\partial^2 \overline{\omega}}{\partial \sigma_\eta \partial \mu_\eta} = \frac{\ln(Y/E)^2}{2}\,\frac{\partial \overline{\omega}}{\partial \mu_\eta} \overset{(A.18)}{=} \frac{\ln(Y/E)^3}{2}\,\overline{\omega}, \tag{A.19}$$

for which the sign is determined by $\ln(Y/E)$ since $\overline{\omega} > 0$. It holds:

$$\frac{\partial^2 \overline{\omega}}{\partial \sigma_\eta \partial \mu_\eta} \gtreqless 0 \iff Y \gtreqless E.$$

4. Differentiating Eq. (A.18) with respect to Y gives

$$\frac{\partial^2 \overline{\omega}}{\partial \sigma_\eta \partial Y} = \ln(Y/E)\,\frac{E}{Y}\,\overline{\omega} + \frac{\ln(Y/E)^2}{2}\frac{\partial \overline{\omega}}{\partial Y}, \tag{A.20}$$

where $\frac{\partial \overline{\omega}}{\partial Y} = \overline{\omega}\,\frac{E}{Y}\left(\mu_\eta + \ln(Y/E)\sigma_\eta^2\right)$ and hence

$$\begin{aligned}\frac{\partial^2 \overline{\omega}}{\partial \sigma_\eta \partial Y} &= \overline{\omega}\,\frac{E}{Y}\,\ln(Y/E)\left[1 + \frac{\ln(Y/E)\mu_\eta + \ln(Y/E)^2\sigma_\eta^2}{2}\right] \\ &= \ln(Y/E)\left[\overline{\omega}\,\frac{E}{Y} + \frac{\ln(Y/E)}{2}\left(\overline{\omega}\,\frac{E}{Y}\left(\mu_\eta + \ln(Y/E)\sigma_\eta^2\right)\right)\right] \\ &= \ln(Y/E)\left[\overline{\omega}\,\frac{E}{Y} + \frac{\partial \overline{\omega}}{\partial Y}\,\frac{\ln(Y/E)}{2}\right]. \end{aligned} \tag{A.21}$$

Thus,

$$\frac{\partial^2 \overline{\omega}}{\partial \sigma_\eta \partial Y} \gtreqless 0 \iff \ln(Y/E)\left[\overline{\omega}\,\frac{E}{Y} + \frac{\partial \overline{\omega}}{\partial Y}\,\frac{\ln(Y/E)}{2}\right] \gtreqless 0. \tag{A.22}$$

To analyse what determines the sign of $\frac{\partial^2 \overline{\omega}}{\partial \sigma_\eta \partial Y}$ we have to distinguish two cases.

Case 1: For $Y > E$ Eq. (A.22) simplifies to

$$\overline{\omega}\,\frac{E}{Y} + \frac{\partial \overline{\omega}}{\partial Y}\,\frac{\ln(Y/E)}{2} \gtreqless 0 \iff \frac{\partial \overline{\omega}}{\partial Y}\frac{Y}{\overline{\omega}} \gtreqless \underbrace{-\frac{2\,E}{\ln(Y/E)}}_{<0,\,\text{for } Y>E}, \tag{A.23}$$

where $\eta_{\overline{\omega},Y} := \frac{\partial \overline{\omega}}{\partial Y}\frac{Y}{\overline{\omega}}$ is the income elasticity of mean marginal WTP or the elasticity of complementarity. Since Y is a normal good by assumption and thus $\eta_{\overline{\omega},Y} > 0$, it holds that $\frac{\partial^2 \overline{\omega}}{\partial \sigma_\eta \partial Y} > 0$ if $Y > E$.

Case 2: For $Y < E$ Eq. (A.22) simplifies to

$$\overline{\omega}\,\frac{E}{Y} + \frac{\partial \overline{\omega}}{\partial Y}\,\frac{\ln(Y/E)}{2} \lesseqgtr 0 \iff \frac{\partial \overline{\omega}}{\partial Y}\frac{Y}{\overline{\omega}} \lesseqgtr \underbrace{-\frac{2\,E}{\ln(Y/E)}}_{>0,\,\text{for } Y<E}, \tag{A.24}$$

and consequently $\frac{\partial^2 \overline{\omega}}{\partial \sigma_\eta \partial Y} > 0$ if $\eta_{\overline{\omega},Y} < 0$ and $Y < E$.

Considering both cases together establishes the Proposition. Note that the elasticity of complementarity (or income elasticity of mean marginal WTP), $\eta_{\overline{\omega},Y}$, is generally not

equal to the mean of the individual elasticities, μ_η, since (written for N individuals):

$$\mu_\eta := \frac{1}{N}\sum_{i=1}^{N}\eta_i = \frac{1}{N}\sum_{i=1}^{N}\frac{\partial\omega_i}{\partial Y}\frac{Y}{\omega_i} \neq \frac{\partial\left[\frac{1}{N}\sum_{i=1}^{N}\omega_i\right]}{\partial Y}\frac{Y}{\frac{1}{N}\sum_{i=1}^{N}\omega_i} = \frac{\partial\overline{\omega}}{\partial Y}\frac{Y}{\overline{\omega}} =: \eta_{\overline{\omega},Y}. \quad \text{(A.25)}$$

A.3 Proof of Proposition 3

The elasticity of $\overline{\omega}$ with respect to μ_η and the elasticity of $\overline{\omega}$ with respect to σ_η are

$$\left|\psi_{\overline{\omega},\mu_\eta}\right| := \left|\frac{\partial\overline{\omega}}{\partial\mu_\eta}\frac{\mu_\eta}{\overline{\omega}}\right| \overset{\text{(A.16)}}{=} \left|\ln(Y/E)\mu_\eta\right| = \left|\ln(Y/E)\right|\left|\mu_\eta\right|, \quad \text{(A.26)}$$

$$\left|\psi_{\overline{\omega},\sigma_\eta}\right| := \left|\frac{\partial\overline{\omega}}{\partial\sigma_\eta}\frac{\sigma_\eta}{\overline{\omega}}\right| \overset{\text{(A.18)}}{=} \left|\frac{\ln(Y/E)^2}{2}\sigma_\eta\right| \overset{\sigma_\eta\geq 0}{=} \frac{\ln(Y/E)^2}{2}\sigma_\eta. \quad \text{(A.27)}$$

It thus directly follows that

$$\begin{aligned}
\left|\psi_{\overline{\omega},\sigma_\eta}\right| \gtreqless \left|\psi_{\overline{\omega},\mu_\eta}\right| \quad &\overset{\text{(A.26)(A.27)}}{\Longleftrightarrow} \quad \frac{\ln(Y/E)^2}{2}\sigma_\eta \gtreqless \left|\ln(Y/E)\right|\left|\mu_\eta\right| \\
&\overset{Y\neq E}{\Longleftrightarrow} \quad \sigma_\eta \gtreqless 2\,\frac{\left|\ln(Y/E)\right|}{\ln(Y/E)^2}\left|\mu_\eta\right| \\
&\Longleftrightarrow \quad \sigma_\eta \gtreqless 2\left|\frac{\ln(Y/E)}{\ln(Y/E)^2}\right|\left|\mu_\eta\right| \\
&\Longleftrightarrow \quad \sigma_\eta \gtreqless \frac{2}{\left|\ln(Y/E)\right|}\left|\mu_\eta\right|. \quad \text{(A.28)}
\end{aligned}$$

A.4 Additional Tables and Figures

Table A1: Descriptive statistics.

	Full sample				Final sample			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Age	50.91	15.44	18	88	51.03	15.25	18	86
Gender								
Male	0.50	0.50	0	1	0.53	0.50	0	1
Female	0.49	0.50	0	1	0.46	0.50	0	1
Non-binary	0.00	0.00	0	0	0.00	0.00	0	0
Marital status								
Married / cohabiting	0.60	0.49	0	1	0.60	0.49	0	1
Single	0.26	0.44	0	1	0.27	0.44	0	1
Separated / divorced / widowed	0.14	0.35	0	1	0.13	0.34	0	1
University degree	0.30	0.46	0	1	0.32	0.47	0	1
Monthly household income								
$\leq$ 500 Euro	0.02	0.13	0	1	0.01	0.12	0	1
500 – 999 Euro	0.05	0.22	0	1	0.05	0.23	0	1
1000 – 1499 Euro	0.10	0.30	0	1	0.09	0.29	0	1
1500 – 1999 Euro	0.11	0.31	0	1	0.11	0.31	0	1
2000 – 2499 Euro	0.13	0.33	0	1	0.13	0.34	0	1
2500 – 2999 Euro	0.12	0.33	0	1	0.12	0.33	0	1
3000 – 3499 Euro	0.10	0.30	0	1	0.11	0.31	0	1
3500 – 3999 Euro	0.10	0.30	0	1	0.10	0.30	0	1
4000 – 4499 Euro	0.09	0.29	0	1	0.08	0.28	0	1
4500 – 4999 Euro	0.07	0.26	0	1	0.08	0.27	0	1
5000 – 6000 Euro	0.06	0.24	0	1	0.07	0.25	0	1
$\geq$ 6000 Euro	0.04	0.20	0	1	0.04	0.20	0	1
Observations	2,181				1,428			

Notes: This table shows descriptive statistics for the full and final sample. The full sample includes all participants that took part in our experiment. The final sample consists of participants that passed several quality checks and made choices that allow us to recover their preference parameters.

Table A2: Balance test of the treatment groups.

	Private Incentivized	Private Hypothetical	Public Incentivized	Public Hypothetical
Age	52.79	50.31 **	49.45 ***	51.12
Gender				
Male	0.51	0.52	0.46	0.49
Female	0.48	0.46	0.52	0.49
Non-binary	0.00	0.00	0.00	0.00
Marital status				
Married / cohabiting	0.59	0.58	0.61	0.63
Single	0.24	0.27	0.27	0.25
Separated / divorced / widowed	0.18	0.15	0.12 *	0.13 *
University degree	0.31	0.31	0.30	0.30
Monthly household income				
$\leq$ 500 Euro	0.01	0.02	0.02	0.02
500 – 999 Euro	0.06	0.05	0.06	0.05
1000 – 1499 Euro	0.12	0.09	0.07 *	0.10
1500 – 1999 Euro	0.11	0.11	0.12	0.11
2000 – 2499 Euro	0.12	0.15	0.13	0.12
2500 – 2999 Euro	0.13	0.12	0.14	0.11
3000 – 3499 Euro	0.10	0.11	0.09	0.11
3500 – 3999 Euro	0.11	0.09	0.13	0.09
4000 – 4499 Euro	0.07	0.11	0.09	0.09
4500 – 4999 Euro	0.09	0.06	0.06	0.08
5000 – 6000 Euro	0.05	0.06	0.06	0.06
$\geq$ 6000 Euro	0.04	0.04	0.04	0.05
Observations	518	596	509	558

Notes: This table compares participant's characteristics of the final sample between treatment groups. The final sample includes participants that passed several quality checks and for which we can recover their preference parameters. The table shows mean values for each treatment group. Stars in Columns (2) to (4) indicate significance differences in the mean values between the respective treatment group and the private incentivized treatment group in Column (1). We use t-tests to compare mean values. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A3: Treatment effects on η and α.

	η	α
Private Hypothetical	0.000	0.000
	(.)	(.)
Private Incentivized	0.421	-0.039
	(1.539)	(0.025)
Public Hypothetical	1.950	-0.165***
	(1.513)	(0.025)
Public Incentivized	-0.007	-0.184***
	(1.557)	(0.026)
N	1,428	1,428
R^2	0.00	0.05
Fisher's p-value	0.222	0.000

Notes: This table shows OLS regression results for the treatment effects on η and α. The private hypothetical treatment serves as the baseline. While the OLS regressions test for differences in the mean values, we also run Fisher's exact test of the equality of the medians across treatments and report their corresponding p-values. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A4: Treatment effects of private settings for η and α.

	η	α
Public setting	0.000	0.000
	(.)	(.)
Private setting	-0.824	0.156***
	(1.096)	(0.018)
N	1,428	1,428
R^2	0.00	0.05
Fisher's p-value	0.751	0.000

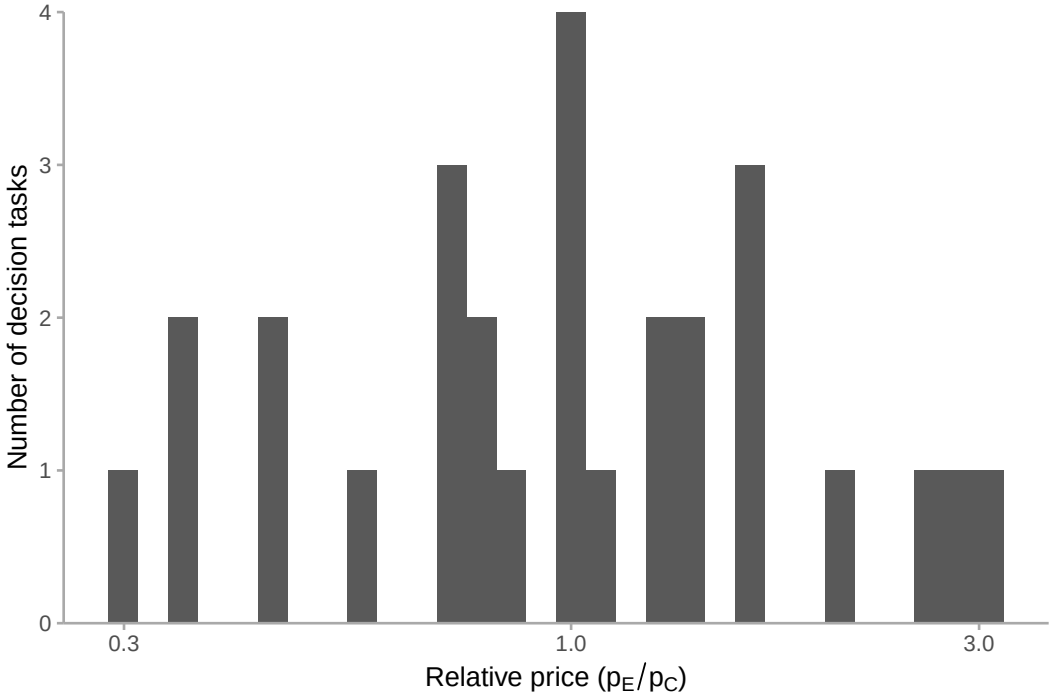
Notes: This table shows OLS regression results comparing the private treatments with the public treatments on η and α. The public treatments serve as the baseline. While the OLS regressions test for differences in the mean values, we also run Fisher's exact test of the equality of the medians across treatments and report their corresponding p-values. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A5: Regression results of η for income and environmental preferences.

	Dependent variable: η				
	(1)	(2)	(3)	(4)	(5)
Constant	14.796***	12.025***	16.672***	13.421***	12.697***
	(3.316)	(1.218)	(3.081)	(0.659)	(0.550)
Household Income	0.227	0.249			
(in 1000 EUR)	(0.355)	(0.352)			
Forest Importance	−0.367		−0.640		
	(0.521)		(0.501)		
Forest Visits Frequency	−0.015			−0.017*	
(in visits/year)	(0.010)			(0.010)	
Tree Donations 2023	1.204				1.324*
(in 1000 EUR)	(0.775)				(0.767)
Observations	1,422	1,422	1,422	1,422	1,422
R^2	0.005	0.0004	0.001	0.002	0.002

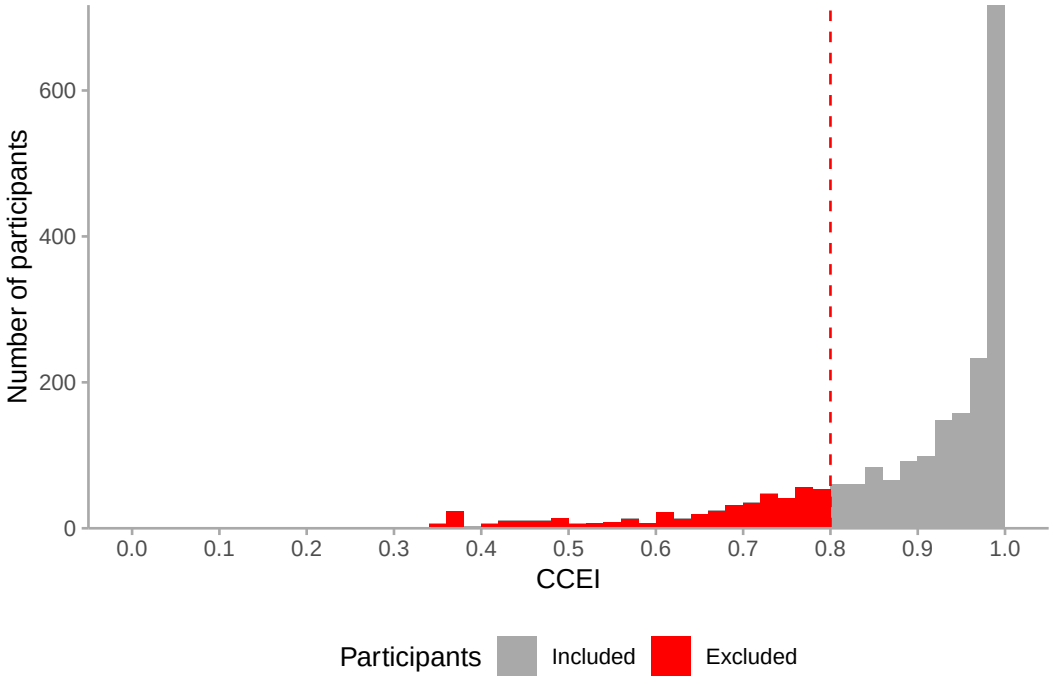
Notes: This Table shows results from OLS regressions. The independent variable *Household Income* is defined as midpoints of the income categories (e.g. 750 EUR for the category 500-999 EUR) and 7000 EUR for the highest category (>6000 EUR/month). *Forest Importance* is measured on a 7-point Likert scale and treated as quasi-continuous. *Forest Visit Frequency Importance* is re-scaled to visits per year and assuming 4 visits per week for the highest category (>3 visits per week). For *Tree Donations 2023* we assume that an omitted answer corresponds to 0 EUR. Standard errors are shown in parentheses. While coefficients for two environmental preference proxies are marginally significant in univariate regressions, they show opposite signs and disappear in a multivariate regression. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Figure A1: Distribution of the price ratio in our experiment.



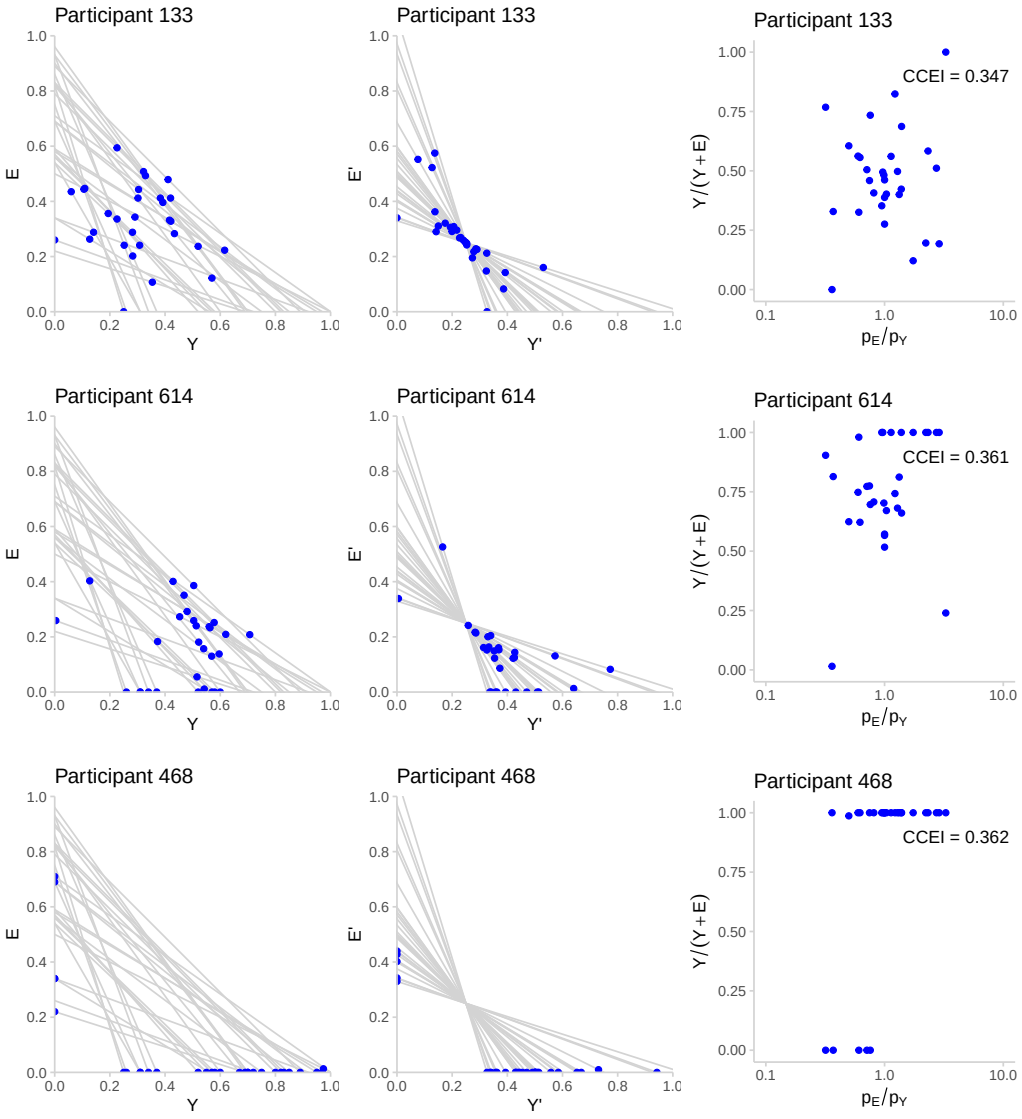
Notes: This figure shows the distributions of the relative prices between the consumption good and public environmental good that participants saw in our experiment. Prior to the experiment, we randomly generated 30 budget lines in a way that one axis intercept is between 0.1 and 1 and the other between 0.5 and 1. As a result, we obtain normally distributed price ratios when using a logarithmic scale.

Figure A2: Distribution of the CCEI scores.



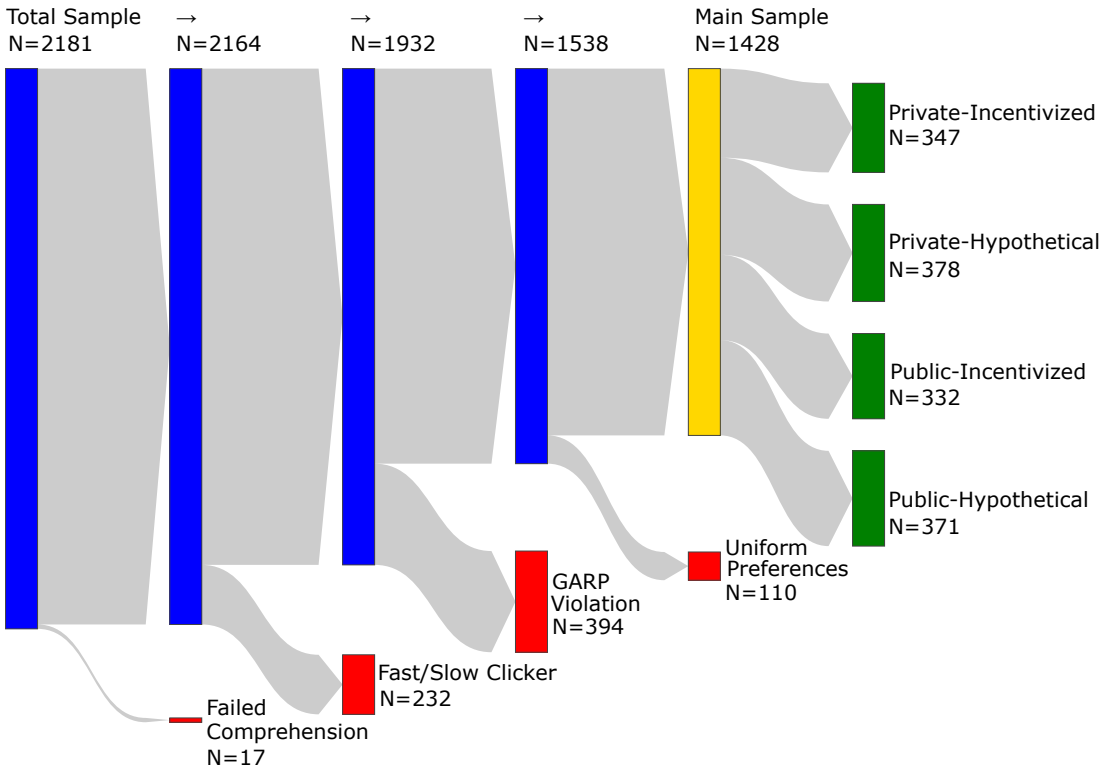
Notes: This figure shows the distributions of the critical cost efficiency index (CCEI) suggested by Afriat (1972). The score informs about the severity of GARP violations as a measure for the rationality of choices. Following Fisman et al. (2007), we exclude participants which a CCEI of less than 0.8 due to concerns about their rationality.

Figure A3: Examples of choices with severe GARP violations (irrational participants).



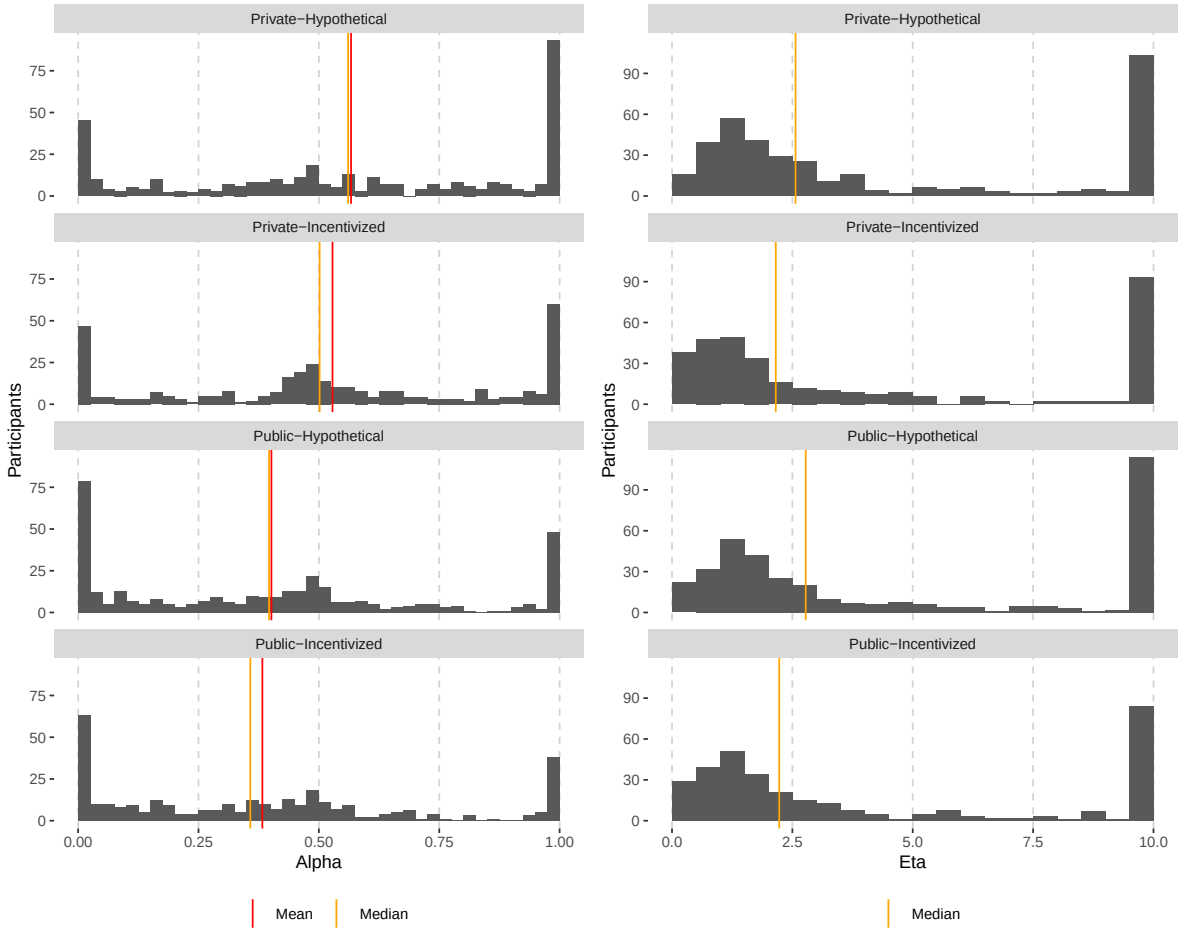
Notes: This figure shows the choices of selected participants with inconsistent and irrational choices that we identified through their severe GARP violations. Participant 133, for example, made choices that seem to be random with no particular pattern. Participant 614 made several choices where only income was preferred, but also made intermediary choices in tasks with similar price ratios. That participant may have switched strategies during the experiment which causes these inconsistencies and render the whole set of choices irrational. In a similar vein, participant 468 chose the full amount of income in most tasks, but also chose the full amount of forest trees in some tasks with almost the same price ratios. Again, this can be due to different strategies applied during the same experiment which leaves some choices inconsistent to other choices.

Figure A4: Main sample composition.



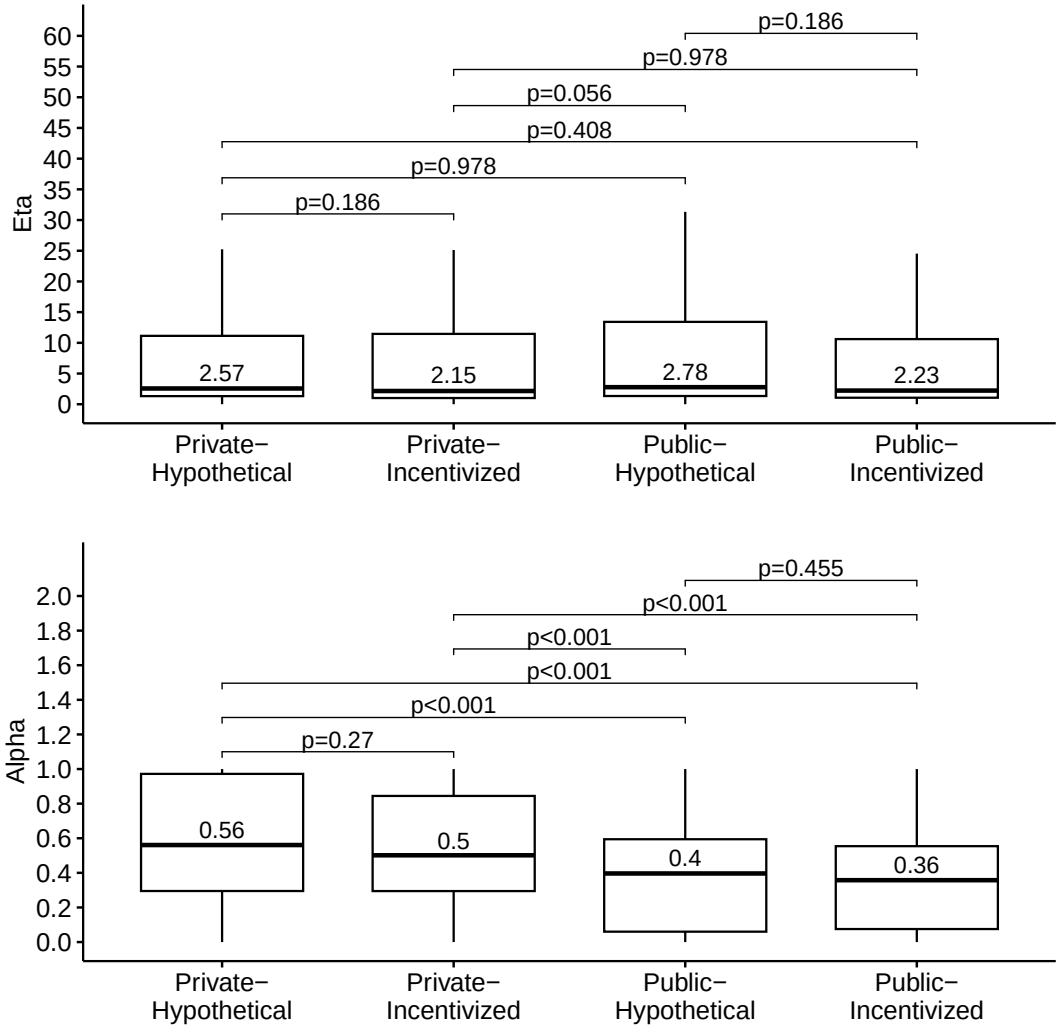
Notes: Failed Comprehension indicates that a participant failed a comprehension check at least 10 times. *Fast/Slow* clicker includes participants that finsihed the experiment in less than 5 minutes or more than 60 minutes. *Uniform Preferences* denotes participants that are insensitive to relative price changes, meaning that on average they allocated more than 98% of their budget to either income or trees. *GARP Violation* includes all participants below the CCEI threshhold of 0.8.

Figure A5: Distribution of the estimated α and η parameters by treatment group.



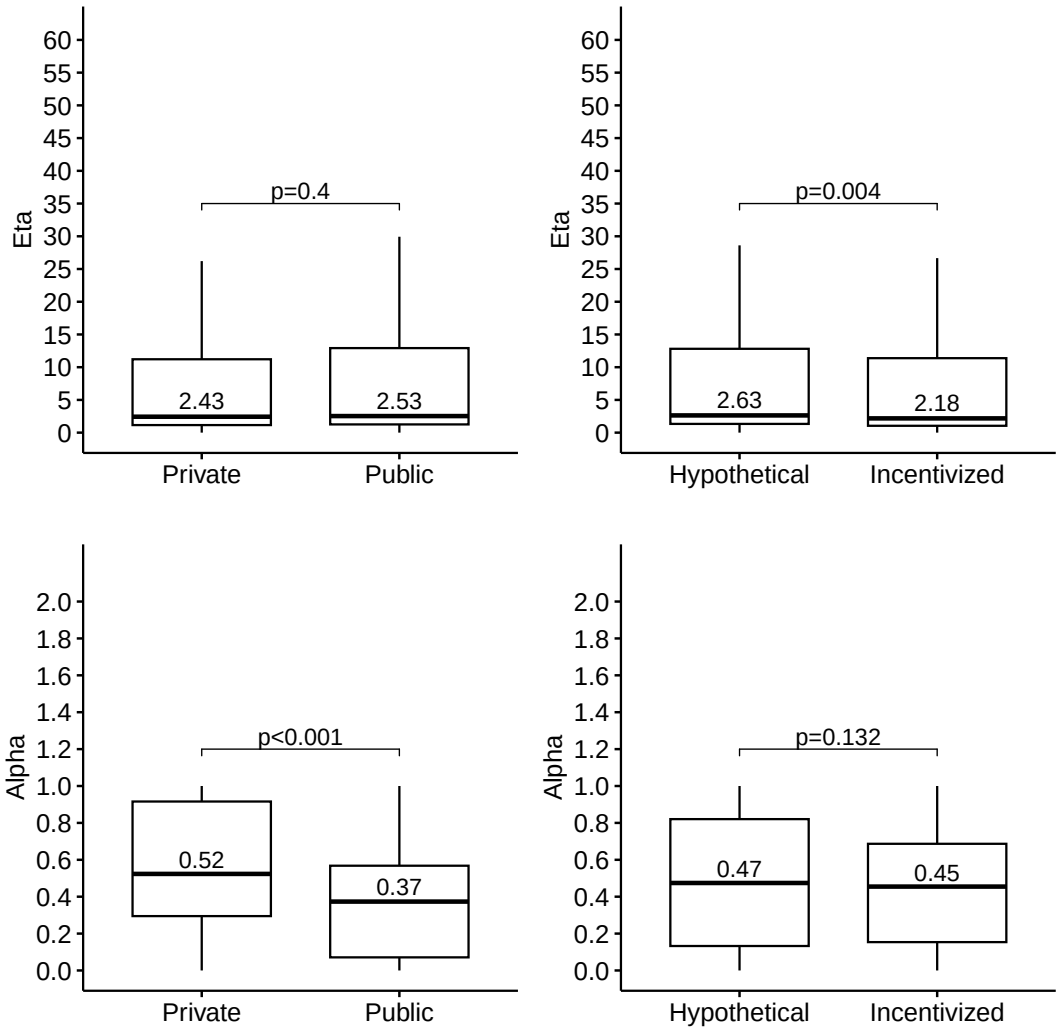
Notes: This figure shows two distributions of the individual-level estimates of α and η by treatment group. The left panel shows the distribution for α and indicates the respective mean and median values in red and orange. The right panel shows the distribution for η. To improve the readability of the plot, we have capped the elasticity of complementarity, η, at a value of 10 in this Figure and only show the respective median values for η in orange.

Figure A6: Boxplots & treatment differences: All treatment combinations.



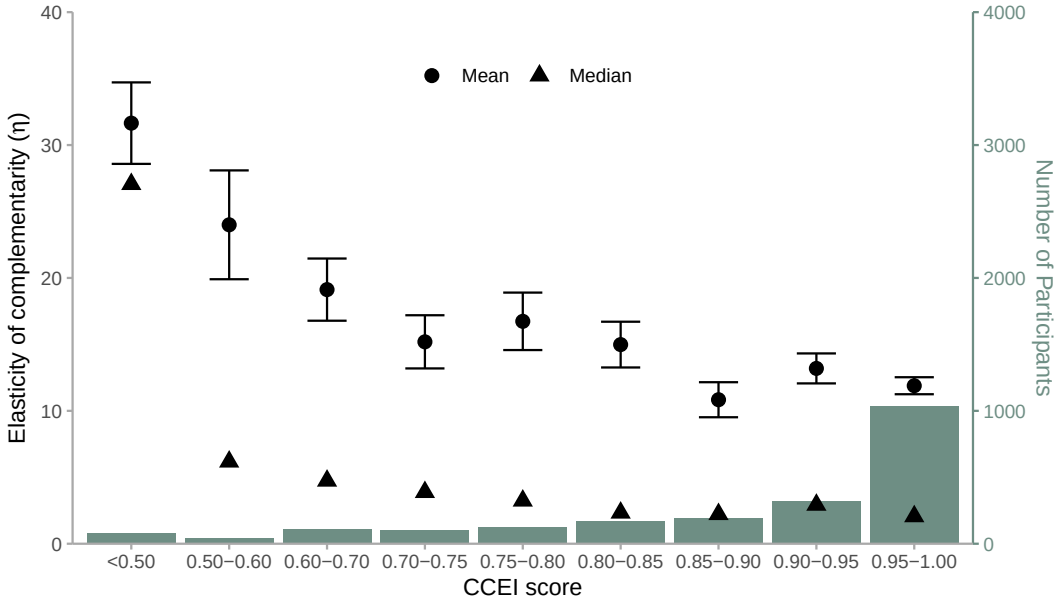
Notes: Standard boxplots for η (top) and α (bottom) by treatment, using the main sample data (N=1,428; upper 90% winsorization for η). The numeric value inside each boxplot denotes the respective median. Brackets in the top figure indicate pairwise Wilcoxon rank-sum tests for median equality of the two treatment combinations below the two tips. Brackets in the bottom figure indicate pairwise t-tests for mean equality of the two treatment combinations below the two tips. The p-value above a bracket denotes the p-value for the corresponding pairwise test, adjusted by the Holm-Bonferroni method.

Figure A7: Boxplots & treatment differences: Overall treatment categories



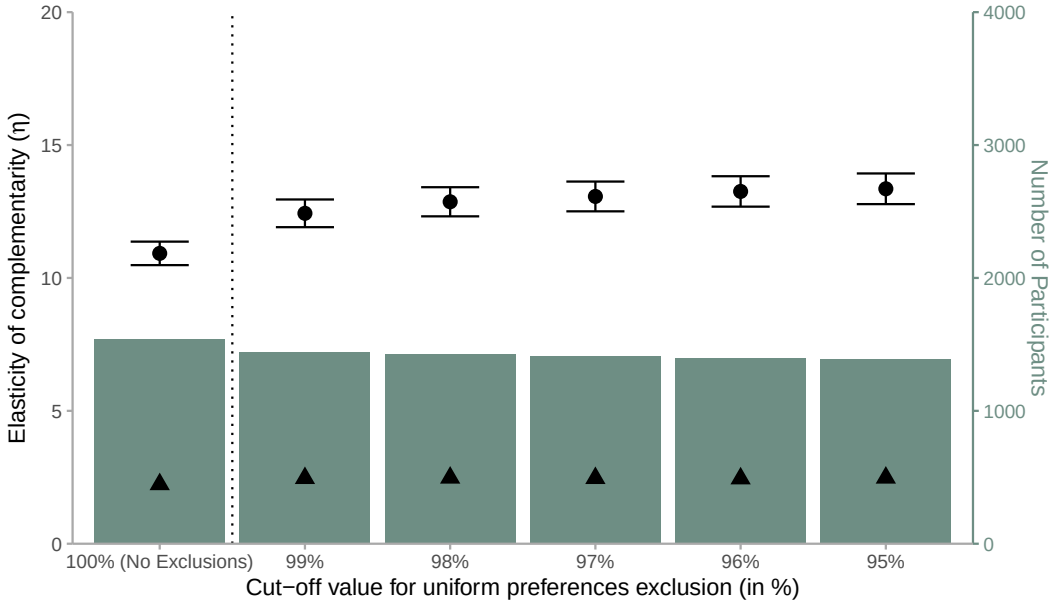
Notes: Standard boxplots for η (top) and α (bottom) by treatment categories, using the main sample data (N=1,428; upper 90% winsorization for η). The numeric value inside each boxplot denotes the respective median. Brackets in the top figures indicate Wilcoxon rank-sum tests for median equality of the two treatment categories below the two tips. Brackets in the bottom figures indicate t-tests for mean equality of the two treatment categories below the two tips. The p-value above a bracket denotes the p-value for the corresponding test.

Figure A8: Elasticity of complementarity by CCEI bins



Notes: This figure shows the mean and median elasticitiy of complementarity (η) for participants along their CCEI score. Deviations of the CCEI score from unity indicate by how much participants violate GARP. It thus informs how well choices can be rationalized with a well-defined utility maximization function. This figure also includes participants with a CCEI score of less than 0.80, which we exclude in our main analysis due to sizable violations of rational choices. We observe that participants with a lower CCEI score tend to a exhibit, on average, a higher estimated elasticity of complementarity (η).

Figure A9: Sensitivity of η regarding the uniform preferences cut-off



Notes: This figure shows the sensitivity of our η estimates with respect to the chosen cut-off for the uniform preferences exclusion criterion. With this criterion we exclude participants who allocated, on average, more than 98% of their budget to a single good. For these participants we cannot separately identify their substitutability preferences. Here, we vary this cut-off value. All other exclusion criteria are applied and the values for η are winsorized at the upper 90th percentile. Error bars around the mean, black dot, indicate the corresponding standard error; the median is represented by the black triangle, while the green bars denote the number of participants.

A.5 Full Experimental Instructions (Translation)

Welcome

Welcome to this study on decisions that are important for economic and environmental policy. The study is conducted by researchers at the University of Hamburg. Your answers will be stored and processed **anonymously**.

Background

This study will be used for a research project funded by the **Federal Ministry of Education and Research** (Bundesministerium für Bildung und Forschung). The results are intended to help with economic and environmental policy decisions. To this end, we also share the results of this study with our project partners, the **Federal Environment Agency** (Umweltbundesamt) and the **Federal Agency for Nature Conservation** (Bundesamt für Naturschutz).

Remuneration

[Private Incentivized Version]

If you participate in the study and answer all the questions, you will receive a **lump-sum payment**. Depending on your answers, you might also receive a **variable remuneration** of up to EUR 1 (converted to LifePoints).

[Private Non-Incentivized Version, Public Incentivized Version and Public Non-Incentivized Version]

If you participate in the study and answer all the questions, you will receive a **lump-sum payment**.

Requirements

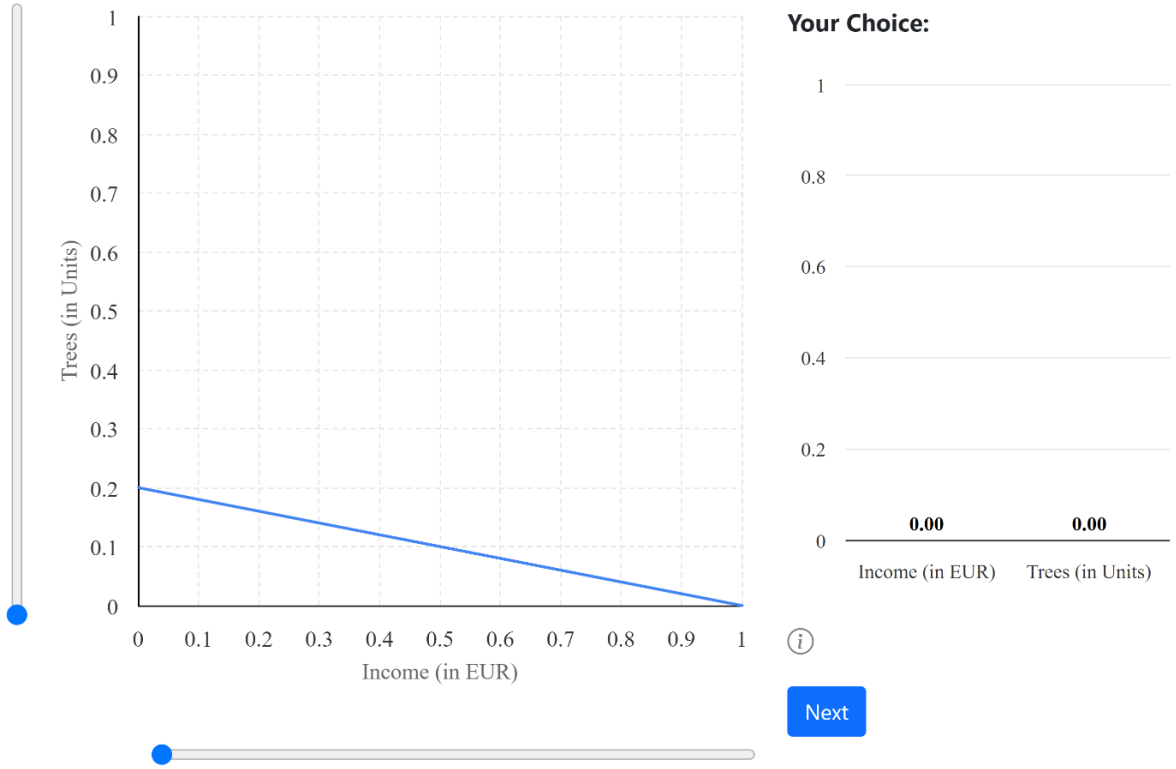
- You will need about **20 minutes**.

- You must **concentrate** and read thoroughly.

- You may **not use a smartphone**.

Preview

We will ask you to make **30 distribution decisions** using interactive illustrations. Here is an example of how we illustrate the distribution decisions:



[Public incentivized version and public non-incentivized version]

This is **followed** by a **questionnaire with 13 questions**.

[Horizontal line]

Your consent

Have you read the above text and do you give your consent?

- Yes
- No

Would you like to participate in this study?

- Yes
- No

[Page break]

Your age and gender

Please state your age and gender.

How old are you? [16 - 99]

What gender do you identify with?

- Male
- Female
- Non-binary
- Prefer not to respond
- Other

[Page break]

General information

In studies like ours it sometimes occurs that participants do not thoroughly read all questions. This is a problem as it may distort the research results. Therefore, it is very important that you read and answer each question carefully.

To show that you read our questions attentively, please select “Newspapers”.

- Radio
- Newspapers
- Other
- Twitter
- Facebook

- TikTok
- Television
- Reddit
- YouTube

[Page break]

General information

[Private Incentivized Version]

As mentioned before, you might receive an additional variable renumeration, depending on the decisions you make. In addition to that, based on your decisions, we will donate money to a state forestry operation for the planting of trees.

On the following pages, we will explain how your decisions are linked to an additional variable renumeration or a donation for planting trees.

First, you must **give your consent** that we may **donate for planting trees on your behalf**. Without this consent, you cannot participate in this study.

Instructions:
If you decide to assign a part of the variable remuneration to a donation for planting trees, you agree that the execution of the donations will be carried out collectively for all participants by the head of this experiment (Prof. Dr. Moritz Drupp). To document the assigned donations, the donation receipt will be published on the website of the professorship at the University of Hamburg after completion of this study: https://uhh.de/wiso-baumpflanzen

Have you read the instructions and do you agree to them?
- Yes
- No

[Public Incentivized Version]

As mentioned before, you will receive a lump-sum payment. Furthermore, based on your decisions we will donate to the Federal Treasury (Bundeskasse), financially benefitting all residents of Germany, and to a state forestry operation for the planting of trees, benefitting all residents of Germany by improving air quality.

On the following pages, we will explain how your decisions are linked to an additional donation to the Federal Treasury and to a donation for planting trees.

First, you must **give your consent** that we may **donate to the Federal Treasury** and **donate for planting trees** on your behalf. Without this consent, you cannot participate in this study.

Instructions:
If you decide to assign a part of the money to a donation to the Federal Treasury or to a donation for planting trees, you agree that the execution of the donations will be carried out collectively for all participants by the head of this experiment (Prof. Dr. Moritz Drupp). To document the assigned donations, the donation receipts will be published on the website of the professorship at the University of Hamburg after completion of this study: https://uhh.de/wiso-baumpflanzen

Have you read the instructions and do you agree to them?
- Yes
- No

[Skip page for Private Non-incentivized Version and Public Non-incentivized Version]

[Page break]

General information

[Private Version]

We will ask you to make **30 distribution decisions**.

When making these distribution decisions, you need to weigh the following aspects against each other:

- **income** and
- **trees.**

Please select distributions between income and trees that best reflect your wishes.

Consequences

[Private Incentivized Version]

Your decisions are <u>not</u> hypothetical. Both the income and the number of trees that you choose will be paid out to you or planted through a donation.

To do this, we will **randomly select one of the 30 distribution decisions** at the end of the study and **implement your respective decision**.

[Private Non-Incentivized Version]

Your decisions are hypothetical, but not without consequences. Neither the income nor the number of trees that you choose will be paid out to you or planted through a donation.

However, the results of how you would decide will be passed on to the Federal Environment Agency to contribute to the further development of environmental policies. Therefore, your decisions may have actual consequences.

Background

In this study, we want to understand how you deal with the **trade-off** between **income** for you and **public environmental quality** (here in the form of more trees). To this end, we show you various situations (i.e. distribution decisions) that differ in terms of the distribution *options*.

[Public Version]

We will ask you to make **30 distribution decisions**.

When making these distribution decisions, you need to weigh the following aspects against each other:

- **money for the Federal Treasury** and
- **trees**.

Please select distributions between money for the treasury and trees that best reflect your wishes.

Consequences

[Public Incentivized Version]

Your decisions are <u>not</u> hypothetical. Both the money for the Federal treasury and the number of trees that you choose will be donated or planted through a donation.

To do this, we will **randomly select one of the 30 distribution decisions** at the end of the study and **implement your respective decision**.

[Public Non-Incentivized Version]

Your decisions are hypothetical, but not without consequences. Neither the money for the Federal Treasury nor the number of trees that you choose will be donated or planted through a donation.

However, the results of how you would decide will be passed on to the Federal Environment Agency to contribute to the further development of environmental policies. Therefore, your decisions may have actual consequences.

Background

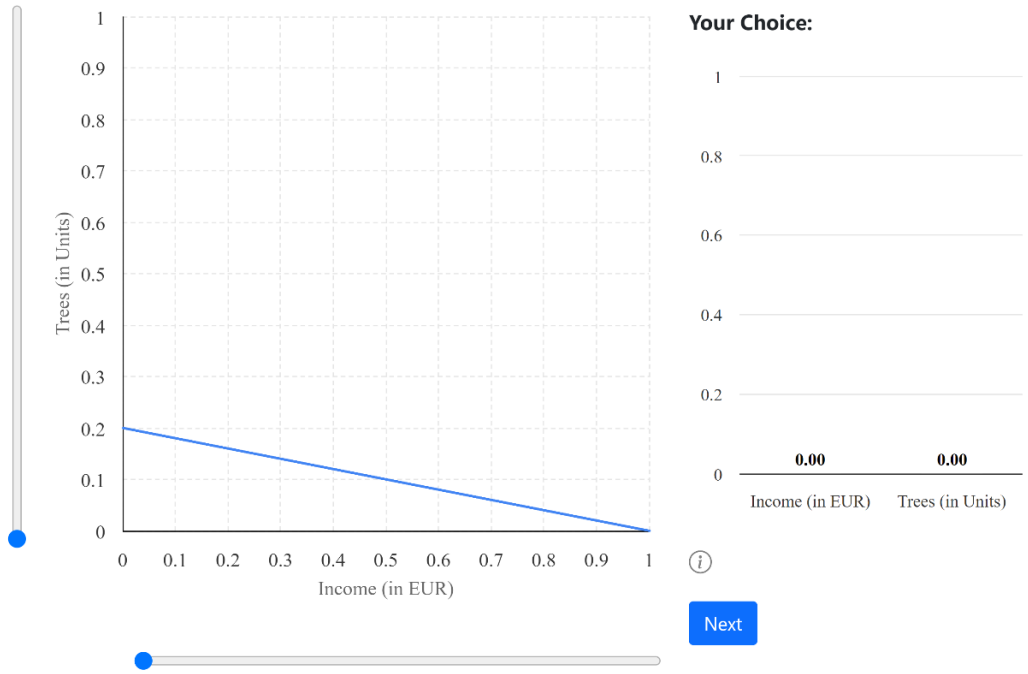
In this study, we want to understand how you deal with the **trade-off** between **money for the Federal Treasury** and **public environmental quality** (here in the form of more trees). To this end, we show you various situations (i.e. distribution decisions) that differ in terms of the distribution *options*.

[Pagebreak]

General information

We will visualize the different distribution decisions using an interactive illustration. Here is an example:

[Private Incentivized Version and Private Non-incentivized Version]



[Public Incentivized Version and Public Non-incentivized Version]

Please pay particular attention to the **blue line**. It indicates the following:

[Private Incentivized Version and Private Non-incentivized Version]

1. It shows **all distributions** between income and trees that **are possible** in the respective situation.
2. Its **axis intercepts** describe the maximum possible income for you (here EUR 1) and the maximum possible number of trees (0.2) that you can plant with a donation.
3. Its **slope** describes the exchange rate between income for you and planted trees.

[Public Incentivized Version and Public Non-incentivized Version]

1. It shows **all distributions** between money for the Federal Treasury and trees that **are possible** in this situation.
2. Its **axis intercepts** describe the maximum possible amount of money for the Federal Treasury (here EUR 1) and the maximum possible number of trees (0.2) that you can plant with a donation.
3. Its **slope** describes the exchange rate between income for all German citizens (paid to the Federal Treasury) and planted trees.

To choose a distribution that most closely reflects your preferences, **please click** on the desired distribution on the blue line **or** use the **slider**. After you have made your decision, please click "Next".

You will see another, unrelated distribution decision. This process will be repeated until you have completed all distribution decisions.

[Pagebreak]

Costs of a tree donation

[Private Incentivized Version]

It currently costs EUR 5 to plant a tree at a state forestry operation in Germany. A donation of EUR 1 therefore corresponds to a fifth of a tree. If you forgo the same amount in our study, you can always have *at least* one tree planted, often even more. So, you won't see any situations where you can have more trees planted by a state forestry operation in Germany for the same amount of income that you can receive instead.

This is explained by us topping up your donation. For example, if you decide to have one tree planted and forgo EUR 1, we will pay the remaining EUR 4 to have the tree planted by a state forestry operation. The purpose of the donation increase is merely to generate different situations for distribution decisions. Therefore, please do not donate more money than you would otherwise.

Payment of donations
Upon completion of the study, we **add up** the **number of trees chosen by all participants** in one of the 30 random distribution decisions, round it up to a full number of trees and **have these trees planted** through a donation to a state forestry operation.

[Private Non-Incentivized Version]

It currently costs EUR 5 to plant a tree at a state forestry operation in Germany. If you forgo the same amount in our study, you can always have *at least* one tree planted, often even more. So, you won't see any situations where you can have more trees planted by a state forestry operation in Germany for the same amount of income that you can receive instead.

This is explained by us hypothetically topping up your donation. For example, if you decide to have two trees planted and forgo EUR 5, we will pay the remaining EUR 5 to have the corresponding number of trees planted by a state forestry operation. The purpose of the hypothetical donation increase is merely to

generate different situations for distribution decisions. Therefore, please do not donate more money than you would otherwise.

Payment of donations
Since your decision is **merely hypothetical**, no trees will be planted through a donation to a state forestry operation. However, your hypothetical distribution decisions still provide important data to inform environmental policies.

[Public Incentivized Version]

It currently costs EUR 5 to plant a tree at a state forestry operation in Germany. If you decide against donating the same amount to the Federal Treasury in our study, you can always have *at least* one tree planted, often even more. So, you won't see any situations where you can have more trees planted by a state forestry operation in Germany for the same amount of money that you can donate to the Federal Treasury instead.

This is explained by us topping up your donation. For example, if you decide to have two trees planted and forgo giving EUR 5 to the Federal Treasury, we will pay the remaining EUR 5 to have the corresponding number of trees planted by a state forestry operation. The purpose of the donation increase is merely to generate different situations for distribution decisions. Therefore, please do not donate more money than you would otherwise.

Payment of donations
Upon completion of the study, we **add up** the **number of trees chosen by all participants** in one of the 30 random distribution decisions, round it up to a full number of trees and **have these trees planted** through a donation to a state forestry operation.

In addition to that, we **sum up the amount of money to the Federal Treasury** given by all participants in one of the 30 random distribution decisions, round it up to a full euro amount and **donate it to the Federal Treasury**.

[Public Non-incentivized Version]

It currently costs EUR 5 to plant a tree at a state forestry operation in Germany. If you decide against donating the same amount to the Federal Treasury in our study, you can always have *at least* one tree planted, often even more. So, you

won't see any situations where you can have more trees planted by a state forestry operation in Germany for the same amount of money that you can donate to the Federal Treasury instead.

This is explained by us topping up your donation. For example, if you decide to have two trees planted and forgo giving EUR 5 to the Federal Treasury, we will pay the remaining EUR 5 to have the corresponding number of trees planted by a state forestry operation. The purpose of the donation increase is merely to generate different situations for distribution decisions. Therefore, please do not donate more money than you would otherwise.

Payment of donations
Since your decision is **merely hypothetical**, no money will be donated to the Federal Treasury. However, your hypothetical distribution decisions still provide important data to inform environmental policies.

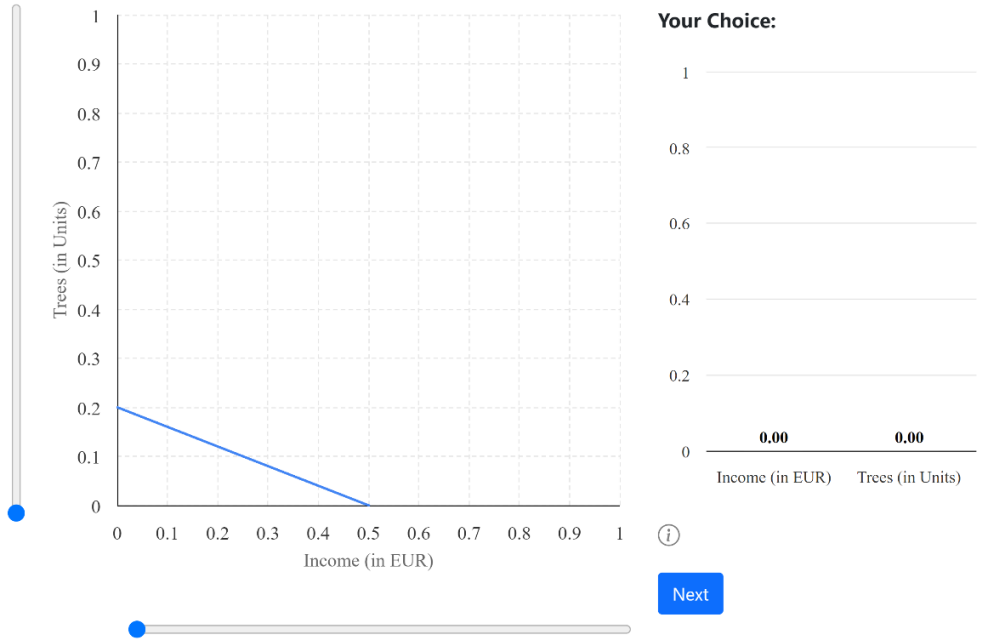
[Pagebreak]

[Private Incentivized Version and Private Non-Incentivized Version]

Exchange rate between income for you and trees

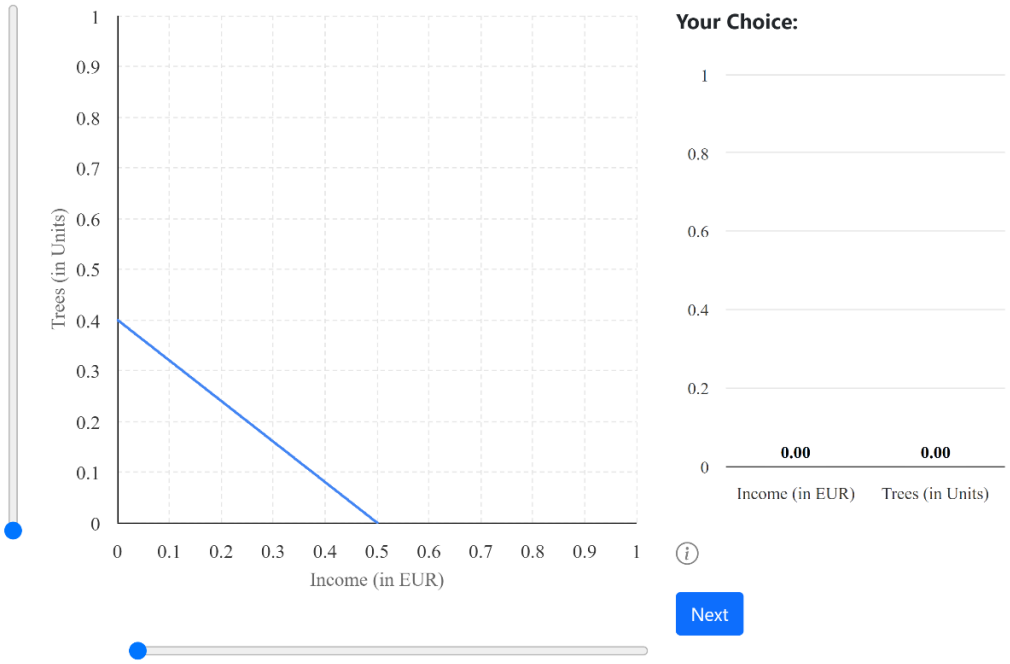
The **gradient of the blue line** in the interactive illustrations informs you about the exchange rate between income and trees. It tells you how many trees you can have planted for every euro of income you forgo. The **steeper** the blue line, **the more trees** you can have planted for every euro of income you choose to forgo. The **flatter** the blue line, the **more income** you can receive for every tree you choose not to plant. Please take a look at the following two examples:

Example 1:
In this situation, if you forgo an income of EUR 0.5, you can plant 0.2 trees for that amount of income.



Example 2:

In this situation, if you forgo an income of EUR 0.5, you can plant 0.4 trees for that amount of income.

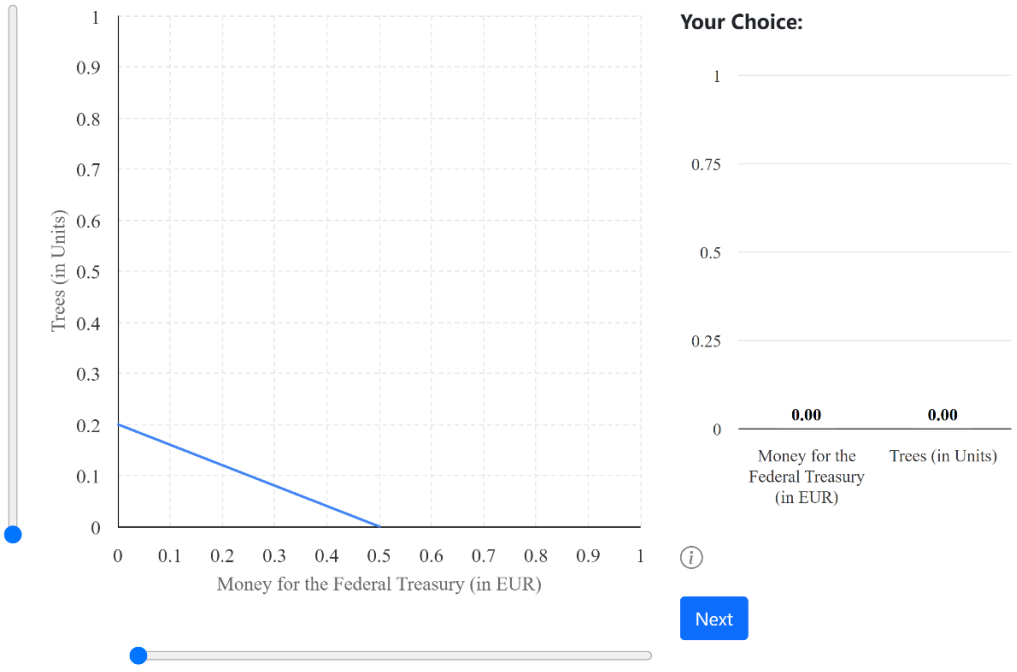


[Public Incentivized Version and Public Non-Incentivized Version]

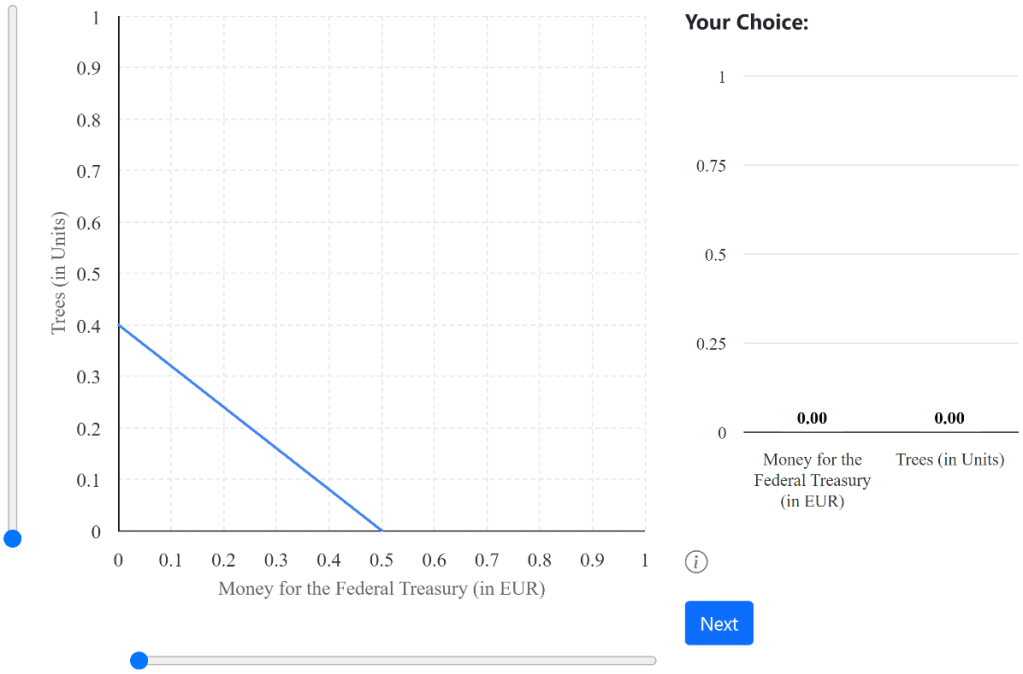
Exchange rate between income for all and trees

The **gradient of the blue line** in the interactive illustrations informs you about the exchange rate between income for all (money given to the Federal Treasury) and trees. It tells you how many trees you can have planted for every euro of money you decide not to donate to the Federal Treasury. The **steeper** the blue line, **the more trees** you can have planted for every euro of income you decide not to give to the Federal Treasury. The **flatter** the blue line, the **more money you can donate to the Federal Treasury** for every tree you choose not to plant. Please take a look at the following two examples:

Example 1:
In this situation, if you decide not to give EUR 0.5 to the Federal Treasury, you could plant 0.2 trees for that amount of money.



Example 2:
In this situation, if you decide not to give EUR 0.5 to the Federal Treasury, you could plant 0.4 trees for that amount of money.



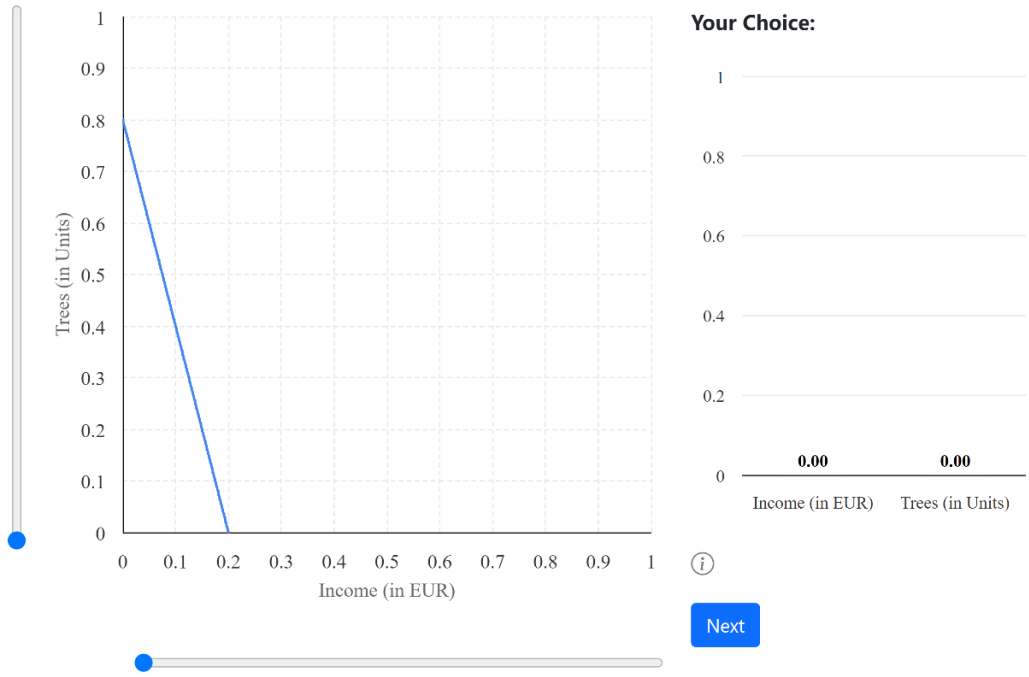
[Page break]

[Private Incentivized Version and Private Non-Incentivized Version]

Exchange rate between income for you and trees

On the previous page you have read information about the exchange rate between income and trees. Now please choose the answer option that best summarizes the exchange rate in the following situation:

- You can have 0.8 trees planted if you forgo EUR 0.2 of income.
- You can have 0.2 trees planted if you forgo EUR 0.8 of income.
- You can have 1 tree planted if you forgo EUR 1 of income.



[Public Incentivized Version and Public Non-Incentivized Version]

Exchange rate between income for all and trees

On the previous page you have read information about the exchange rate between money given to the Federal Treasury and trees. Now please choose the answer option that best summarizes the exchange rate in the following situation:

- You can have 0.8 trees planted if you decide not to donate EUR 0.2 to the Federal Treasury.
- You can have 0.2 trees planted if you decide not to donate EUR 0.8 to the Federal Treasury.
- You can have 1 tree planted if you decide not to donate EUR 1 to the Federal Treasury.

[Pagebreak]

Exercise decisions

On the following page we ask you to familiarize yourself with the interactive illustration. Please click "Next" to start with the **3 exercise decisions**.

[Private-Incentivized Version and Private Non-incentivized Version]

- Please choose a similar distribution between income for you and trees (i.e. approx. EUR 0.25 and 0.25 trees).
- Please choose a distribution where you allocate more than EUR 0.3 of income to yourself.
- Please choose a distribution where you have more than 0.3 trees planted.

[Public-Incentivized Version and Public-Non-incentivized Version]

- Please choose a similar distribution between income for all in form of money given to the Federal Treasury and trees (i.e. approx. EUR 0.25 and 0.25 trees).
- Please choose a distribution where you allocate more than EUR 0.3 to the Federal Treasury.
- Please choose a distribution where you have more than 0.3 trees planted.

[Pagebreak]

Exercise decisions completed

Thank you! You have successfully completed all 3 exercise decisions.

Please click “Next” to start with the **30 distribution decisions**.

[Pagebreak]

Distribution decision

[Private-Incentivized Version and Private Non-incentivized Version]

Please choose a distribution between income for you and trees.

[interactive illustration]

[Public-Incentivized Version and Public-Non-incentivized Version]

Please choose a distribution between income for all in form of money donated to the Federal Treasury and trees.

[interactive illustration]

[Pagebreak]

Distribution decision

Thank you very much for making your decisions. Next, we will ask you to answer a few more questions.

[Pagebreak]

Questionnaire

1. What is the zip code of your home address? _____

2. What is your highest school-leaving qualification?
    - No school-leaving qualification
    - Hauptschulabschluss (lower secondary school certificate)
    - Completed vocational training
    - Mittlere Reife/Realschulabschluss (higher secondary school certificate)
    - Hochschulabschluss (Universität, FH) (university degree)
    - Abitur (certificate of general qualification for university entrance)
    - Other
3. What is your marital status?
    - Married/registered partnership
    - Single
    - Living together
    - Separated/widowed/divorced
4. How many persons reside in your household (yourself included)?
5. How many of these persons are under the age of 18?
6. Which party do you lean towards?
    - SPD
    - CDU
    - CSU
    - FDP
    - Bündnis 90 / Die Grünen
    - Die Linke
    - AfD
    - Freie Wähler
    - Bündnis Sahra Wagenknecht
    - Other
7. What is your monthly net household income (the income of all household members together, including transfer payments such as child benefit, after deduction of taxes and social insurance)? For our evaluation, it is sufficient if you classify the net household income in one of the following categories:

    - Less than EUR 500 per month
    - EUR 500-999 per month
    - EUR 1000-1499 per month
    - EUR 1500-1999 per month
    - EUR 2000-2499 per month
    - EUR 2500-2999 per month
    - EUR 3000-3499 per month
    - EUR 3500-3999 per month
    - EUR 4000-4499 per month
    - EUR 4499-4999 per month
    - EUR 5000-6000 per month

- More than EUR 6000 per month

8. Approximately how often do you go into a forest?
    - Never
    - Once a year
    - Twice a year
    - Three times a year
    - Four times a year
    - Once a month
    - Twice a month
    - Three times a month
    - Four times a month
    - Once a week
    - Twice a week
    - Three times a week
    - More than three times a week
9. How important is the availability of sufficiently wooded areas in your proximity to you?
    - Not important at all
    - Not important
    - Rather not important
    - Neither important nor unimportant
    - Rather important
    - Important
    - Very important
    - No assessment
10. Aside from this study, have you ever donated money for the planting of trees before? [Yes] [No] [Don't remember]
11. In case you donated to nature and environment protection in 2023, how much did you donate?
12. To what extent do you agree to the following statement:

"I am worried about the state of ecosystems worldwide." [5-point Likert scale]

	Do not agree at all	Rather do not agree	Neither agree nor disagree	Rather agree	Completely agree

13. In your opinion, how trustworthy are the following institutions?
    - University of Hamburg
    - State forestry operations

- Federal Government of Germany

  Not trustworthy – Very trustworthy [0-10]

[Pagebreak]

Questionnaire

Thank you very much for your answers. Please contact us with any comments you may have. We look forward to your feedback.

Did any part of this survey seem confusing to you, and if yes, which one?

Are there any comments you would like to share with us?

Incentivized Version:

[Pagebreak]

End

Thank you very much for your participation!

[Private Incentivized Version]
Your variable remuneration will be paid out with a time delay following the study.

To document the donations made, the donation receipt will be published on the website of the professorship at the University of Hamburg after completion of the study: https://uhh.de/wiso-baumpflanzen

[Public Incentivized Version]
To document the donations made, the donation receipts will be published on the website of the professorship at the University of Hamburg after completion of the study: https://uhh.de/wiso-baumpflanzen