

# Environmental Inequality and Economic Valuation

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This paper studies how the distribution of environmental goods and income affect the economic valuation of local public goods. I show that environmental inequality affects societal willingness to pay (WTP) for environmental local public goods and that this is determined by their substitutability as well as by how their provision is correlated with income. Specifically, I find that in cases where environmental inequality is weakly greater than income inequality or the correlation between income and environmental good endowment is negative, environmental inequality decreases (increases) societal WTP if and only if the environmental good is a substitute to (complement for) manufactured consumption goods. Moreover, I show that sorting of richer households into places with higher levels of a given environmental good increases (decreases) societal WTP if and only if it is a substitute for (complement to) manufactured consumption goods. I obtain novel closed-form adjustment factors for benefit transfer to control for differences in the (spatial) distribution of environmental local public goods. Using forest preservation in Poland as an empirical example, I find that societal WTP is up to 4 percent higher for equal access to forests and up to 8 percent higher for an equal distribution of both income and access to forests.

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# 1 Introduction

Environmental policy making is increasingly informed by economic values assigned to non-market environmental goods, which are often distributed highly unequal among households. For instance, Boyce et al. (2016) recently found that exposure to industrial air pollution in the United States is even more unequally distributed than income. In many cases environmental inequalities reinforce prevailing economic inequalities. For centuries, wealthy citizens have tended to live in areas where environmental quality is high, while pollution has been burdened disproportionately on poor citizens.<sup>1</sup> It is timely to study the interplay of environmental inequalities and economic inequalities, as economic inequalities are on the rise in most parts of the world (Alvaredo et al. 2017), while the loss of biodiversity and many ecosystem services is accelerating (Baumgärtner et al. 2015, Butchart et al. 2010, MEA 2005).

The monetary valuation of non-market goods has become a central challenge for environmental economics. So far, however, valuation studies have paid little attention to the implications of (spatially) coupled environmental and income inequalities (Drupp 2018). Recently, Baumgärtner et al. (2017) presented a model of how the distribution of income affects the societal value of pure public goods at the stage of aggregating individual values. For an equal preference model set-up in which all households are endowed with the same level of an environmental good but differ in exogenously given income, they find that aggregate willingness to pay (WTP) decreases (increases) with income inequality if and only if the environmental good is a substitute for (complement to) manufactured consumption goods. As the majority of environmental goods considered in non-market valuation are unevenly distributed across households, it is crucial to extend this model framework to local public environmental goods and to analyze how

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<sup>1</sup>For instance, Lee and Lin (2018) show that in the period from 1880 to 2010, U.S. metropolitan neighborhoods that are close to environmental amenities increase in income over time, and that cities with a pronounced heterogeneous distribution of natural amenities are also characterized by a persistent heterogeneous spatial distribution of income. Heblich et al. (2017) show that in 90 English cities, air pollution around 1880 explains a large share of both the historical and current spatial income distribution.

environmental inequalities affects aggregate WTP (cf. Drupp 2018).

In this paper, I study how the joint distribution of environmental goods and income – and in particular, environmental and income inequality – affect the valuation of local public goods. I present a model of society’s aggregate willingness to pay (WTP) for an environmental local public good where households differ in both the environmental good and income. Building on the model developed by Baumgärtner et al. (2017) for pure public goods, I assume (a) households to have identical preferences regarding a manufactured private consumption good and an environmental good represented by a constant elasticity of substitution (CES) utility function, and (b) log-normally distributed household income. I extend their model to the case of environmental *local* public goods by assuming (c) that households are heterogeneous in their endowment with environmental goods, represented by a log-normal distribution. While this is certainly an approximation, the assumption of log-normality reflects that the distribution of many environmental goods across households in a society is strongly right-skewed and positive. Assumptions (b) and (c) make it possible to employ a bi-variate log-normal distribution to study different correlations between the environmental good endowment and income.

I find that the distribution of the environmental good – and how this is correlated with income – affects society’s aggregate WTP. In particular, I show that (i) societal WTP for the environmental local public good increases (decreases) with the level of the environmental good (‘scope’) if and only if the environmental good and the private consumption good are substitutes (complements); (ii) the effect of environmental and income inequality on mean WTP is determined by whether the environmental good is a substitute for or a complement to manufactured consumption goods and by how environmental good endowment is correlated with income; (iii) sorting of richer households such that they are endowed with higher levels of the environmental good increases (decreases) societal WTP if and only if the environmental good is a substitute for (complement to) manufactured consumption goods. Based on these theoretical insights, I derive theory-based adjustment factors for benefit transfer to account for differences in the distribution of environmental local public goods and income. Finally, an applica-

tion to forest preservation in Poland illustrates considerable economic effect sizes of the proposed adjustments.

My research adds to several strands of literature: First, I contribute to the development of theory-based ('structural') methods for spatial benefit transfer. Practical policy analysis usually draws on monetary values from past studies to inform policy making in a different context (OECD 2018), which is commonly referred to as 'benefit' or 'value transfer'. As the associated errors are often large, several scholars have argued that benefit transfers should be based more firmly in micro-economic theory (Bateman et al. 2011, Smith et al. 2002). Recently, there has been a growing interest in spatially explicit approaches to benefit transfer (e.g. Kuminoff 2018, Turner 2017, Perino et al. 2014, Brander et al. 2012). In the present paper, I qualify the conditions under which the transfer factors proposed by Baumgärtner et al. (2017) and empirically tested by Meya et al. (2017) and also hold for environmental local public goods.

Second, I contribute to the theoretical underpinnings of primary valuation of non-market environmental goods. The sensitivity of mean WTP to the amount of the valued environmental good ('scope effect') is a common validity test for stated preference studies (e.g. Arrow et al. 1993). However, the absence of positive scope effects in several valuation studies has spurred a heated debate on the underlying reasons, leading some scholars to discard the practice of contingent valuation as a whole.<sup>2</sup> Here, I link the existence of a positive sensitivity to scope to the substitutability of the valued environmental good by manufactured consumption goods.

Third, I contribute to the literature on spatial inequality and neighborhood sorting. My analysis is thus related to Brueckner et al. (1999), Lee and Lin (2018), Heblich et al. (2017), who show that environmental amenities induce neighborhood sorting, with higher-income households sorting into neighborhoods where environmental quality is high. The correlation between environmental quality and socio-demographic variables such as income has been scrutinized under the headline of 'environmental justice' for

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<sup>2</sup>A review of the extensive discussion on the scope effect is beyond the scope of this introduction. Early contributions include the study by Kahneman and Knetsch (1992) and the critical response of Smith (1992). A recent overview on the debate can be found in Whitehead (2016).

decades (e.g. Ash and Fetter 2004). Here, I link the effect of sorting to the societal valuation of environmental amenities by analyzing changes in the correlation between environmental goods and income.

The remainder is structured as follows. I present the model in Section 2, and the results from the model analysis in Section 3. An empirical application for a forest protection policy in Poland is presented in Section 4. I discuss major limitations of my analysis in Section 5 and conclude in Section 6. The Appendix contains all formal proofs.

## 2 Model

I build on and extend the pure public good model developed in Baumgärtner et al. (2017) to make it applicable to local public goods. Consider a society that consists of a population of  $n$  households, denoted  $i = 1, \dots, n$ . This might be a city, region, or country. There is a single environmental amenity,  $E$ , that households enjoy at different levels,  $E_i$ . Several households might be endowed with the same level of the environmental good, which is locally public.<sup>3</sup> A household  $i$  derives utility by consuming two goods: a private, manufactured consumption good,  $X_i > 0$ , traded on a market at price  $P > 0$ , and the non-market-traded environmental local public good,  $E_i > 0$ . The household cannot choose the level of the environmental good, which is rationed at quantity  $E_i$ . Household  $i$ 's endowment with the environmental good,  $E_i$ , might be measured in physical units, for

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<sup>3</sup>By 'environmental good' I refer to all types of goods and services people receive from nature. In the following, I study environmental goods that are locally public, i.e. they are non-excludable and non-rival but only available within a limited geographic area so that the exposure varies across households within a society. My analysis therefore applies mainly to use values as opposed to non-use values, which generally do not depend on exposure to the environmental good. For example, one may think of regulatory ecosystem services such as clean air and cultural ecosystem services such as recreation opportunities provided by urban green spaces or forests. For the sake of brevity, I only refer to  $E$  as environmental *good* in the following. Nevertheless, the analysis equally holds for a reduction in environmental *bads*, such as local air pollution or environmental disamenities such as hazardous waste sites or highways.

example ‘parts per million’, ‘park area density’ or ‘distance to the nearest environmental amenity’ such as an urban park or forest.

Households have equal preferences regarding these two goods, represented by a constant elasticity of substitution (CES) utility function

$$U(X_i, E_i) = \left( \alpha X_i^{\frac{\theta-1}{\theta}} + (1 - \alpha) E_i^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}}, \quad (1)$$

where  $\theta \in (0, +\infty)$  is the constant elasticity of substitution between the market-traded consumption good and the non-market-traded environmental local public good. The other preference parameter  $\alpha \in (0, 1)$  is the weight of the consumption good relative to the environmental good in the household’s overall utility. The CES utility function is the simplest preference representation that is still rich enough to study different degrees of substitutability in the consumption of the environmental good and manufactured goods. It contains the cases where both are substitutes ( $\theta > 1$ ), Cobb-Douglas ( $\theta = 1$ ) and complements ( $\theta < 1$ ).

Household  $i$ ’s decision problem is then to maximize utility from the consumption good,  $X_i$ , and the environmental good,  $E_i$ , subject to a budget constraint given by their income,  $Y_i > 0$ , and the exogenously fixed level  $E_i$ :<sup>4</sup>

$$\max_{X_i, E_i} U(X_i, E_i) \quad s.t. \quad P X_i = Y_i, \quad E_i \text{ fixed.} \quad (2)$$

I follow Aaron and McGuire (1970), Ebert (2003) and Baumgärtner et al. (2017) by defining household  $i$ ’s income-equivalent total WTP for the local public environmental good at level  $E_i$  as the marginal willingness to pay,  $\omega$ , per unit of the environmental good at level  $E_i$  times the enjoyed quantity of  $E_i$ :  $WTP(Y_i, E_i) = \omega(Y_i, E_i) E_i$ . The marginal WTP (so called ‘Lindahl price’),  $\omega$ , is obtained as the price the household would have been willing to pay if the level of the environmental good that household enjoys,  $E_i$ , had been freely chosen on a hypothetical market. As such, marginal WTP can be derived from household  $i$ ’s indirect utility function at the currently enjoyed level

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<sup>4</sup>To save on notation, I use  $E_i$  to denote both the variable ‘household  $i$ ’s endowment with the local public environmental good’ and the actual consumed quantity, as the consumed quantity  $E_i$  is fixed throughout the main analysis (see Appendix A.9 for how this assumption might be relaxed).

of the environmental good,  $E_i$ , the market prices of consumption goods,  $P$ , and income,  $Y_i$  (see Appendix A.1).

For the CES utility function, household  $i$ 's total WTP for the environmental good at level  $E_i$  can be expressed as a function of income,  $Y_i$ , price level,  $P$ , and preference parameters,  $\alpha$  and  $\eta$  or  $\theta$ , as follows (Appendix A.1):

$$\text{WTP}(Y_i, E_i) = \frac{1 - \alpha}{\alpha} P^{1-\eta} E_i^{1-\eta} Y_i^\eta, \quad \eta = \frac{1}{\theta}, \quad (3)$$

where  $\eta$  denotes the income elasticity of WTP. Except for the household index  $i$  on the environmental good, Eq. (3) is identical to household's WTP for pure public goods derived by Baumgärtner et al. (2017). The CES utility function implies that the elasticity of substitution,  $\theta$ , between the manufactured consumption good,  $X_i$ , and the environmental good,  $E_i$ , is the inverse of the income elasticity of WTP,  $\eta$ , (Baumgärtner et al. 2017, Ebert 2003, Kovenock and Sadka 1981), which consequently is also constant.<sup>5</sup> As most approaches to benefit transfer are based on a constant income elasticity of WTP, this property makes the CES utility framework the preferred functional form to deduct benefit transfer factors in the following.

Recall that there is a single environmental local public good  $E$ , which households enjoy at different exogenously fixed levels  $E_i$ . In order to model the local public good character, I assume that the environmental good is unevenly and continuously distributed over households, represented by a log-normal distribution,

$$E_i \propto \text{LN}(\mu_E; \sigma_E^2), \quad (4)$$

where  $\mu_E > 0$  is the mean level of the environmental good and  $\sigma_E$  is the spread of environmental good endowment across households. The frequency of households endowed with a certain level of the environmental good is given by the corresponding density function. Assuming a log-normal distribution reflects that the endowment with environmental goods is positive and that some households in society enjoy a higher level of the environmental good than the majority of households – for instance, households

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<sup>5</sup>The income elasticity of WTP,  $\eta$ , has been elicited in a number of stated preference studies and mostly found to be below unity (Drupp 2018, Kriström and Riera 1996).

living very close to environmental amenities. The assumption of log-normality is in line with empirical evidence that the endowment with environmental goods is strongly right-skewed (see Section 5).

Households are also heterogeneous in income, represented by a log-normal distribution

$$Y_i \propto \text{LN}(\mu_Y; \sigma_Y^2), \quad (5)$$

where  $\mu_Y > 0$  is the level of mean income and  $\sigma_Y$  is the spread of the income distribution in the society. Empirical evidence supports this assumption of log-normality as a fairly good approximation for many national income distributions as well as the global distribution of income (Pinkovskiy and Sala-i-Martin 2009).

In this setting, society's mean WTP,  $\mu_{WTP}$ , for the environmental local public good is given as

$$\mu_{WTP}(\mu_Y, \sigma_Y, \mu_E, \sigma_E, \rho) = \int_0^\infty \int_0^\infty f_{\ln}(Y, E; \mu_Y, \sigma_Y, \mu_E, \sigma_E, \rho) WTP(Y, E) dY dE, \quad (6)$$

where  $f_{\ln}(Y, E; \mu_Y, \sigma_Y, \mu_E, \sigma_E, \rho)$  is the density function of the bivariate log-normal distribution for income,  $Y$  - with mean  $\mu_Y$  and standard deviation  $\sigma_Y$  - and the environmental good,  $E$  - with mean  $\mu_E$  and standard deviation  $\sigma_E$  - and their correlation,  $\rho$ .

The density function of the bivariate log-normal distribution is given by (e.g. Yue 2000)

$$f_{\ln}(Y, E; \mu_Y, \sigma_Y, \mu_E, \sigma_E, \rho) = \frac{\exp \left[ -\frac{1}{2(1-\rho^2)} \left( \frac{(\ln(Y)-m_Y)^2}{s_Y^2} - 2\rho \frac{\ln(Y)-m_Y}{s_Y} \frac{\ln(E)-m_E}{s_E} + \frac{(\ln(E)-m_E)^2}{s_E^2} \right) \right]}{2\pi Y E \sqrt{s_Y^2 s_E^2 (1-\rho^2)}}, \quad (7)$$

$$\text{with } m_j = \ln(\mu_j) - \frac{1}{2} \ln \left( 1 + \frac{\sigma_j^2}{\mu_j^2} \right), \quad s_j^2 = \ln \left( 1 + \frac{\sigma_j^2}{\mu_j^2} \right), \quad j \in \{Y, E\}, \quad (8)$$

where  $\rho \in (-1, 1)$  is the product-moment correlation coefficient of  $Y$  and  $E$ .<sup>6</sup> The

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<sup>6</sup>The product-moment correlation coefficient (often also referred to as Pearson correlation coefficient),  $\rho$ , is defined as  $\rho(Y, E) = \frac{\mathbf{E}[(Y-\mu_Y)(E-\mu_E)]}{\sigma_Y \sigma_E}$ , where  $\mathbf{E}[\cdot]$  is the expected value. Applied to a sample with  $\{Y_1, \dots, Y_N\}$  and  $\{E_1, \dots, E_N\}$ , the sample Pearson correlation coefficient,  $r$ , is  $r = \frac{\sum_1^N (Y_i - \mu_Y)(E_i - \mu_E)}{\sqrt{\sum_1^N (Y_i - \mu_Y)^2} \sqrt{\sum_1^N (E_i - \mu_E)^2}}$ , where  $\mu_Y$  and  $\mu_E$  are the sample means.

bivariate log-normal distribution contains the cases where income and endowment with the environmental good are positively correlated ( $\rho > 0$ ), negatively correlated ( $\rho < 0$ ), or distributed independently ( $\rho = 0$ ). While all three cases seem plausible, several empirical studies report a positive correlation between income and the endowment with environmental goods such as urban green spaces (Jensen et al. 2016, Tan and Samsudin 2017) or air quality (Ash and Fetter 2004, Hsiang et al. 2017).

Mean WTP can then be expressed as a function of the moments  $-\mu_Y, \sigma_Y, \mu_E, \sigma_E, \rho$  – of the distribution of income and environmental good endowment (see Appendix A.2):

$$\mu_{WTP}(\mu_Y, CV_Y, \mu_E, CV_E, \rho) = \frac{1-\alpha}{\alpha} P^{\frac{\theta-1}{\theta}} \mu_Y^{\frac{1}{\theta}} (1 + CV_Y^2)^{\frac{1-\theta}{2\theta^2}} \mu_E^{\frac{\theta-1}{\theta}} (1 + CV_E^2)^{\frac{1-\theta}{2\theta^2}} \Psi$$

with  $\Psi(CV_Y, CV_E, \rho) := \exp \left[ \rho \frac{\theta-1}{\theta^2} \sqrt{\ln(1 + CV_Y^2) \ln(1 + CV_E^2)} \right], \quad (9)$

where the coefficients of variation  $CV_Y := \frac{\sigma_Y}{\mu_Y}$  and  $CV_E := \frac{\sigma_E}{\mu_E}$  describe the spread of the distribution of income and the environmental good relative to their mean level. In the following I employ  $CV_Y$  and  $CV_E$  as measures for relative *income inequality* and relative *environmental inequality*, respectively.<sup>7</sup> When all households are exposed to the same amount of the environmental good, i.e.  $\sigma_E = 0$  or equivalently  $CV_E = 0$ , mean WTP for the environmental good in Eq. (9), reduces to the case of a pure public good,  $\forall i : E_i = E$ , studied by Baumgärtner et al. (2017).

When income and the environmental local public good are distributed independently,  $\rho = 0$ , then the last term in Eq. (9) becomes one,  $\Psi(CV_Y, CV_E, \rho) = 1$ , and the expression for mean WTP reduces to

$$\mu_{WTP}^{\text{ind}}(\mu_Y, CV_Y, \mu_E, CV_E) = \frac{1-\alpha}{\alpha} P^{\frac{\theta-1}{\theta}} \mu_Y^{\frac{1}{\theta}} (1 + CV_Y^2)^{\frac{1-\theta}{2\theta^2}} \mu_E^{\frac{\theta-1}{\theta}} (1 + CV_E^2)^{\frac{1-\theta}{2\theta^2}}, \quad (10)$$

which is an import special case as the terms for income inequality and environmental inequality factorize. It follows directly that the key result of Baumgärtner et al. (2017) on how income inequality affects mean WTP for pure public goods can be generalized to local public goods that are distributed independently of income.

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<sup>7</sup>In the remainder I focus on the coefficient of variation as measure of spread to facilitate comparisons between environmental and income inequality. Thus, I conduct a variable transformation where  $\sigma_j$  is replaced by a function  $CV_j(\sigma_j)$  which scales  $\sigma_j$  by  $\mu_j$  with  $j \in Y, E$ .

In the following, I study the effects of marginal changes in income inequality,  $CV_Y$ , and in the distribution of an environmental local public good  $(\mu_E, CV_E, \rho)$ . Marginal changes in the distribution of the environmental good can be understood as various stylized, not explicitly modelled environmental policies: Increases in  $\mu_E$  can be interpreted as environmental policies that increase the quality or quantity of environmental goods, whereby decreases in  $\mu_E$  can be interpreted as environmental degradation. Increases (decreases) in  $CV_E$  can be interpreted as environmental policies that decrease (increase) equity in the endowment with environmental goods. Increases (decreases) in  $\rho$  can be interpreted as environmental policies that increase (decrease) the endowment of richer households with environmental goods relative to poorer households or as the effect of some exogenous, not-modelled neighborhood sorting.

### 3 Results of model analysis

#### 3.1 Societal WTP for environmental local public goods

I am now prepared to study how mean WTP for the environmental local public good,  $\mu_{\text{WTP}}$  (Eq. (9)), changes with a marginal change in (i) the mean level of the environmental good,  $\mu_E$ , (ii) income inequality,  $CV_Y$ , (iii) environmental inequality,  $CV_E$ , or (iv) the correlation between income and endowment with the environmental good,  $\rho$ .

*Question 1: How does the mean environmental good level affect society's mean WTP for a marginal increase in the environmental local public good?*

##### Proposition 1

Mean WTP for the environmental local public good,  $\mu_{\text{WTP}}$  (Eq. (9)), increases (decreases) with the mean level of the environmental local public good,  $\mu_E$ , if and only if the environmental local public good and the private consumption good are substitutes (complements):

$$\frac{\partial \mu_{\text{WTP}}(\mu_Y, CV_Y, \mu_E, CV_E, \rho)}{\partial \mu_E} \gtrless 0 \text{ if and only if } \theta \gtrless 1. \quad (11)$$

*Proof.* See Appendix A.3.

□

Proposition 1 implies that there is only a positive *scope effect*, defined as an increase in mean WTP for an increase in the level of the environmental good, when the environmental good and the consumption good are substitutes ( $\theta > 1$ ), or analogously, when the income elasticity of WTP for the environmental good is below unity ( $\eta < 1$ ). However, for complements ( $\theta < 1$ ), or analogously, an income elasticity of WTP above unity ( $\eta > 1$ ), there is not a positive scope effect but a negative one. Note that Proposition 1 also holds for the special case of pure public goods, i.e. where  $\forall i : E_i = E$ , which is equivalent to  $CV_E = 0$ .<sup>8</sup>

The negative sensitivity to scope for complements can be explained as follows: Recall that a household's WTP is given as the product of marginal WTP for the environmental good at level  $E_i$  times the quantity of the environmental good,  $E_i$ . Marginal WTP is positive and decreasing in  $E_i$  (see Eq. A.30). The more difficult it is to replace environmental goods by manufactured goods in a household's utility, the more convex household's marginal WTP becomes in  $E_i$ . An increase in  $E_i$  now has two effects on a household's total WTP: a '(Lindahl) price effect' due to the decrease in marginal WTP and a 'quantity effect' due to an increase in the  $E_i$  quantity of environmental good consumed. For complements, the negative effect of a decrease in marginal WTP on total WTP outweighs the positive effect of an increase in quantity  $E_i$  on total WTP.

*Question 2: How does income inequality affect society's mean WTP for a marginal*

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<sup>8</sup>The same holds true at the household level: It is apparent from Eq. (3) that a household  $i$ 's WTP increases (decreases) with the amount of the environmental good,  $\frac{\partial \text{WTP}(Y_i, E_i)}{\partial E_i} \gtrless 0$ , if and only if the income elasticity of WTP is below (above) unity,  $\eta \lesseqgtr 1$ , or equivalently, if the environmental good is a substitute for (complement to) manufactured consumption goods,  $\theta \gtrless 1$ . Thus, if a household's endowment with the environmental good is inversely related to the household's distance to the environmental good – think, for instance, of  $E_i$  as household  $i$ 's proximity to urban green space – WTP decreases with distance ('distance decay') if and only if the income elasticity of WTP is below unity. As  $\eta$  is usually found to be well below unity, my model supports the distance decay of WTP found for many environmental local public goods (Bateman et al. 2006).

*increase in the environmental local public good?*

Next, I am interested in how the mean WTP for the local environmental public good changes with a marginal change in income inequality or environmental inequality. I assume that there is some inequality in income and the environmental good has some local public good characteristics,  $CV_Y, CV_E > 0$ . These assumptions are necessary to differentiate mean WTP given in Eq. (9) with respect to income inequality,  $CV_Y$ , and environmental inequality,  $CV_E$ . Note that I assume the correlation between income and the exposure to the environmental good to remain unchanged, while evaluating the sign of the mean WTP function for a marginal change in income inequality or environmental inequality. I conduct this stepwise for the case that the distribution of the environmental good is correlated with income ( $\rho \neq 0$ ) and for the important special case that the environmental good and income are distributed independently ( $\rho = 0$ ), which generates simpler results.

**Proposition 2**

Mean WTP for the environmental local public good,  $\mu_{\text{WTP}}$ , decreases (increases) with relative income inequality,  $CV_Y$ , if and only if the environmental good and the private consumption good are substitutes (complements) and their point correlation is lower than a weighted ratio of income inequality and environmental inequality, *or* the environmental good and the private consumption good are complements (substitutes) and their point correlation is higher than a weighted ratio of income inequality and environmental inequality.

$$\frac{\partial \mu_{\text{WTP}}(\mu_Y, CV_Y, \mu_E, CV_E, \rho)}{\partial CV_Y} \begin{matrix} \leq \\ \geq \end{matrix} 0 \text{ if and only if } \begin{cases} \theta > 1, \rho < a & \text{or } \theta < 1, \rho > a \\ \theta = 1 & \text{or } \rho = a \\ \theta < 1, \rho < a & \text{or } \theta > 1, \rho > a \end{cases}, \quad (12)$$

where  $a := \sqrt{\frac{\ln(1+CV_Y^2)}{\ln(1+CV_E^2)}}$  and  $\rho \neq 0$ .

*Proof.* See Appendix A.4. □

Proposition 2 states that the effect of income inequality on mean WTP for the en-

environmental local public good is determined both by whether the environmental good is a substitute for or a complement to the manufactured consumption good and by the correlation of environmental good endowment and income in the society. Compared to the case of pure public goods, which is a special case in my analysis, the latter is an additional determinant for local public goods. It shows that the key result of Baumgärtner et al. (2017) that mean WTP for environmental goods decreases (increases) with income inequality if and only if the environmental good and the private consumption good are substitutes (complements) applies only to local public goods when the correlation with income is lower than a weighted ratio of income inequality and environmental inequality,  $\rho < a$ . For cases where the correlation between income and the environmental local public good is strongly positive,  $\rho > a$ , the reverse might be true: mean WTP increases (decreases) with income inequality if and only if the environmental good and the private consumption good are substitutes (complements).

The threshold  $a$  thereby captures how unequal a society's income distribution is relative to the provision of environmental goods. The parameter  $a$  is above unity when income inequality is relatively larger,  $CV_Y > CV_E$ , but below unity when environmental inequality is relatively larger,  $CV_Y < CV_E$ . I will now briefly discuss both cases in turn.

First, if income inequality is weakly greater than environmental inequality,  $CV_Y \geq CV_E$ , it follows directly that  $\rho < 1 \leq a$  as  $\rho \in (-1, 1)$ . Thus it becomes evident that for income inequality being weakly greater than environmental inequality,  $CV_Y \geq CV_E$ , mean WTP for the local environmental good always decreases (increases) with income inequality if and only if the environmental good is a substitute for (complement to) manufactured consumption goods.

Second, for the case of income inequality being lower than environmental inequality,  $CV_Y < CV_E$ , the effect of income inequality depends on the correlation,  $\rho$ . When poorer households are endowed with a comparably high level of the environmental good  $\rho < 0$ , then it generally holds that  $\rho < 0 < a$  as  $a > 0$ . Thus, we can directly conclude that if income and environmental good provision are negatively correlated,  $\rho < 0$ , mean WTP for the local environmental good decreases (increases) with income inequality if and only if environmental goods are substitutes (complements) to manufactured consumption

goods. Only for the case of the environmental good being distributed more unequally than income  $CV_Y < CV_E$  and richer households enjoying comparably high levels of the environmental good  $\rho > 0$  can the effect of income inequality become the reverse. Note that the more unequal the provision of environmental goods relative to the distribution of income, the lower  $a$  becomes and the less strongly positive the correlation,  $\rho$ , needs to be to end up in the case where societal WTP for environmental goods increases (decreases) with income inequality if and only if the environmental good and the private consumption good are substitutes (complements).

The rationale behind the reverse effect of income inequality on mean WTP in the case of a strongly positive correlation and relatively high environmental inequality is as follows: A decrease in income inequality means that at least one of the poorer households is better off, while at least one of the richer households is worse off and mean income in the society remains unchanged. This has two opposing effects. First, the environmental good being a substitute for consumption goods is equivalent to an income elasticity of WTP being below unity, i.e. richer households are willing to pay a smaller share of their income than poorer households for the environmental local public good. A reduction of income inequality therefore increases mean WTP, as the gains in WTP of the poorer household overcompensate for the losses in WTP of the richer household. Second, a positive correlation between income and the environmental local public good means that households with higher incomes enjoy more of the environmental good than households with lower incomes. For substitutes, a higher endowment with the environmental good contributes to a higher WTP, and thus for a positive correlation, to a higher WTP of richer households relative to their income. Through this second channel of the 'environmental-endowment-income-correlation' effect, reducing income inequality decreases mean WTP. Hence, in cases where the environmental good provision is more unequal than the distribution of income, the second effect might outweigh the first if the correlation between income and environmental good provision is sufficiently strong.

**Corollary 1** (E and Y distributed independently)

For the case of the environmental good and income being distributed independently

( $\rho = 0$ ), it holds that mean WTP for the environmental local public good,  $\mu_{\text{WTP}}^{\text{ind}}$  (Eq. (10)), decreases (increases) with relative income inequality,  $CV_Y$ , if and only if the environmental local public good and the private consumption good are substitutes (complements):

$$\frac{\partial \mu_{\text{WTP}}^{\text{ind}}(\mu_Y, CV_Y, \mu_E, CV_E)}{\partial CV_Y} \begin{matrix} \leq \\ \geq \end{matrix} 0 \text{ if and only if } \theta \begin{matrix} \geq \\ \leq \end{matrix} 1. \quad (13)$$

*Proof.* See Appendix A.5. □

*Question 3: How does environmental inequality affect society's mean WTP for a marginal increase in the environmental local public good?*

### Proposition 3

Mean WTP for the environmental local public good,  $\mu_{\text{WTP}}$ , decreases (increases) with relative environmental inequality,  $CV_E$ , if and only if the environmental good and the private consumption good are substitutes (complements) and their point correlation is lower than a weighted ratio of environmental and income inequality, *or* the environmental good and the private consumption good are complements (substitutes) and their point correlation is larger than a negative weighted ratio of environmental and income inequality.

$$\frac{\partial \mu_{\text{WTP}}(\mu_Y, CV_Y, \mu_E, CV_E, \rho)}{\partial CV_E} \begin{matrix} \leq \\ \geq \end{matrix} 0 \text{ if and only if } \begin{cases} \theta > 1, \rho < b & \text{or } \theta < 1, \rho > b \\ \theta = 1 & \text{or } \rho = b \\ \theta < 1, \rho < b & \text{or } \theta > 1, \rho > b \end{cases}, \quad (14)$$

where  $b := \sqrt{\frac{\ln(1+CV_E^2)}{\ln(1+CV_Y^2)}} = a^{-1}$  and  $\rho \neq 0$ .

*Proof.* See Appendix A.6. □

Proposition (3) depicts that for environmental local public goods, environmental inequality has a similar effect on mean WTP as income inequality. The effect of environmental inequality on the mean WTP for environmental local public goods is determined

both by whether the environmental good is a substitute for or complement to manufactured consumption goods and by how the correlation between environmental goods and income in the population of households,  $\rho$ , is related to the extent of environmental inequality relative to income inequality,  $b$ .

The logic behind the effect of environmental inequality on mean WTP for local public goods is as follows. For the case of substitutes,  $\theta \in (1, \infty)$ , which is for CES preferences analogous to an income elasticity of WTP below unity,  $\eta \in (0, 1)$ , individual WTP for the local public good increases with environmental good endowment  $E_i$ , but at a decreasing rate (see Eq. (3)). Thus, households that enjoy less of the environmental good ('environmentally poor' households) have a relatively higher WTP for the environmental local public good than households that enjoy more of the environmental good ('environmentally rich' households). A more equitable environmental good provision implies that at least one environmentally poor household faces an increase in environmental good endowment, while at least one environmentally rich household faces a decrease. As a result, the gains in WTP of environmentally poor households exceed the losses in WTP of environmentally rich households so that society's mean WTP for the environmental local public good increases.

When the provision of environmental goods in society is not independent of income, the effect of environmental inequality also depends on their correlation,  $\rho$ , relative to a weighted ratio of environmental inequality and income inequality,  $b$ . For environmental inequality weakly greater than income inequality,  $CV_E \geq CV_Y$ , the condition  $\rho < b$  is generally fulfilled as  $b > 1 > \rho$ . It also follows directly for a negative correlation,  $\rho < 0$ , that  $\rho < 0 < b$  as  $b > 0$ . Thus, Proposition (3) states that in societies where environmental inequality is higher than income inequality or where the correlation between income and environmental good provision is negative, mean WTP decreases (increases) with environmental inequality if and only if the environmental local public good is a substitute for (complement to) manufactured consumption goods. The effect of environmental inequality is reverse for cases of environmental inequality lower than income inequality and a positive correlation of income and environmental good provision, if only if the correlation is stronger than a weighted ratio of environmental and income

inequality.

**Corollary 2** (E and Y distributed independently)

For the case of the environmental good and income distributed independently ( $\rho = 0$ ), it holds that mean WTP for the environmental local public good,  $\mu_{\text{WTP}}^{\text{ind}}$  (Eq. (10)), decreases (increases) with relative environmental inequality,  $\text{CV}_E$ , if and only if the environmental local public good and the private consumption good are substitutes (complements):

$$\frac{\partial \mu_{\text{WTP}}^{\text{ind}}(\mu_Y, \text{CV}_Y, \mu_E, \text{CV}_E)}{\partial \text{CV}_Y} \begin{matrix} \leq 0 \\ \geq 0 \end{matrix} \text{ if and only if } \theta \begin{matrix} \geq 1 \\ \leq 1 \end{matrix}. \quad (15)$$

*Proof.* See Appendix A.7. □

Corollary 2 shows that for the case of environmental goods uncorrelated with income, the effect of environmental inequality on mean WTP,  $\mu_{\text{WTP}}^{\text{ind}}$ , is the same as of income inequality. This is of course due to the identical structure of the problem.

*Question 4: How does the correlation between income and environmental good endowment affects society's mean WTP for a marginal increase in the environmental local public good?*

Next, I study how a change in the correlation between environmental good endowment and income,  $\rho$ , affects the societal valuation of the environmental local public good,  $\mu_{\text{WTP}}$ . A change in  $\rho$  might result from an environmental policy altering the spatial distribution of environmental amenities or of households adapting their location to the spatial distribution of environmental goods ('sorting').

Household sorting will generally change how income and endowment with the environmental local public good is correlated within society. Richer (poorer) households moving to places where environmental quality is high will increase (decrease) the correlation,  $\rho$ , between income and environmental good endowment. The effect of sorting on societal WTP can thus indirectly be studied via its effect on  $\rho$ .

Recall that to focus my model on valuation, I treat the level of the environmental good enjoyed as exogenous from the viewpoint of the household, and therefore do not

study sorting explicitly. I nevertheless sketch in Appendix A.8 for a simple case of two income groups and CES preferences that in a situation where neighborhood sorting arises only from differences in the endowment with the environmental good, households with higher incomes will sort into places with higher environmental quality. In such a situation, sorting increases the correlation between income and endowment with the environmental local public good,  $\rho$ . This finding is in line with other theoretical models on how households adapt their place of residence to the spatial distribution of environmental goods. In a seminal paper, Brueckner et al. (1999) show that if households have CES preferences over a consumption good, a housing good, and an amenity, and if these goods are substitutes, then the marginal valuation of amenities increases faster than housing consumption with income, resulting in richer households living where the amenity value is high (abstracting from commuting cost). Heblich et al. (2017) and Lee and Lin (2018) study models with two neighborhoods, two income groups, and Cobb-Douglas preferences regarding environmental amenities and consumption goods, and find that richer households sort into neighborhoods where the endowment with the environmental amenity is high.

**Proposition 4**

Mean WTP for the local environmental public good,  $\mu_{WTP}$ , increases (decreases) with the correlation between income and environmental good endowment in society,  $\rho$ , if and only if the local environmental public good and the private consumption good are substitutes (complements).

$$\frac{\partial \mu_{WTP}(\mu_Y, CV_Y, \mu_E, CV_E, \rho)}{\partial \rho} \underset{\leq}{\underset{\geq}} 0 \text{ if and only if } \theta \underset{\geq}{\underset{\leq}} 1. \quad (16)$$

*Proof.* See Appendix A.9.

□

Proposition 4 shows that the way an increase in the correlation between income and endowment with the environmental local public good,  $\rho$ , affects societal WTP,  $\mu_{WTP}$ , is determined by the substitutability between private consumption goods and the environmental good,  $\theta$ . An increase in  $\rho$  reinforces societal WTP for the environmental

good for the case of substitutes, but decreases societal WTP in the case of complements. For instances where household sorting increases the correlation of environmental good endowment and income,  $\rho$ , it will thus indirectly increase (decrease) societal WTP for the local environmental public good if this is a substitute for (complement to) manufactured consumption goods.

### 3.2 Benefit transfer and environmental local public goods

Next, I derive structural transfer factors to account for differences in the distribution of the environmental local public good and income. These transfer factors can be used to adjust WTP estimates from primary valuation studies to inform environmental policy and management in other contexts, as well as to adjust for the socially desired distribution. In benefit transfer, WTP estimates from a valuation study conducted in one context  $s$  – the ‘study’ site – inform policy making in other context  $p$  – the ‘policy’ site. Based on the model set-up presented above, I specify the benefit transfer function approach (e.g. Loomis 1992) for environmental local public goods.

#### Proposition 5

Assume households’ preferences  $(\theta, \alpha)$  are identical at study site  $s$  and policy site  $p$ . If at the study site mean WTP for the environmental local public good is  $\mu_{\text{WTP}}^s$  (Eq. 9), the market price level for consumption goods is  $P^s$ , mean income is  $\mu_Y^s$ , relative income inequality is  $\text{CV}_Y^s$ , the mean quantity of the environmental local public good is  $\mu_E^s$ , the relative environmental inequality is  $\text{CV}_E^s$  and the correlation between income and the environmental local public good is  $\rho^s$ , then at the policy site with  $(P^p, \mu_Y^p, \text{CV}_Y^p, \mu_E^p, \text{CV}_E^p, \rho^p)$  the mean WTP for the environmental local public good is given as

$$\mu_{\text{WTP}}^p = \mathcal{T}(P^p, \mu_Y^p, \text{CV}_Y^p, \mu_E^p, \text{CV}_E^p, \rho^p; P^s, \mu_Y^s, \text{CV}_Y^s, \mu_E^s, \text{CV}_E^s, \rho^s) \cdot \mu_{\text{WTP}}^s, \quad (17)$$

where the transfer function  $\mathcal{T}()$  factorizes into the following transfer factors

$$\begin{aligned} & \mathcal{T}(P^p, \mu_Y^p, \text{CV}_Y^p, \mu_E^p, \text{CV}_E^p, \rho^p; P^s, \mu_Y^s, \text{CV}_Y^s, \mu_E^s, \text{CV}_E^s, \rho^s) \\ &= \mathcal{T}_P(P^p, P^s) \cdot \mathcal{T}_{\mu_Y}(\mu_Y^p, \mu_Y^s) \cdot \mathcal{T}_{\mu_E}(\mu_E^p, \mu_E^s) \cdot \mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(\text{CV}_Y^p, \text{CV}_E^p, \rho^p, \text{CV}_Y^s, \text{CV}_E^s, \rho^s), \end{aligned} \quad (18)$$

with

$$\mathcal{T}_P(P^p, P^s) = \left( \frac{P^p}{P^s} \right)^{\frac{\theta-1}{\theta}}, \quad (19)$$

$$\mathcal{T}_{\mu_Y}(\mu_Y^p, \mu_Y^s) = \left( \frac{\mu_Y^p}{\mu_Y^s} \right)^{\frac{1}{\theta}}, \quad (20)$$

$$\mathcal{T}_{\mu_E}(\mu_E^p, \mu_E^s) = \left( \frac{\mu_E^p}{\mu_E^s} \right)^{\frac{\theta-1}{\theta}}, \quad (21)$$

$$\begin{aligned} \mathcal{T}_{CV_Y, CV_E, \rho}(CV_Y^p, CV_E^p, \rho^p, CV_Y^s, CV_E^s, \rho^s) &= \left( \frac{1 + CV_Y^{p2}}{1 + CV_Y^{s2}} \right)^{\frac{1-\theta}{2\theta^2}} \cdot \left( \frac{1 + CV_E^{p2}}{1 + CV_E^{s2}} \right)^{\frac{1-\theta}{2\theta^2}} \\ &\cdot \exp \left[ \frac{\theta-1}{\theta^2} \left( \rho^p \sqrt{\ln(1 + CV_Y^{p2}) \ln(1 + CV_E^{p2})} - \rho^s \sqrt{\ln(1 + CV_Y^{s2}) \ln(1 + CV_E^{s2})} \right) \right]. \end{aligned} \quad (22)$$

*Proof.* See Appendix A.10. □

Proposition 5 shows how to control for differences in income inequality, environmental inequality and the correlation of income and endowment with the environmental good by using a closed-form transfer factor  $\mathcal{T}_{CV_Y, CV_E, \rho}$ . The transfer factor  $\mathcal{T}_{CV_Y, CV_E, \rho}$  captures the dynamics studied in Proposition 2 - 4. It is thus not surprising that  $\mathcal{T}_{CV_Y, CV_E, \rho}$  can be greater or smaller than unity – implying a downward or upward adjustment of societal WTP – depending on whether income and the environmental good are distributed more equally at the study site or at the policy site, whether the income and the environmental good are more strongly correlated at the policy or at the study site, and whether the environmental good is a substitute for or complement to manufactured consumption goods. Note that for  $\theta = 1$ , no adjustment is necessary,  $\mathcal{T}_{CV_Y, CV_E, \rho} = 1$ .

This transfer factor might also be applied to account for sorting effects. Governmental project appraisal on the efficient allocation of environmental local public goods are usually done ex-ante, i.e. before project implementation, and therefore capture households' current WTP. If the project is actually implemented, the distribution of environmental goods will change and thereby induce sorting effects, changing the correlation between income and endowment with the environmental local public good,  $\rho$ , which in turn changes societal WTP. Welfare analyses will aim at measuring WTP both ex-ante

and ex-post in order to assess welfare gains and identify who might (potentially) need to compensate whom. Thus, welfare analysis generally requires information on household WTP after project implementation and sorting has taken place. The transfer factor  $\mathcal{T}_{CV_Y, CV_E, \rho}$  shows how to correct WTPs elicited ex-ante to be used for ex-post welfare analysis by specifying  $\rho^s$  and  $\rho^p$ .

Moreover, the transfer factor might be applied in the context of sustainability policy that aims at the two normative goals of allocative efficiency and distributional justice (Baumgärtner and Quaas 2010). To attain the normative goal of distributional justice, resources have to be redistributed within society, and to ensure allocative efficiency, mean WTPs have to be adjusted when conducting efficiency analysis in accordance with the target distribution (Drupp et al. 2018).<sup>9</sup> When efficiency is assessed by the means of environmental cost-benefit analysis the proposed transfer factor might be employed to directly adjust mean WTP for the desired distribution.

For  $E$  and  $Y$  being distributed independently ( $\rho = 0$ ) at both sites, the transfer factor for inequalities  $\mathcal{T}_{CV_Y, CV_E, \rho}^{ind}$ , Eq. (22), simplifies to two disentangled transfer factors for income inequality and environmental inequality (Appendix A.10):

$$\mathcal{T}_{CV_Y, CV_E}^{ind}(CV_Y^p, CV_E^p, CV_Y^s, CV_E^s) = \left( \frac{1 + CV_Y^{p2}}{1 + CV_Y^{s2}} \right)^{\frac{1-\theta}{2\theta^2}} \cdot \left( \frac{1 + CV_E^{p2}}{1 + CV_E^{s2}} \right)^{\frac{1-\theta}{2\theta^2}} \quad (23)$$

$$=: \mathcal{T}_{CV_Y}(CV_Y^p, CV_Y^s) \cdot \mathcal{T}_{CV_E}(CV_E^p, CV_E^s). \quad (24)$$

Note that as  $\mathcal{T}_{CV_Y, CV_E}^{ind}$  factorizes into two variable-specific factors, one can correct for differences in  $CV_Y$  or  $CV_E$  separately and without paying attention to the other type of inequality. In this case the transfer factors for environmental inequality is absolute analogue to the one for income inequality.

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<sup>9</sup>According to Lindahl-Samuelson, a necessary condition for a Pareto-efficient allocation is that the sum of household WTPs – or the product of mean WTP and the number of households – equals the marginal costs of providing the environmental local public good (Samuelson 1954).

## 4 Empirical application

Next I illustrate empirical magnitudes for a case study on forest preservation in Poland. This application serves the purpose of assessing whether the argument developed above is associated with considerable economic effect sizes that warrant the actual use of the novel benefit transfer factor,  $\mathcal{T}_{CV_Y, CV_E, \rho}$ , in public policy making. I draw on a valuation study offering a unique case for illustration, as WTP was elicited for a single national environmental good ('Polish ecologically-valuable forest'), the access to which differs in society ('proximity to the next forest') and substantially affects households' WTPs.

Forests are subject to high rates of degradation and deforestation globally. Until the late nineteenth century, deforestation was most pronounced in the temperate climate zone, where recent decades have seen net gains in forest area (FAO 2016). Forests serve crucial ecological functions such as carbon sequestration, water purification, and soil conservation, and offer habitats for a variety of wildlife (FAO 2016). They contribute substantially to human well-being (SCBD 2001), with forest ecosystem services encompassing a range of use values, such as timber supply and opportunities for recreation, as well as non-use values, such as the existence values of various rare flora and fauna. A forest's actual array of ecosystem services depends on the management regime and varies from heavily economically used forests, which are associated with high timber production but little biodiversity and recreational value, to pristine forests, which are associated with very little timber production but high biodiversity and recreational value (SCBD 2001). People live in different proximities to forests, which is likely to result in an unequal distribution of forest ecosystem services, such as recreational values. Thus, forests are likely to exhibit local public good characteristics.

Polish forests are among the largest and most valuable forests in Europe. 29.3% of Poland's land area is covered by forest, including the Bialawiza forest, which is commonly referred to as the last lowland forest in temperate Europe with primeval fragments (CBD Fifth National Report of Poland 2014). Overall, 65% of Poland's biodiversity resources and 50% of Poland's Natura 2000 sites are situated in forests (Czajkowski et al. 2009, CBD Fifth National Report of Poland 2014). Approximately 3% of Poland's 90,000 km<sup>2</sup>

total forest area is considered to be highly ecologically valuable, as it is still in almost pristine condition. Only half of this forest area is under effective nature protection (Czajkowski et al. 2017). The remaining half is under pressure from human use and exploited as regular economically used forests (Czajkowski et al. 2014a).

To investigate the relationship between the distribution of forest ecosystem services and income and the societal WTP for forest protection, I draw on survey and forest data studied in depth by Budziński et al. (2018) and Czajkowski et al. (2014a,b, 2017). Respondents were asked for their willingness to pay for an increase in national income taxes for different national forest management options, including protecting all of Poland’s most ecologically valuable forests (3% of the Polish forest area).<sup>10</sup> The survey was carried out on a representative sample of 1001 Polish adults in January 2010 employing face-to-face computer-assisted interviews. To ensure representativeness, a multi-stage sampling strategy was applied, randomly selecting first communities and then adult household members. Survey data included respondents’ household income and ZIP codes. Additionally data on forest characteristics at a high spatial resolution were obtained from the European Environmental Agency’s CORINE Land Cover dataset and the Polish Information System of State Forests and aggregated on  $10 \times 10\text{km}^2$  grid squares.<sup>11</sup>

A subset of  $N = 714$  respondents also provided information on their monthly net household income [in 2011-PLN], defining the sample used in the following. Income,  $Y_i$ , is distributed with a mean of  $\mu_Y^s = 2758$  and a standard deviation of  $\sigma_Y^s = 1857$ , corresponding to a relative income inequality of  $CV_Y^s = 0.66$ . With this, the sample’s relative income inequality is slightly below the national average according to official statistics.<sup>12</sup>

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<sup>10</sup>Respondents were informed that forest protection would mean prohibiting any human interference except recreational use.

<sup>11</sup>For further details on the survey design, see Czajkowski et al. (2014a), and on forest data, see Czajkowski et al. (2017).

<sup>12</sup>The World Bank estimates a coefficient of variation of disposable household income for Poland of  $CV_Y^{\text{POL}} = 0.69$  (Zaidi 2009), based on data from the 2006 European Union Survey of Income and

I use a household’s forest proximity as a proxy for the endowment with forest ecosystem services,  $E_i$ . Forest proximity is measured as the inverse of the average Euclidean distance from any point in a respondent’s  $10 \times 10\text{km}^2$  grid square to the nearest forest (Czajkowski et al. 2017). Proximity is chosen as a proxy for the endowment with forest ecosystem services as it has the strongest effect on WTP for forest protection among different forest characteristics – such as area of coniferous forest, deciduous forest, mixed forest, old or particularly biodiverse forest – with larger distances substantially reducing WTP for forest protection (Czajkowski et al. 2017). The coefficient of variation of households’ forest proximity is  $CV_E^s = 0.57$ . Thus, forest proximity is more equally distributed than income in Poland. The correlation between respondents’ forest proximity,  $E_i$ , and household income,  $Y_i$ , is  $\rho^s = -0.1$ .<sup>13</sup> Thus, richer households tend to live further away from forests in Poland. The average distance to the nearest forest, the location of respondents, and their household income is depicted in Figure 1. Histograms on the distribution of  $Y_i$  and  $E_i$  are depicted in Appendix A.11.

I complement these data from Czajkowski et al. (2017) with a parameter range for the elasticities of substitution,  $\theta$ , found in two global meta-studies.<sup>14</sup> Thereby I infer  $\theta$  indirectly from the income elasticities of WTP,  $\eta$ , as elicited in recent valuation studies. As a best guess estimate, I take the income elasticity of WTP for forest ecosystem services from Chiabai et al. (2011), who provide a global meta-study on forest ecosystem services encompassing 86 WTP estimates from 27 valuation studies. They estimate an income elasticity of WTP for forest recreation of  $\eta = 0.63$  and for non-use forest ecosystem services of  $\eta = 0.75$ . As the forest preservation under question would allow

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Living Conditions. In a contingent valuation study on water quality improvement in the Baltic Sea conducted in 2011, a representative sample of Polish respondents exhibited exactly the same coefficient of variation of their monthly disposable income (Meya et al. 2017).

<sup>13</sup>The correlation coefficient  $\rho$  is significant at the  $p < 0.01$  level.

<sup>14</sup>The use of an elasticity of substitution from meta-studies is in line with the model assumption that people have identical preferences. While I only aim at illustrating ranges, I admit that these general measures for the elasticity of substitution will most likely not be a precise estimate for the population and ecosystem service under consideration, but might arguably be more accurate for a policy site.

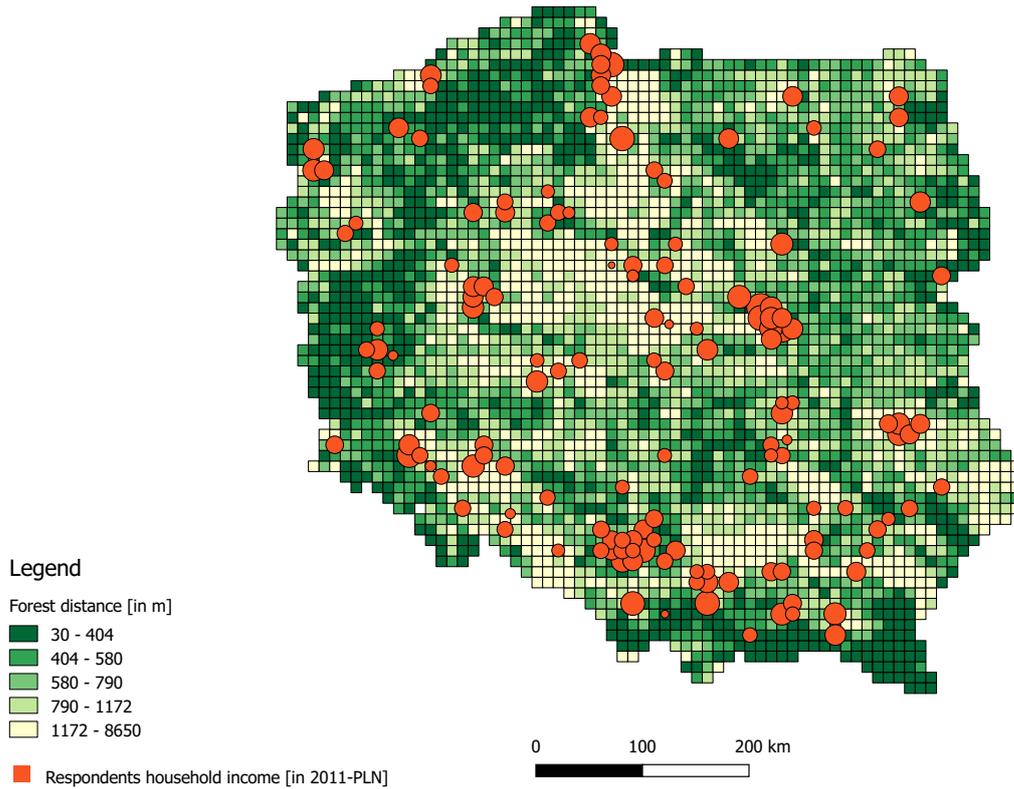


Figure 1: Spatial distribution of distance to forests in Poland and respondents' income. Circle sizes represent mean household income stated by respondents in the  $10 \times 10 \text{ km}^2$  grid square of their residency. The average Euclidean distance from each point in a  $10 \times 10 \text{ km}^2$  grid square to the nearest forest is shown in green.

for recreational use, I take the arithmetic mean of both elasticities and derive as its inverse the elasticity of substitution between non-consumptive forest ecosystem services and manufactured consumption goods,  $\theta^{\text{forest}} = \left(\frac{0.63+0.75}{2}\right)^{-1} = 1.46$ .<sup>15</sup> Additionally I take a range of elasticities of substitution from Drupp (2018), who reviews existing empirical estimates for the income elasticity of WTP from contingent valuation studies since 2000 for different ecosystems and services to indirectly assess  $\theta$ , finding a range

<sup>15</sup>Remarkably, this is close to an income elasticity elicited for another type of environmental local public good in the same region. Czajkowski and Scasny (2010) find an income elasticity of WTP of  $\eta = 0.64$ , corresponding to an elasticity of substitution of  $\theta = 1.56$ , for lake water quality improvements in Poland and the Czech Republic.

Table 1: Parameter values used in empirical application.

Variable	Value	Source
elasticity of substitution ( $\theta^{\text{forest}}[\theta^{\text{min}}; \theta^{\text{max}}]$ )	1.46 [0.86; 7.14]	Chiabai et al. (2011), Drupp (2018)
coefficient of variation of forest proximity ( $CV_E^s$ )	0.57	Own calculation based on Czajkowski et al. (2017)
coefficient of variation of dispo- sable household income ( $CV_Y^s$ )	0.66	Czajkowski et al. (2014a)
correlation of income and forest proximity ( $\rho^s$ )	-0.10	Own calculation based on Czajkowski et al. (2017)

from  $\theta^{\text{min}} = 0.86$  to  $\theta^{\text{max}} = 7.14$ .<sup>16</sup> I use these three estimates to explore the effect of different degrees of substitutability between forest ecosystem services and manufactured consumption goods. All parameter inputs are summarized in Table 1.

I now study how my model predicts societal WTP for forest protection to change if households were more (un)equal in their proximity to forests, if household income were distributed more (un)equally, or if forest proximity were more strongly negatively (positively) correlated with income. To this end, I specify the transfer factor  $\mathcal{T}_{CV_Y, CV_E, \rho}$  (Eq. (22)) with the parameters in Table 1 for different hypothetical choices of  $CV_Y^p$ ,  $CV_E^p$  and  $\rho^p$ .<sup>17</sup>

The resulting WTP adjustments are considerable (Table 2). Hypothetically reducing environmental inequality to zero,  $\mathcal{T}_{CV_Y, CV_E, \rho}(CV_Y^s, 0, 0, CV_Y^s, CV_E^s, \rho^s)$ , would increase

<sup>16</sup>Drupp (2018) finds a mean of  $\theta^{ES} = 2.31$  across all kinds of ecosystem services, which implies a slightly larger degree of substitutability than I assume here for forest ecosystem services based on Chiabai et al. (2011).

<sup>17</sup>For  $CV_Y^p$  or  $CV_E^p$  equal to zero, i.e. when the standard deviation of  $Y$  or  $E$  is zero, the correlation coefficient  $\rho$  does not exist. I therefore assume independently distributed endowments with the environmental good and income,  $\rho = 0$ , to evaluate these extreme scenarios.

Table 2: Resulting transfer factors to correct WTP for differences in the distribution environmental local public good and income.

Transfer factor	$\theta^{\text{forest}} = 1.46$	$\theta^{\text{min}} = 0.86$	$\theta^{\text{max}} = 7.14$
$\mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(\text{CV}_Y^s, 0, 0, \text{CV}_Y^s, \text{CV}_E^s, \rho^s)$	1.04	0.97	1.04
$\mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(0, \text{CV}_E^s, 0, \text{CV}_Y^s, \text{CV}_E^s, \rho^s)$	1.05	0.96	1.05
$\mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(0, 0, 0, \text{CV}_Y^s, \text{CV}_E^s, \rho^s)$	1.08	0.94	1.07
$\mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(\text{CV}_Y^s, 2\text{CV}_E^s, \rho^s, \text{CV}_Y^s, \text{CV}_E^s, \rho^s)$	0.94	1.06	0.95
$\mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(2\text{CV}_Y^s, \text{CV}_E^s, \rho^s, \text{CV}_Y^s, \text{CV}_E^s, \rho^s)$	0.93	1.07	0.94
$\mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(\text{CV}_Y^s, \text{CV}_E^s, 0, \text{CV}_Y^s, \text{CV}_E^s, \rho^s)$	1.01	0.99	1.03
$\mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(\text{CV}_Y^s, \text{CV}_E^s, -0.5, \text{CV}_Y^s, \text{CV}_E^s, \rho^s)$	0.96	1.02	0.90
$\mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(\text{CV}_Y^s, \text{CV}_E^s, 0.5, \text{CV}_Y^s, \text{CV}_E^s, \rho^s)$	1.06	0.97	1.18

mean WTP by 4 %. As income inequality is larger in the status quo, reducing it to zero,  $\mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(0, \text{CV}_E^s, 0, \text{CV}_Y^s, \text{CV}_E^s, \rho^s)$ , would imply a slightly higher upward adjustment of WTP by 5 %. Adjusting for the even more extreme situation with an equal distribution of forest proximity and income,  $\mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(0, 0, 0, \text{CV}_Y^s, \text{CV}_E^s, \rho^s)$ , societal WTP for forest protection would be 8% higher. If forest ecosystem services were complements,  $\theta^{\text{min}}$ , the effect would be reversed, and a complete egalitarian distribution would imply a downward adjustment of societal WTP by 6%.

It is also apparent from comparing  $\mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(0, 0, 0, \text{CV}_Y^s, \text{CV}_E^s, \rho^s)$  for  $\theta^{\text{forest}}$  and  $\theta^{\text{max}}$  that the required WTP adjustment does not strictly increase or decrease with the degree of substitutability,  $\theta$ . Figure 2 depicts  $\mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(0, 0, 0, \text{CV}_Y^s, \text{CV}_E^s, \rho^s)$  as a function of  $\theta$ , which has its maximum value close to the mean elasticity of substitution reviewed by Drupp (2018) for global ecosystem services,  $\theta^{\text{ES}}$ , and decreases sharply with stronger complementarity,  $\theta \rightarrow 0$ , where predicted adjustments become enormous. Moreover, I find that for a doubling of current environmental inequality or income inequality – implying adjustment factors of  $\mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(\text{CV}_Y^s, 2\text{CV}_E^s, \rho^s, \text{CV}_Y^s, \text{CV}_E^s, \rho^s)$  or  $\mathcal{T}_{\text{CV}_Y, \text{CV}_E, \rho}(2\text{CV}_Y^s, \text{CV}_E^s, \rho^s, \text{CV}_Y^s, \text{CV}_E^s, \rho^s)$  – WTP would decrease by 6% or 7%, respec-

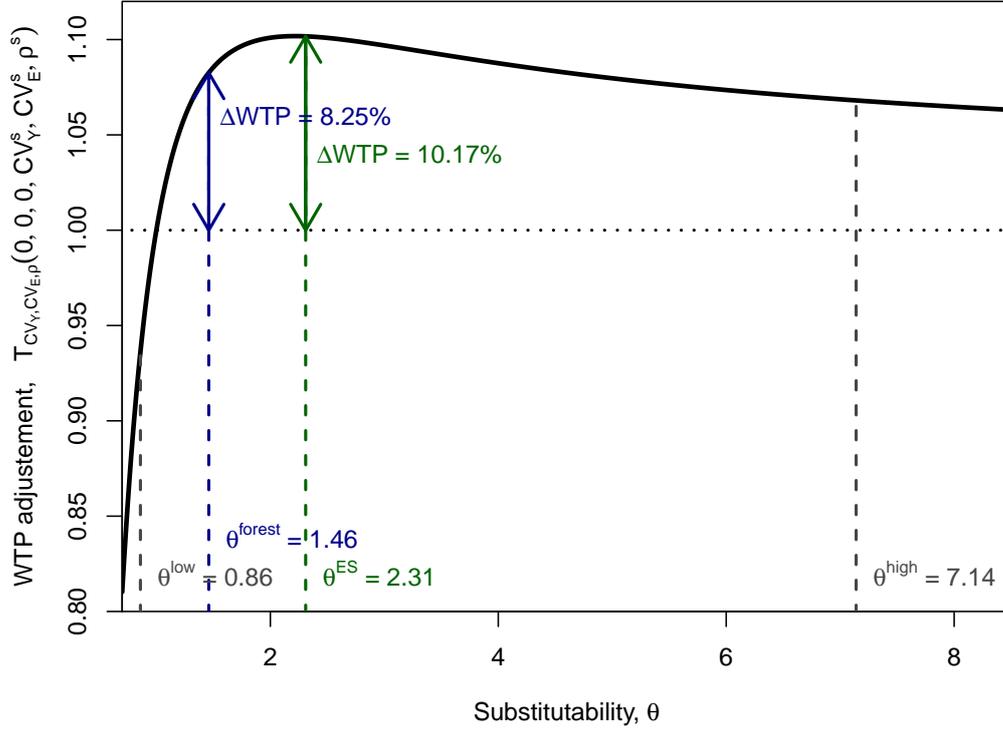


Figure 2: Relationship between the transfer factor to adjust societal WTP for differences in the distribution of the environmental local public good and income,  $\mathcal{T}_{CV_Y, CV_E, \rho}$ , and different degrees of substitutability. In the hypothetical transfer depicted, the societal WTP for forest protection in Poland is adjusted to a situation where proximity to forests and income is distributed equally over the population.

tively. Again, the larger effect of income inequality thereby reflects that income is more unequally distributed in Poland than forest proximity.

Finally, I find that differences in the correlation between environmental good endowment and income require remarkable WTP adjustment. All else equal, in a situation where forest proximity and income were positively correlated with a Pearson correlation coefficient of  $\rho^p = 0.5$  societal WTP would be 6% higher than elicited in the present study, corresponding to a transfer factor of  $\mathcal{T}_{CV_Y, CV_E, \rho}(CV_Y^s, CV_E^s, 0.5, CV_Y^s, CV_E^s, \rho^s)$ . For a high degree of substitutability, this would imply a WTP adjustment of 18%. For

complements,  $\theta^{\min}$ , the case would be the opposite: societal WTP would be lowered by 3%. Figure 5 (Appendix A.11) illustrates  $\mathcal{T}_{CV_Y, CV_E, \rho^p}(CV_Y^s, CV_E^s, \rho^p, CV_Y^s, CV_E^s, \rho^s)$  as a function of  $\rho^p$  for different degrees of substitutability.

These estimates illustrate the importance of considering the distribution of environmental goods and income when aggregating WTP for environmental local public goods and in particular when using these aggregate WTPs in benefit transfer or environmental cost-benefit analysis.<sup>18</sup>

## 5 Discussion

Here I discuss several assumptions made in the analysis and the extent to which these might limit the generality of my results. These assumptions are (i) the absence of household mobility, (ii) the purely bio-physical heterogeneity in environmental good endowment, (iii) the log-normal distribution of the environmental local public good, and (iv) the coefficient of variation as a measure of environmental inequality.<sup>19</sup>

First, there is no household mobility and in particular no sorting with respect to environmental quality in the main model. The model framework studied here allows me to evaluate an exogenous change in the correlation between environmental good endowment and income (in Appendix (A.8), I sketch how sorting will increase this correlation under certain conditions), but does not anticipate sorting effects induced by a change in the distribution of an environmental local public good. Hence, the proposed benefit transfer factors do not account for sorting effects, and are thus valid in the short run (before sorting takes place), or valid for the evaluation of environmental policies and projects that are ‘small’ in the sense that the resulting change in the distribution of the

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<sup>18</sup>As expected, differences in the mean forest proximity and mean income require comparably larger adjustments. For instance, doubling mean forest proximity,  $\mathcal{T}_{\mu_E}(2\mu_E^s, \mu_E^s)$ , would imply an upward adjustment of mean WTP by 24.37%, and doubling mean income,  $\mathcal{T}_{\mu_Y}(2\mu_Y^s, \mu_Y^s)$ , would even imply an upward adjustment of mean WTP by 60.81%.

<sup>19</sup>For a discussion of the CES utility function employed, the equal-preference framework, as well as the log-normal distribution of income, the reader is referred to Baumgärtner et al. (2017).

environmental good is not large enough to motivate households to move. Turner (2017) makes a first conceptual attempt to account in benefit transfer for the possibility that people and firms change locations in response to a ‘large’ environmental regulation. Future research could attempt to extend my model to endogenous sorting. Since valuation studies indicate that the income elasticity of WTP is below unity, my model nevertheless suggests that sorting is likely to increase the societal value of environmental local public goods by changing the correlation between environmental goods and income in society. Whether changes in the specific environmental goods studied in the valuation literature are below or above a level that induces households to move is ultimately an empirical question that remains to be answered in future research.

Second, I studied a heterogeneous distribution of environmental benefits over households in a society arising only from an uneven distribution of biophysical quantities,<sup>20</sup> but there are other sources of heterogeneity in environmental benefits. In particular, an uneven distribution of benefits might result from heterogeneous preferences regarding the environmental good or because vulnerability – for example, measured as ‘dose-response functions’ – differs across groups within a society (Hsiang et al. 2017). Moreover, it seems plausible that both preferences regarding the environment and dose-response functions differ across income groups. However, there is little empirical research to date on these sources of heterogeneity and how they are linked to income. Furthermore, empirical measurement of biophysical environmental good endowment is already challenging (Hsiang et al. 2017). For simplicity and applicability, I therefore stick to the simplest case of heterogeneity in the physical endowment with environmental goods and leave other sources of heterogeneity as an issue for future research.

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<sup>20</sup>Measuring exposure to environmental goods and the corresponding environmental inequality is often challenging. While the unit of observation for measuring economic inequality is usually the individual or household, the exposure to environmental goods and ‘bads’ is usually not known on the level of the individual or household. In order to avoid errors in inferring individual exposure from aggregate data, one should aim at using small-scale data (Boyce et al. 2016). However, in primary valuation studies, it is often straightforward to collect data on the endowment with environmental goods from respondents, for instance, the distance to environmental amenities or the frequency of visits.

Third, I approximated the distribution of the environmental good by a log-normal distribution. It is necessary to assume a specific distributional form in order to derive closed-form solutions and to develop parameterized adjustment factors for benefit transfer. Employing a continuous representation extends upon the previous dichotomous representations in stylized two-region models in the sorting literature. The assumption of log-normality is certainly only a first approximation, and its empirical fit has to be tested in further applications. Nevertheless, the assumption of log-normal distribution is generally in line with empirical evidence that the distribution of environmental goods and ‘bads’ is non-negative and right-skewed, which makes it a preferred choice over symmetric distributions like a normal distribution. It has been shown, for instance, in the case of Singapore, that access to urban green spaces in cities is strongly right-skewed (Tan and Samsudin 2017), which also holds true for exposure to industrial air pollution in the U.S. (Boyce et al. 2016). Moreover, airborne particulate matter in London seems to follow a log-normal distribution (MacKerron and Morato 2009), as does historic air pollution in English cities (Heblich et al. 2017, Fig A7ab).

Finally, I employed the coefficient of variation,  $CV_E$ , as a measure of environmental inequality, but there are several other measures that one could apply. Using the  $CV_E$  is in line with the idea of relative inequality, which feature prominently in scientific and public debates on distributive justice. For instance, Chancel and Piketty (2015) find that relative inequality in individual CO<sub>2</sub>-eq emissions increased over the period from 1998 to 2013 and interfere from this design options for an equitable financing of global climate adaptation. However, one might argue that when considering the endowment with environmental goods and exposure to environmental pollution, such as air pollution, water pollution or noise, it is the absolute level and hence the absolute inequality that matters for health and general well-being. However, employing a relative and thereby unit-less measure was advantageous for the purpose of this study, as it allows a direct comparison between environmental and income inequality (see Propositions 2 and 3). Again, I leave an extension to other measures of environmental inequality for future work.

## 6 Conclusion

I have studied how environmental and income inequality affect the valuation of environmental local public goods. To this end, I analyzed a model in which households have identical preferences characterized by a constant elasticity of substitution utility function and are heterogeneous in both their endowment with a local public good and their income.

My main results are: (i) there is a positive (negative) scope effect, if and only if the environmental good and consumption goods are substitutes (complements); (ii) the effect of environmental and income inequality on mean WTP for the environmental local public good is determined by whether the environmental good is a substitute for or a complement to manufactured consumption goods and by how environmental good endowment is correlated with income; (iii) an increase in the correlation between environmental good endowment and income – for example, due to richer households sorting into places where environmental quality is high – increases (decreases) mean WTP if and only if the environmental good and consumption goods are substitutes (complements). Moreover, I derived closed-form transfer factors for application in benefit transfer and environmental cost-benefit analysis that account for differences in the distribution of the environmental good and income and which are particularly simple if both are distributed independently. Using a forest preservation in Poland as an example, I illustrated that this theory-based adjustment is associated with considerable effect sizes – increasing societal WTP by up to 8% for an equal distribution of the environmental good and income compared to the status quo. Note that these results also hold for the valuation of non-environmental local public goods, such as transportation infrastructure or historical amenities that are exogenously given.

These findings extend the recent literature on how income inequality affects mean WTP for pure public goods. In particular, I showed that the key result of Baumgärtner et al. (2017) according to which mean WTP decreases (increases) with relative income inequality if and only if the environmental good and the consumption good are substitutes (complements) also holds for local public goods in cases where (i) they are

distributed independently of income, (ii) their endowment is negatively correlated with income, or (iii) relative income inequality is larger than relative environmental inequality. Moreover, the transfer factor for income inequality proposed by Baumgärtner et al. (2017) and empirically validated by Meya et al. (2017) for a multi-country valuation study, also holds for environmental local public goods uncorrelated with income.

My results are relevant in several respects: First, when applying benefit transfer to value local public goods one should correct for differences in environmental good provision and its correlation with income. Public policy making frequently uses secondary data in cost-benefit analysis, as primary valuation studies are time intensive and costly. Therefore, ‘value’ or ‘benefit transfer’ has become a dominant method of environmental valuation (Pearce et al. 2006, Richardson et al. 2015) and is by now “far more pervasive to policy analysis than many perhaps [...] realize” (OECD 2018, p.160). The development of benefit transfer methods in the context of environmental local public goods is of major importance for environmental policy and management, as most environmental goods are distributed unevenly. Government agencies are required to conduct environmental valuation and cost-benefit analysis on local public goods under several regulatory acts, such as the EU Water Framework Directive, the European Marine Strategy Framework Directive, and U.S. regulations like the Clean Air Act. However, even though a grounding of benefit transfers in economic theory is generally held to ensure quality (Smith et al. 2002), the practical application of such structural benefit transfers remains very limited in the domains of policy making and management, probably due to the advanced micro-economic skills required (Phaneuf and Requate 2017: 685). Here, I contribute to the development of structural benefit transfer by clarifying the conditions under which existing transfer factors may be used to value local public goods and by presenting novel transfer factors to control for differences in their distribution. I thus hope to serve the high policy demand to improve benefit transfer methods for natural capital accounting (United Nations et al. 2014), in particular regarding the scaling-up of site-specific WTP estimates to larger areas.<sup>21</sup>

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<sup>21</sup>Another extension that it necessary to make the structural benefit transfer approach of

Second, when conducting validity tests of environmental valuation studies one should also consider the substitutability of the valued environmental good. The existence of a positive scope effect is a key criterion for assessing the construct validity of stated preference studies. Against the backdrop of the controversies on contingent valuation following the Exxon Valdez oil spill, the NOAA panel suggested to cast doubt on the reliability of contingent valuation studies if the elicited WTPs show “[i]nadequate responsiveness to the scope” (Arrow et al. 1993, p.37) of the environmental good, as “[u]sually, though not always, it is reasonable to suppose that more of something regarded as good is better so long as an individual is not satiated” (Arrow et al. 1993, p.11). Many studies on scope sensitivity take the statement that economic theory predicts an increase in WTP for an increase in the environmental good as their point of departure (e.g. Borzykowski et al. 2018, Whitehead 2016).<sup>22</sup> However, several valuation studies do not find a sensitivity to scope or even find a negative scope effect,<sup>23</sup> which has spurred a heated debate on the reliability of the contingent valuation method as a whole. This paper adds another explanation from economic theory to the debate on scope effects:<sup>24</sup> The existence of a negative scope effect might result from the environmental good under examination being a complement to manufactured consumption goods, and the absence of a scope effect might result from Cobb-Douglas preferences over the environmental good under examination and consumption goods.

Third, my study highlighted the importance of accounting for the spatial distribution of environmental goods and income when aggregating WTP for local public goods

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Baumgärtner et al. (2017) suitable for natural capital accounting is to generalize the model framework from a static to a dynamic setting, as done in Meya et al. (2018).

<sup>22</sup>Sensitivity to scope is commonly tested by comparing mean WTP values from split samples in which WTP is elicited for different qualities or quantities of the environmental good.

<sup>23</sup>For instance, Ojea and Loureiro (2011) provide an overview of meta-studies that test the effect of the quantity of the environmental good on mean WTP. Of the 14 meta-studies reported, six find no or a negative scope effect.

<sup>24</sup>Banerjee and Murphy (2005) already show that regular preferences in general do not necessarily imply the existence of a scope effect.

in environmental valuation. It is well known that the aggregation process of individual WTPs itself can substantially shape the resulting societal values (Bateman et al. 2006, Loomis 2000, Smith 1993). Primary valuation studies should report distributional parameters on the valued environment good and income to facilitate more sophisticated environmental cost-benefit analysis and estimate income elasticities of WTP,  $\eta$ , to cross-validate the existence of a scope effect. In particular, primary valuation studies eliciting WTP for local public goods should report how the valued environmental good is distributed,  $\mu_E$  and  $\sigma_E$  or  $CV_E$ , and correlated with income,  $\rho$ . Moreover, this analysis once more emphasizes that the income elasticity of WTP,  $\eta$ , which, for CES preferences, is inversely related to the elasticity of substitution between consumption and environmental goods, is crucial to determine how the distribution of both the environmental good endowment and income affects societal WTP for environmental local public goods. This points to a need for more robust empirical estimates on  $\eta$ .

Fourth, my findings are relevant for environmental policy makers who are concerned with both equity and allocative efficiency. When deciding where to create new environmental amenities, place new sources of pollution, or reduce existing ones, and when employing environmental cost-benefit analysis (CBA) to ensure efficiency, policy makers should use inequality-adjusted WTPs in CBA. Under certain conditions, the developed transfer factors are a specification of distributional weights (Drupp et al. 2018). They are probably easier to use, however, as policy analysts only need approximating  $CV_Y$ ,  $CV_E$  and  $\rho$  and their target levels rather than specifying weights and assessing the distribution of environmental benefits across income groups. In the context of gentrification, for instance, policy makers might have a preference regarding the correlation of environmental goods with income,  $\rho$ , and aim at counteracting the distributional effects of decentralized market forces by introducing explicit measures like social housing or spatially sensitive development of urban green spaces.

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## Appendix

### A.1 Derivation of household's total WTP, $\text{WTP}(Y_i, E_i)$ (Eq. (3))

In the following I derive the household's total WTP for the environmental local public good. In doing so, I build on Ebert (2003) and Baumgärtner et al. (2017, Appendix A.1), who have already obtained the household's WTP for a constant elasticity of substitution (CES) utility function for environmental pure public goods.

From the perspective of the household, the quantity of the environmental good is fixed. Household  $i$  faces the following constrained maximization problem (Ebert 2003: 439)

$$\max_{X_i, E_i} U(X_i, E_i) \tag{A.25}$$

$$s.t. \quad P X_i = Y_i, \quad E_i \text{ fixed.} \tag{A.26}$$

For the CES utility function given in Eq (1) and using  $X_i = \frac{Y_i}{P}$  the corresponding

indirect utility function reads

$$V(P, Y_i, E_i) = \left[ \alpha \left( \frac{Y_i}{P} \right)^{\frac{\theta-1}{\theta}} + (1-\alpha) E_i^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}. \quad (\text{A.27})$$

The marginal WTP for environmental local public good  $E_i$  can then be derived by an extension of Roy's identity from the household's indirect utility function,  $V(P, Y_i, E_i)$  (Eq. (A.27)), (Ebert 2003: 440):

$$w(Y_i, E_i) := \frac{\frac{\partial V(P, Y_i, E_i)}{\partial E_i}}{\frac{\partial V(P, Y_i, E_i)}{\partial Y_i}} \quad (\text{A.28})$$

$$\stackrel{(\text{A.27})}{=} \frac{\left[ \alpha \left( \frac{Y_i}{P} \right)^{\frac{\theta-1}{\theta}} + (1-\alpha) E_i^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} (1-\alpha) E_i^{-1/\theta}}{\left[ \alpha \left( \frac{Y_i}{P} \right)^{\frac{\theta-1}{\theta}} + (1-\alpha) E_i^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \alpha P^{\frac{1-\theta}{\theta}} Y_i^{-1/\theta}} \quad (\text{A.29})$$

$$= \frac{1-\alpha}{\alpha} P^{\frac{\theta-1}{\theta}} Y_i^{1/\theta} E_i^{-1/\theta}. \quad (\text{A.30})$$

The marginal WTP,  $\omega$ , can be interpreted as the virtual price the household is willing to pay in a hypothetical choice problem where the household would have voluntarily chosen quantity  $E_i$ , given income  $Y_i$  and consumption good prices  $P$ . One can directly observe that marginal WTP,  $\omega$ , increases with income, but decreases with the quantity of the environmental good, as  $P, E_i, Y_i > 0$ ,  $\alpha \in (0, 1)$ .

Total WTP,  $\text{WTP}(Y_i, E_i)$ , for the environmental local public good is then given as marginal WTP,  $\omega$ , at levels  $E_i$  and  $Y_i$  times the level of the environmental good  $E_i$  (Ebert 2003: 442)

$$\text{WTP}(Y_i, E_i) = w(Y_i, E_i) E_i \quad (\text{A.31})$$

$$\stackrel{(\text{A.30})}{=} \frac{1-\alpha}{\alpha} (P E_i)^{\frac{\theta-1}{\theta}} Y_i^{1/\theta}, \quad (\text{A.32})$$

where the income elasticity of WTP,  $\eta$ , is the inverse of the elasticity of substitution,  $\eta = \frac{1}{\theta}$ . Hence, the WTP function can also be written directly for the income elasticity of WTP as

$$\text{WTP}(Y_i, E_i) = \frac{1-\alpha}{\alpha} (P E_i)^{1-\eta} Y_i^\eta. \quad (\text{A.33})$$

## A.2 Derivation of mean WTP, $\mu_{\text{WTP}}$ , (Eq. (9))

Mean WTP,  $\mu_{\text{WTP}}$  (Eq. (6)), can be reformulated with respect to the moments of the bivariate log-normal distribution -  $\mu_Y, \sigma_Y, \mu_E, \sigma_E, \rho$  - as follows

$$\begin{aligned}
\mu_{\text{WTP}}(\mu_Y, \sigma_Y, \mu_E, \sigma_E, \rho) &= \int_0^\infty \int_0^\infty f_{\ln}(Y, E; \mu_Y, \sigma_Y, \mu_E, \sigma_E, \rho) \text{WTP}(Y, E) dY dE \\
&\stackrel{(3)}{=} \int_0^\infty \int_0^\infty f_{\ln}(Y, E; \mu_Y, \sigma_Y, \mu_E, \sigma_E, \rho) \frac{1-\alpha}{\alpha} P^{1-\eta} E^{1-\eta} Y^\eta dY dE \\
&= \frac{1-\alpha}{\alpha} P^{1-\eta} \int_0^\infty \int_0^\infty f_{\ln}(Y, E; \mu_Y, \sigma_Y, \mu_E, \sigma_E, \rho) E^{1-\eta} Y^\eta dY dE \\
&\stackrel{(7)}{=} \frac{1-\alpha}{\alpha} P^{1-\eta} \int_0^\infty \int_0^\infty \frac{\exp\left[-\frac{1}{2(1-\rho^2)} \left(\frac{(\ln(Y)-m_Y)^2}{s_Y^2} - 2\rho \frac{\ln(Y)-m_Y}{s_Y} \frac{\ln(E)-m_E}{s_E} + \frac{(\ln(E)-m_E)^2}{s_E^2}\right)\right]}{2\pi Y E \sqrt{s_Y^2 s_E^2 (1-\rho^2)}} E^{1-\eta} Y^\eta dY dE \\
&= \frac{1-\alpha}{\alpha} P^{1-\eta} \int_0^\infty \int_0^\infty \frac{\exp\left[-\frac{1}{2(1-\rho^2)} \left(\frac{(\ln(Y)-m_Y)^2}{s_Y^2} - 2\rho \frac{\ln(Y)-m_Y}{s_Y} \frac{\ln(E)-m_E}{s_E} + \frac{(\ln(E)-m_E)^2}{s_E^2}\right)\right]}{2\pi \sqrt{s_Y^2 s_E^2 (1-\rho^2)}} E^{-\eta} Y^{\eta-1} dY dE \\
&= \frac{1-\alpha}{\alpha} P^{1-\eta} \int_0^\infty \frac{1}{\sqrt{2\pi s_Y^2}} \exp\left[-\frac{m_E + \eta^2(\rho^2 - 1)s_E^2 s_Y^2 + 2\eta s_E(-s_E m_Y + \rho m_E s_Y) + \ln(E)^2}{2s_E}\right] \\
&\quad \frac{E^{\frac{m_E + \eta s_E(-s_E + \rho s_Y)}{s_E}}}{s_E} dE \\
&= \frac{1-\alpha}{\alpha} P^{1-\eta} \exp\left[\frac{1}{2}(\eta-1)^2 s_E^2 + \eta(m_Y - m_E) + m_E - \rho(\eta-1)\eta s_E s_Y + \frac{1}{2}\eta^2 s_Y^2\right] \\
&\stackrel{(8)}{=} \frac{1-\alpha}{\alpha} P^{1-\eta} \exp\left[\frac{1}{2}(\eta-1)^2 \ln\left(1 + \frac{\sigma_E^2}{\mu_E^2}\right) + \eta\left(\ln(\mu_Y) - \frac{1}{2}\ln\left(1 + \frac{\sigma_Y^2}{\mu_Y^2}\right) - \ln(\mu_E) + \frac{1}{2}\ln\left(1 + \frac{\sigma_E^2}{\mu_E^2}\right)\right)\right. \\
&\quad \left. + \ln(\mu_E) - \frac{1}{2}\ln\left(1 + \frac{\sigma_E^2}{\mu_E^2}\right) - \rho(\eta-1)\eta \sqrt{\ln\left(1 + \frac{\sigma_E^2}{\mu_E^2}\right)} \sqrt{\ln\left(1 + \frac{\sigma_Y^2}{\mu_Y^2}\right)} + \frac{1}{2}\eta^2 \ln\left(1 + \frac{\sigma_Y^2}{\mu_Y^2}\right)\right] \\
&= \frac{1-\alpha}{\alpha} P^{1-\eta} \exp\left[\frac{\eta^2 - \eta}{2} \ln\left(1 + \frac{\sigma_E^2}{\mu_E^2}\right) + \frac{\eta^2 - \eta}{2} \ln\left(1 + \frac{\sigma_Y^2}{\mu_Y^2}\right) + (1-\eta)\ln(\mu_E) + \eta\ln(\mu_Y)\right. \\
&\quad \left. - \rho(\eta-1)\eta \sqrt{\ln\left(1 + \frac{\sigma_E^2}{\mu_E^2}\right)} \sqrt{\ln\left(1 + \frac{\sigma_Y^2}{\mu_Y^2}\right)}\right] \\
&= \frac{1-\alpha}{\alpha} P^{1-\eta} \exp\left[\ln\left(\left(1 + \frac{\sigma_E^2}{\mu_E^2}\right)^{\frac{\eta^2 - \eta}{2}}\right)\right] \exp\left[\ln\left(\left(1 + \frac{\sigma_Y^2}{\mu_Y^2}\right)^{\frac{\eta^2 - \eta}{2}}\right)\right] \exp[\ln(\mu_E^{1-\eta})] \exp[\ln(\mu_Y^\eta)] \\
&\quad \exp\left[-\rho(\eta-1)\eta \sqrt{\ln\left(1 + \frac{\sigma_E^2}{\mu_E^2}\right)} \sqrt{\ln\left(1 + \frac{\sigma_Y^2}{\mu_Y^2}\right)}\right]
\end{aligned}$$

$$\begin{aligned}
&= \frac{1-\alpha}{\alpha} P^{1-\eta} \mu_Y^\eta \left(1 + \frac{\sigma_Y^2}{\mu_Y^2}\right)^{\frac{\eta^2-\eta}{2}} \mu_E^{1-\eta} \left(1 + \frac{\sigma_E^2}{\mu_E^2}\right)^{\frac{\eta^2-\eta}{2}} \exp \left[ \rho(-\eta^2 + \eta) \sqrt{\ln \left(1 + \frac{\sigma_E^2}{\mu_E^2}\right) \ln \left(1 + \frac{\sigma_Y^2}{\mu_Y^2}\right)} \right] \\
&\stackrel{\eta=1/\theta}{=} \frac{1-\alpha}{\alpha} P^{\frac{\theta-1}{\theta}} \mu_Y^{\frac{1}{\theta}} \left(1 + \frac{\sigma_Y^2}{\mu_Y^2}\right)^{\frac{1-\theta}{2\theta^2}} \mu_E^{\frac{\theta-1}{\theta}} \left(1 + \frac{\sigma_E^2}{\mu_E^2}\right)^{\frac{1-\theta}{2\theta^2}} \exp \left[ \rho \frac{\theta-1}{\theta^2} \sqrt{\ln \left(1 + \frac{\sigma_E^2}{\mu_E^2}\right) \ln \left(1 + \frac{\sigma_Y^2}{\mu_Y^2}\right)} \right].
\end{aligned} \tag{A.34}$$

Equivalently mean WTP can be expressed for relative income inequality,  $CV_Y := \frac{\sigma_Y}{\mu_Y}$ , and relative environmental inequality,  $CV_E := \frac{\sigma_E}{\mu_E}$ . Eq. (A.34) then becomes:

$$\begin{aligned}
\mu_{WTP}(\mu_Y, CV_Y, \mu_E, CV_E, \rho) &= \frac{1-\alpha}{\alpha} P^{\frac{\theta-1}{\theta}} \mu_Y^{\frac{1}{\theta}} (1 + CV_Y^2)^{\frac{1-\theta}{2\theta^2}} \mu_E^{\frac{\theta-1}{\theta}} (1 + CV_E^2)^{\frac{1-\theta}{2\theta^2}} \Psi, \\
\text{with } \Psi(CV_Y, CV_E, \rho) &:= \exp \left[ \rho \frac{\theta-1}{\theta^2} \sqrt{\ln(1 + CV_E^2) \ln(1 + CV_Y^2)} \right].
\end{aligned} \tag{A.35}$$

### A.3 Proof of Proposition 1

Differentiating  $\mu_{WTP}$  (Eq. (9)) with respect to  $\mu_E$  yields

$$\begin{aligned}
\frac{\partial \mu_{WTP}(\mu_Y, CV_Y, \mu_E, CV_E, \rho)}{\partial \mu_E} &= \frac{\theta-1}{\theta} \frac{1-\alpha}{\alpha} P^{\frac{\theta-1}{\theta}} \mu_Y^{\frac{1}{\theta}} (1 + CV_Y^2)^{\frac{1-\theta}{2\theta^2}} \mu_E^{-1/\theta} (1 + CV_E^2)^{\frac{1-\theta}{2\theta^2}} \Psi \\
\text{with } \Psi(CV_Y, CV_E, \rho) &:= \exp \left[ \rho \frac{\theta-1}{\theta^2} \sqrt{\ln(1 + CV_E^2) \ln(1 + CV_Y^2)} \right],
\end{aligned} \tag{A.36}$$

the sign of which is determined by  $\frac{\theta-1}{\theta}$ , as  $\alpha \in (0, 1)$  and  $P, \mu_E, \mu_Y, CV_Y, CV_E, \Psi > 0$ .

It holds that  $\frac{\theta-1}{\theta} \gtrless 0 \iff \theta \gtrless 1$ .

### A.4 Proof of Proposition 2

Differentiating  $\mu_{WTP}$  given in Eq. (9) with respect to  $CV_Y$  yields

$$\begin{aligned}
&\frac{\partial \mu_{WTP}(\mu_Y, CV_Y, \mu_E, CV_E, \rho)}{\partial CV_Y} \\
&= k' \frac{1-\theta}{\theta^2} CV_Y (1 + CV_Y^2)^{\frac{1-\theta-2\theta^2}{2\theta^2}} \Psi + k' (1 + CV_Y^2)^{\frac{1-\theta}{2\theta^2}} \Psi \rho \frac{\theta-1}{\theta^2} \\
&\quad \frac{\ln(1 + CV_E^2)}{\sqrt{\ln(1 + CV_E^2) \ln(1 + CV_Y^2)}} \frac{CV_Y}{1 + CV_Y^2} \\
&= k' \Psi CV_Y (1 + CV_Y^2)^{\frac{1-\theta-2\theta^2}{2\theta^2}} \left[ \frac{1-\theta}{\theta^2} + \rho \frac{\theta-1}{\theta^2} \frac{\ln(1 + CV_E^2)}{\sqrt{\ln(1 + CV_E^2) \ln(1 + CV_Y^2)}} \right] \\
&= k' \Psi \frac{1-\theta}{\theta^2} CV_Y (1 + CV_Y^2)^{\frac{1-\theta-2\theta^2}{2\theta^2}} \left[ 1 - \rho \sqrt{\frac{\ln(1 + CV_E^2)}{\ln(1 + CV_Y^2)}} \right],
\end{aligned} \tag{A.37}$$

where  $\Psi(\text{CV}_Y, \text{CV}_E, \rho) := \exp \left[ \rho \frac{\theta - 1}{\theta^2} \sqrt{\ln(1 + \text{CV}_E^2) \ln(1 + \text{CV}_Y^2)} \right]$ , (A.38)

$$k'(\mu_Y, \mu_E, \text{CV}_E) := \frac{1 - \alpha}{\alpha} P^{\frac{\theta-1}{\theta}} \mu_Y^{\frac{1}{\theta}} (1 + \text{CV}_E^2)^{\frac{1-\theta}{2\theta^2}} \mu_E^{\frac{\theta-1}{\theta}}. \quad (\text{A.39})$$

As  $\text{CV}_E$ ,  $k'$  and  $\Psi$  are strictly positive, Eq. (A.37) can only become negative if either  $\frac{1-\theta}{\theta^2} < 0$ , or  $1 - \rho \sqrt{\frac{\ln(1+\text{CV}_E^2)}{\ln(1+\text{CV}_Y^2)}} < 0$ , while the respective other factor is strictly positive. It holds that

$$\frac{1 - \theta}{\theta^2} \geq 0 \iff \theta \leq 1, \quad (\text{A.40})$$

and

$$1 - \rho \sqrt{\frac{\ln(1 + \text{CV}_E^2)}{\ln(1 + \text{CV}_Y^2)}} \geq 0 \iff \rho \leq \sqrt{\frac{\ln(1 + \text{CV}_Y^2)}{\ln(1 + \text{CV}_E^2)}}. \quad (\text{A.41})$$

The combination of the sign of both factors establishes the Proposition.

## A.5 Proof of Corollary 1

Differentiating  $\mu_{\text{WTP}}^{\text{ind}}$  given in Eq. (10) with respect to income inequality,  $\text{CV}_Y$ , yields

$$\begin{aligned} & \frac{\partial \mu_{\text{WTP}}^{\text{ind}}(\mu_Y, \text{CV}_Y, \mu_E, \text{CV}_E)}{\partial \text{CV}_Y} \\ &= \frac{1 - \theta}{\theta^2} \frac{1 - \alpha}{\alpha} P^{\frac{\theta-1}{\theta}} \mu_Y^{1/\theta} \text{CV}_Y (1 + \text{CV}_Y^2)^{\frac{1-\theta-2\theta^2}{2\theta^2}} \mu_E^{\frac{\theta-1}{\theta}} (1 + \text{CV}_E^2)^{\frac{1-\theta}{2\theta^2}}. \end{aligned} \quad (\text{A.42})$$

As  $\alpha \in (0, 1)$  and  $\theta, P, \mu_Y, \text{CV}_Y, \mu_E, \text{CV}_E > 0$  the sign of this derivative is determined by the sign of  $\frac{1-\theta}{\theta^2}$ . It holds that  $\frac{1-\theta}{\theta^2} \geq 0 \iff \theta \leq 1$ .

## A.6 Proof of Proposition 3

The proof is completely analogous to the one for Proposition 2. Differentiating  $\mu_{\text{WTP}}$  given in Eq. (9) with respect to  $\text{CV}_E$  yields

$$\begin{aligned} & \frac{\partial \mu_{\text{WTP}}(\mu_Y, \text{CV}_Y, \mu_E, \text{CV}_E, \rho)}{\partial \text{CV}_E} \\ &= k'' \frac{1 - \theta}{\theta^2} \text{CV}_E (1 + \text{CV}_E^2)^{\frac{1-\theta-2\theta^2}{2\theta^2}} \Psi \left[ 1 - \rho \sqrt{\frac{\ln(1 + \text{CV}_Y^2)}{\ln(1 + \text{CV}_E^2)}} \right], \end{aligned} \quad (\text{A.43})$$

where  $\Psi(\text{CV}_Y, \text{CV}_E, \rho) := \exp \left[ \rho \frac{\theta - 1}{\theta^2} \sqrt{\ln(1 + \text{CV}_E^2) \ln(1 + \text{CV}_Y^2)} \right]$ , (A.44)

$$k''(\mu_Y, \text{CV}_Y, \mu_E) := \frac{1 - \alpha}{\alpha} P^{\frac{\theta-1}{\theta}} \mu_Y^{\frac{1}{\theta}} (1 + \text{CV}_Y^2)^{\frac{1-\theta}{2\theta^2}} \mu_E^{\frac{\theta-1}{\theta}}. \quad (\text{A.45})$$

As  $CV_E$ ,  $k$  and  $\Psi$  are strictly positive, the sign of Eq. (A.43) is determined by the sign of the factors  $\frac{1-\theta}{\theta^2} < 0$  and  $1 + \rho\sqrt{\frac{\ln(1+CV_Y^2)}{\ln(1+CV_E^2)}} < 0$ . It holds that

$$\frac{1-\theta}{\theta^2} \gtrless 0 \iff \theta \lesseqgtr 1, \quad (\text{A.46})$$

and

$$1 - \rho\sqrt{\frac{\ln(1+CV_Y^2)}{\ln(1+CV_E^2)}} \gtrless 0 \iff \rho \lesseqgtr \sqrt{\frac{\ln(1+CV_E^2)}{\ln(1+CV_Y^2)}}. \quad (\text{A.47})$$

The combination of the sign of both factors establishes the Proposition.

## A.7 Proof of Corollary 2

Differentiating  $\mu_{\text{WTP}}^{\text{ind}}$  given in Eq. (10) with respect to environmental inequality,  $CV_E$ , yields

$$\begin{aligned} & \frac{\partial \mu_{\text{WTP}}^{\text{ind}}(\mu_Y, CV_Y, \mu_E, CV_E)}{\partial CV_E} \\ &= \frac{1-\theta}{\theta^2} \frac{1-\alpha}{\alpha} P^{\frac{\theta-1}{\theta}} \mu_Y^{1/\theta} (1+CV_Y^2)^{\frac{1-\theta}{2\theta^2}} \mu_E^{\frac{\theta-1}{\theta}} CV_E (1+CV_E^2)^{\frac{1-\theta-2\theta^2}{2\theta^2}}. \end{aligned} \quad (\text{A.48})$$

As  $\alpha \in (0, 1)$  and  $\theta, P, \mu_Y, CV_Y, \mu_E, CV_E > 0$  the sign of this derivative is determined by the sign of  $\frac{1-\theta}{\theta^2}$ . It holds that  $\frac{1-\theta}{\theta^2} \lesseqgtr 0 \iff \theta \gtrless 1$ .

## A.8 Household sorting with respect to the distribution of the environmental local public good

Household sorting generally affects the correlation between income and endowment with environmental goods. I outline how this can be formally proven for CES preferences and common assumptions on the housing market in the following. To this end, I present a stylized model of how the distribution of environmental goods affects the residential choice ('sorting') of households that differ in income. The endowment with the environmental good is now a choice variable in the household's decision problem.

Consider a city, region, or country with an environmental amenity, the exposure to which is distributed unevenly and continuously over locations. Following Tiebout (1956) each household  $i$  is perfectly mobile and chooses its location with the aim of enjoying

a desired level of the environmental good,  $E_i > 0$ . For instance, the environmental good endowment  $E_i$  could be measured as the inverse of the Euclidean distance to the environmental amenity. It is therefore illustrative to consider  $E_i \in (0, 1)$ .

As before, households have identical preferences over a consumption good,  $X_i$ , and the environmental good,  $E_i$ , represented by a CES utility function (see Eq. (1)). Thus, like Lee and Lin (2018) and Heblich et al. (2017), I abstract from other property characteristics (such as size) and implicitly assume non-environmental property characteristics to be identical across locations.

Household  $i$ 's decision problem is then to maximize utility by choosing any combination of these goods subject to a budget constraint,

$$\max_{X_i, E_i} U(X_i, E_i) \quad s.t. \quad PX_i + R(E_i) = Y_i, \quad (\text{A.49})$$

where  $Y_i$  is household income and  $R(E_i)$  is the annual rent collected by absentee landlords. Studying rents rather than property prices makes it possible to consider a static setting and abstract from dynamic effects. To save on notation, I assume  $P = 1$ , i.e.  $X_i$  is the numeraire good. Rearranging the budget constraint and substituting for  $X_i$ , household's utility can be rewritten as  $U(Y_i - R(E_i), E_i)$ .

In equilibrium, the rent  $R(E_i)$  has to vary over  $E_i$  so that utility is uniform across locations (e.g., Brueckner et al. 1999, Phaneuf and Requate 2017, 532). Let  $\bar{u}$  denote the reference utility level so that

$$\bar{u} = U(Y_i - \bar{R}(E_i), E_i), \quad (\text{A.50})$$

where  $\bar{R}(E_i)$  is by definition the maximum household  $i$  is willing to pay for a home in a location characterized by an environmental good at level ( $E_i$ ) and hence referred to as household's bid function.

The slope of the bid function or the marginal WTP for an increase in the environmental good is then given as derivative of the implicit bid function  $\bar{R}(E_i)$  with respect to the environmental good:

$$\frac{\partial \bar{R}(E_i)}{\partial E_i} = \frac{\frac{\partial U}{\partial E_i}(Y_j - \bar{R}_j(\hat{E}), E_i)}{\frac{\partial U}{\partial X_i}(Y_j - \bar{R}_j(\hat{E}), E_i)}. \quad (\text{A.51})$$

Substituting the partial derivatives

$$\frac{\partial U(X_i, E_i)}{\partial E_i} = (1 - \alpha) E^{-1/\theta} \left[ \alpha X_i^{\frac{\theta-1}{\theta}} + (1 - \alpha) E_i^{\frac{\theta-1}{\theta}} \right]^{\frac{1}{\theta-1}} \text{ and} \quad (\text{A.52})$$

$$\frac{\partial U(X_i, E_i)}{\partial X_i} = \alpha X^{-1/\theta} \left[ \alpha X_i^{\frac{\theta-1}{\theta}} + (1 - \alpha) E_i^{\frac{\theta-1}{\theta}} \right]^{\frac{1}{\theta-1}} \quad (\text{A.53})$$

into Eq. (A.51) I obtain the slope of the bid function with respect to a change in  $E_i$

$$\frac{\partial \bar{R}(E_i)}{\partial E_i} = \frac{1 - \alpha}{\alpha} \left( \frac{Y_i - \bar{R}(E_i)}{E_i} \right)^{1/\theta}, \quad (\text{A.54})$$

which is strictly increasing in income as by definition  $Y_i > R(E_i)$  and  $\alpha \in (0, 1)$ ,  $E_i > 0$ . Note that Eq. A.54 almost resembles the marginal WTP derived for an exogenously given  $E_i$  (see Eq. (A.30)), except that the household has to pay rent  $\bar{R}(E_i)$  to enjoy the environmental good at level  $E_i$ .

Now, I extend this model to a situation with two groups of households  $j, k$ , that only differ in income  $Y_j \neq Y_k$ . Without a loss of generality, I assume  $Y_j > Y_k$ . For the remainder, I proceed analogously to the argument presented by Brueckner et al. (1999). Landlords rent houses to the households that pay the highest rent. Thus, the income group that outbids the other income group on the housing market will live where the endowment with  $E$  is high. Let  $\hat{E}$  denote the threshold level of  $E$  where the group's bids are equal  $\bar{R}_j(\hat{E}) = \bar{R}_k(\hat{E})$ . The relative slopes of the bid-price curves at the threshold  $\hat{E}$  determine whether the poor or the rich live in the part of the city (or region or country) where the endowment with the environmental good is high (cf. Brueckner et al. 1999: 96-97): If  $\frac{\partial \bar{R}_j}{\partial E}(\hat{E})$  is greater (smaller)  $\frac{\partial \bar{R}_k}{\partial E}(\hat{E})$  than the rich (poor) will live where environmental quality is higher. The differences between the slopes of the bid-functions is given as:

$$\Delta := \frac{\partial \bar{R}_j}{\partial E}(\hat{E}) - \frac{\partial \bar{R}_k}{\partial E}(\hat{E}) \quad (\text{A.55})$$

$$\stackrel{\text{Eq. (A.54)}}{=} \frac{1 - \alpha}{\alpha} \left[ \left( \frac{Y_j - \bar{R}_j(\hat{E})}{\hat{E}} \right)^{1/\theta} - \left( \frac{Y_k - \bar{R}_k(\hat{E})}{\hat{E}} \right)^{1/\theta} \right], \quad (\text{A.56})$$

which is strictly greater than zero, as by definition  $Y_j > Y_k$  and  $\bar{R}_j(\hat{E}) = \bar{R}_k(\hat{E})$ .

Thus, if the marginal WTP matters for sorting on the housing market and as the marginal WTP increases with income, rich (poor) households will sort into locations

with high (low) environmental quality. As a result, sorting will increase the correlation between income and endowment with the environmental local public good  $\rho$ .

## A.9 Proof of Proposition 4

Differentiating  $\mu_{\text{WTP}}$  given in Eq. (9) with respect to  $\rho$  yields

$$\begin{aligned} & \frac{\partial \mu_{\text{WTP}}(\mu_Y, \text{CV}_Y, \mu_E, \text{CV}_E, \rho)}{\partial \rho} \\ &= \frac{\theta - 1}{\theta^2} \frac{1 - \alpha}{\alpha} P^{\frac{\theta-1}{\theta}} \mu_Y^{\frac{1}{\theta}} (1 + \text{CV}_Y^2)^{\frac{1-\theta}{2\theta^2}} \mu_E^{\frac{\theta-1}{\theta}} (1 + \text{CV}_E^2)^{\frac{1-\theta}{2\theta^2}} \sqrt{\ln(1 + \text{CV}_E^2) \ln(1 + \text{CV}_Y^2)} \Psi, \end{aligned}$$

where  $\Psi(\text{CV}_Y, \text{CV}_E, \rho) := \exp \left[ \rho \frac{\theta - 1}{\theta^2} \sqrt{\ln(1 + \text{CV}_E^2) \ln(1 + \text{CV}_Y^2)} \right],$

the sign of which is determined by  $\frac{\theta-1}{\theta^2}$ , as  $\alpha \in (0, 1)$  and  $P, \mu_E, \mu_Y, \text{CV}_Y, \text{CV}_E > 0$ . It holds that  $\frac{\theta-1}{\theta^2} \gtrless 0 \iff \theta \gtrless 1$ .

## A.10 Proof of Proposition 5

The transfer function, defined as the quotient of mean WTPs at the policy site, p, and at the study site, s, is given as:

$$\begin{aligned} & \mathcal{T}(P^p, \mu_Y^p, \text{CV}_Y^p, \mu_E^p, \text{CV}_E^p, \rho^p; P^s, \mu_Y^s, \text{CV}_Y^s, \mu_E^s, \text{CV}_E^s, \rho^s) \\ &:= \frac{\mu_{\text{WTP}}^p(\mu_Y, \text{CV}_Y, \mu_E, \text{CV}_E, \rho)}{\mu_{\text{WTP}}^s(\mu_Y, \text{CV}_Y, \mu_E, \text{CV}_E, \rho)} \\ &\stackrel{\text{Eq.(9)}}{=} \frac{(P^p)^{\frac{\theta-1}{\theta}} (\mu_Y^p)^{\frac{1}{\theta}} (1 + \text{CV}_Y^{p2})^{\frac{1-\theta}{2\theta^2}} (\mu_E^p)^{\frac{\theta-1}{\theta}} (1 + \text{CV}_E^{p2})^{\frac{1-\theta}{2\theta^2}} \exp \left[ \rho^p \frac{\theta - 1}{\theta^2} \sqrt{\ln(1 + \text{CV}_Y^{p2}) \ln(1 + \text{CV}_E^{p2})} \right]}{(P^s)^{\frac{\theta-1}{\theta}} (\mu_Y^s)^{\frac{1}{\theta}} (1 + \text{CV}_Y^{s2})^{\frac{1-\theta}{2\theta^2}} (\mu_E^s)^{\frac{\theta-1}{\theta}} (1 + \text{CV}_E^{s2})^{\frac{1-\theta}{2\theta^2}} \exp \left[ \rho^s \frac{\theta - 1}{\theta^2} \sqrt{\ln(1 + \text{CV}_Y^{s2}) \ln(1 + \text{CV}_E^{s2})} \right]} \\ &= \left( \frac{P^p}{P^s} \right)^{\frac{\theta-1}{\theta}} \cdot \left( \frac{\mu_Y^p}{\mu_Y^s} \right)^{\frac{1}{\theta}} \cdot \left( \frac{\mu_E^p}{\mu_E^s} \right)^{\frac{\theta-1}{\theta}} \cdot \left( \frac{1 + \text{CV}_Y^{p2}}{1 + \text{CV}_Y^{s2}} \right)^{\frac{1-\theta}{2\theta^2}} \cdot \left( \frac{1 + \text{CV}_E^{p2}}{1 + \text{CV}_E^{s2}} \right)^{\frac{1-\theta}{2\theta^2}} \\ &\cdot \exp \left[ \frac{\theta - 1}{\theta^2} \left( \rho^p \sqrt{\ln(1 + \text{CV}_Y^{p2}) \ln(1 + \text{CV}_E^{p2})} - \rho^s \sqrt{\ln(1 + \text{CV}_Y^{s2}) \ln(1 + \text{CV}_E^{s2})} \right) \right]. \end{aligned} \tag{A.57}$$

If the environmental good and income are distributed independently at both study

and policy site,  $\rho^p = \rho^s = 0$ , the transfer function simplifies to:

$$\begin{aligned}
& \mathcal{T}^{\text{ind}}(P^p, \mu_Y^p, \text{CV}_Y^p, \mu_E^p, \text{CV}_E^p; P^s, \mu_Y^s, \text{CV}_Y^s, \mu_E^s, \text{CV}_E^s) \\
& := \frac{\mu_{\text{WTP}}^{\text{ind, p}}(\mu_Y, \text{CV}_Y, \mu_E, \text{CV}_E)}{\mu_{\text{WTP}}^{\text{ind, s}}(\mu_Y, \text{CV}_Y, \mu_E, \text{CV}_E)} \\
& \stackrel{\text{Eq. (10)}}{=} \frac{\frac{1-\alpha}{\alpha} (P^p)^{\frac{\theta-1}{\theta}} (\mu_Y^p)^{\frac{1}{\theta}} (1 + \text{CV}_Y^{p2})^{\frac{1-\theta}{2\theta^2}} (\mu_E^p)^{\frac{\theta-1}{\theta}} (1 + \text{CV}_E^{p2})^{\frac{1-\theta}{2\theta^2}}}{\frac{1-\alpha}{\alpha} (P^s)^{\frac{\theta-1}{\theta}} (\mu_Y^s)^{\frac{1}{\theta}} (1 + \text{CV}_Y^{s2})^{\frac{1-\theta}{2\theta^2}} (\mu_E^s)^{\frac{\theta-1}{\theta}} (1 + \text{CV}_E^{s2})^{\frac{1-\theta}{2\theta^2}}} \\
& = \left(\frac{P^p}{P^s}\right)^{\frac{\theta-1}{\theta}} \cdot \left(\frac{\mu_Y^p}{\mu_Y^s}\right)^{\frac{1}{\theta}} \cdot \left(\frac{1 + \text{CV}_Y^{p2}}{1 + \text{CV}_Y^{s2}}\right)^{\frac{1-\theta}{2\theta^2}} \cdot \left(\frac{\mu_E^p}{\mu_E^s}\right)^{\frac{\theta-1}{\theta}} \cdot \left(\frac{1 + \text{CV}_E^{p2}}{1 + \text{CV}_E^{s2}}\right)^{\frac{1-\theta}{2\theta^2}},
\end{aligned}$$

which can also be obtained by assuming  $\rho^p = \rho^s = 0$  in Eq. A.57.

### A.11 Histograms on $Y$ and $E$ in empirical application (Section 4)

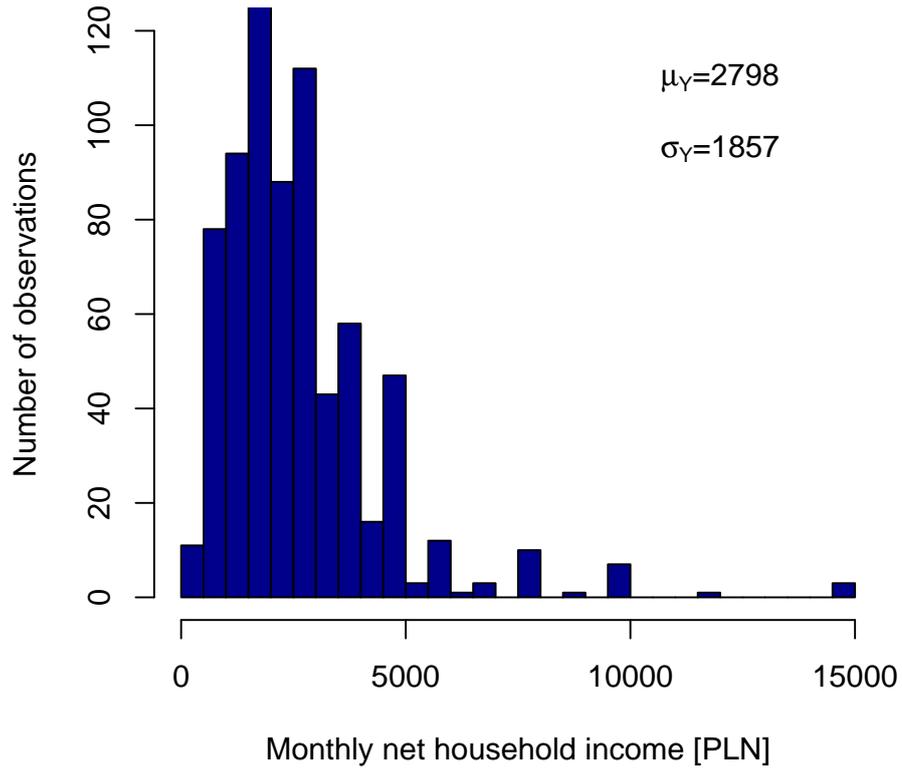


Figure 3: Histogram of the distribution of net monthly household income [in 2011-PLN] in Poland as assessed in the forest preservation survey by Czajkowski et al. (2014a).

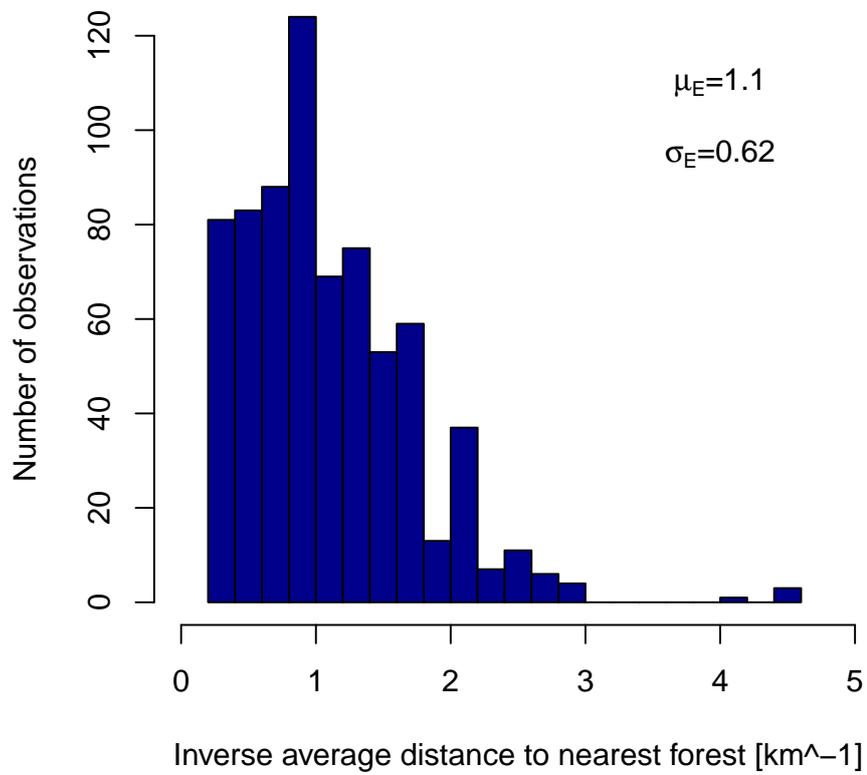


Figure 4: Histogram of the distribution of the inverse average Euclidean distance to the nearest forest (‘forest proximity’) from any point of the  $10 \times 10 \text{ km}^2$  grid square where respondent lives as used by Czajkowski et al. (2017).

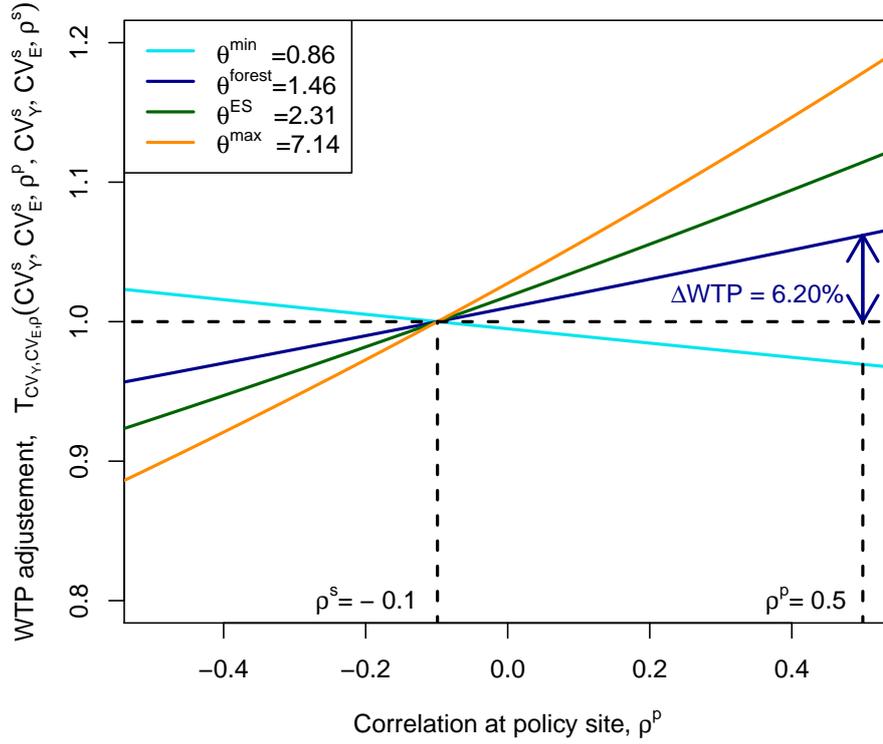


Figure 5: Relationship between the transfer factor to adjust societal WTP for differences in the distribution of income and the local environmental public good,  $\mathcal{T}_{CV_Y, CV_E, \rho^p}$ , and different correlations of income and endowment with the environmental good at the policy site  $\rho^p$ . In the hypothetical transfer depicted, the societal WTP for forest protection in Poland is adjusted to a situation where income inequality and environmental inequality is identical at study and policy site, but the correlation between  $Y$  and  $E$  differs.

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