Income distribution and willingness to pay for public ecosystem services

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Abstract: We study how the distribution of income among members of society affects the average willingness to pay (WTP) for public ecosystem services. Our analysis is based on the model of Ebert (2003), specified with a constant-elasticity-of-substitution utility function and log-normally distributed income. For illustration, we use data on the global income distribution (from World Bank 2011) and on the global income elasticity of WTP for ecosystem services (from the meta-study of Jacobsen and Hanley 2009). We show that (i) average WTP for ecosystem services increases with mean household income; (ii) average WTP for ecosystem services decreases (increases) with income inequality, if ecosystem services and manufactured goods are substitutes (complements); (iii) average WTP for ecosystem services normally changes more elastically with mean household income than with income inequality. Our results are relevant for the practice of benefit transfer, and for policy recommendations aimed at both allocative efficiency and distributive justice.

JEL-Classification: Q51, D63, H23, H43

Keywords: ecosystem services, income distribution, inequality, willingness to pay

1 Introduction

We study how the distribution of income among members of society, in particular mean income and income inequality, affects the average willingness to pay (WTP) for public ecosystem services.

This is an important question for at least two fields of application. First, for the practice of benefit transfer the effect of different income distributions in the study and target societies on WTP estimates needs to be controlled for (Bateman et al. 2011). Second, for the design of sustainability policy that aims at the two normative objectives of allocative efficiency and distributive justice (Baumgärtner and Quaas 2010), the effect of income distribution on WTP observations has to be known. Assessment of allocative efficiency requires the monetary valuation of non-market goods, while the distribution of income influences this monetary valuation in turn. The two aspects are thus mutually interlinked and need to be studied simultaneously.

The question of how WTP for environmental goods depends on income has been studied in the literature, so far, mainly as the question of the income elasticity of WTP. Ebert (2003), following up on previous work by Aaron and McGuire (1970), Kovenock and Sadka (1981), Kriström and Riera (1996), Flores and Carson (1997), has scrutinized the distributional implications of environmental benefits and has shown that the income elasticity of WTP for the environmental good has an inverse relationship to the elasticity of substitution between a composite consumption good and the environmental good in question. Hence, the income elasticity of WTP is smaller (greater) than unity if the environmental good and consumption goods are substitutes (complements).

Empirical evidence, as gathered mainly from contingent valuation (CV) studies, suggests that the income elasticity of WTP for ecosystem services is generally below unity – usually between 0.1 and 0.6 (e.g. Kriström and Riera 1996, Söderqvist and Scharin 2000, Hammitt et al. 2001, Ready et al. 2002, Horowitz and McConnell 2003, Hökby and Söderqvist 2003, Liu and Stern 2008, Scandizzo and Ventura 2008, Jacobsen and Hanley 2009, Khan 2009, Broberg 2010, Chiabai et al. 2011, Wang et al. 2011). It thus follows from Eberts's (2003) argument that the environmental goods assessed in these studies are substitutes to consumption goods. This clear result throughout the CV literature has been challenged by recent work of Schläpfer and Hanley (2006), Schläpfer (2006, 2008, 2009), and Schläpfer et al. (2008). In particular, Schläpfer (2006) argues that the incidences of income elasticities of WTP smaller than unity may be an artifact of the current design of CV studies.

So far, there are – to our knowledge – no studies on how the distribution of income among members of society, and in particular income inequality, affects WTP for ecosystem services. To address this issue, we use a specification of the model of Ebert (2003) where a continuum of individual households have identical preferences over a market-traded private consumption good and a non-market-traded pure-public-good ecosystem service, which are represented by a constant-elasticity-of-substitution utility function, and exogenous income is log-normally distributed over households. We consider two alternative measures of income inequality: the coefficient of variation and the standard deviation of income. These correspond to relative and absolute notions of inequality, respectively. We quantitatively estimate and illustrate our theoretical results of how the income distribution influences WTP with empirical data on the distribution of global household income (adapted from World Bank 2011) and on the global income elasticity of WTP for ecosystem services (from the meta-study of Jacobsen and Hanley 2009).

We show that (i) average WTP for the ecosystem service increases with mean household income, if the ecosystem service and the consumption good are substitutes (for relative inequality) viz. substitutes or weak complements (for absolute inequality); (ii) average WTP for the ecosystem service decreases (increases) with both absolute and relative income inequality, if the ecosystem service and the consumption good are substitutes (complements); (iii) the decrease in average WTP for ecosystem services that are substitutes to consumption goods due to increasing absolute income inequality is aggravated at lower levels of mean income; (iv) average WTP for the ecosystem service changes more elastically with mean household income than with income inequality, except for extreme cases of parameter values. As for the quantitative size of effects, we find that ecosystem services are systematically undervalued by up to nine per cent, if one assumes the current grossly unequal global income distribution rather than an equal distribution. Furthermore, we find that the elasticity of the average WTP for ecosystem services with respect to mean household income is more than three times higher than the respective elasticity for income inequality.

This paper is organized as follows. We present the model in Section 2, and the results of the model analysis in Section 3. In Section 4, we estimate and illustrate these results with empirical data. In Section 5, we discuss our main assumptions. Section 6 concludes. All formal proofs are contained in an appendix

2 Model

We employ the model of Ebert (2003) with a specific utility function and a specific distribution of income. There is a population of households whose well-being is determined by consumption of two goods – a market-traded private consumption good (X) and a non-market-traded pure-public-good (i.e. non-rival and non-excludable) ecosystem service (E). Both goods may be composites, and their amounts are continuously scalable with $X, E \geq 0$. All households have identical preferences over these two goods, represented by the utility function

$$U(X,E) = \left(\alpha X^{\frac{\theta-1}{\theta}} + (1-\alpha)\, E^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}} \quad , \tag{1}$$

where θ with $0 < \theta < +\infty$ is the constant elasticity of substitution between the two goods, and $0 < \alpha < 1$. As this function has the standard properties of a utility function, this implies that the ecosystem service is assumed to be a normal good. Y denotes an individual household's (exogenous) income. The distribution of income over households is described by a continuous density function $f(Y)$ with support $[\underline{Y}, \overline{Y}]$. In the following, we consider only feasible incomes, i.e. $Y \in [\underline{Y}, \overline{Y}]$. While the consumption good is traded on a market at given price $p > 0$, consumption of the ecosystem service is fixed at an exogenously given level $E > 0$ which is the same for all households.[1] We consider

[1]Denoting by E both the variable "ecosystem-service-consumption" and the fixed level at which the ecosystem service is provided should not cause any confusion, as in our analysis the amount of the ecosystem service is never variable but fixed throughout.

one time-period only, so each household maximizes their utility subject to the budget constraint and fixed level of the ecosystem service:[2]

$$\max_{X,E} \; U(X,E) \quad \text{s.t.} \quad pX = Y \text{ and } E \text{ fixed} \; . \tag{2}$$

We follow Aaron and McGuire (1970) and Ebert (2003) in defining the income-equivalent total WTP for the ecosystem service at level E as the willingness to pay per unit (Lindahl price) times the total number E of units. The Lindahl price of the ecosystem service is implicitly defined as the virtual price that yields the ecosystem service level E as the ordinary (unconditional) Marshallian demand in the hypothetical choice problem where the ecosystem service is considered a market good, i.e. it can be individually chosen and must be paid for at this Lindahl price, and the household has an income of Y plus the expenditures on E (Neary and Roberts 1980, Hanemann 1991: Equ. 11, Flores and Carson 1997: 289). Then, a household's total WTP for the ecosystem service at level E depends on income Y and the other parameters as follows (see Appendix A.1):

$$\text{WTP}(Y) = w\,Y^{\eta} \quad \text{with} \quad w = \frac{1-\alpha}{\alpha}(pE)^{\frac{\theta-1}{\theta}}, \quad \eta = \frac{1}{\theta} \; , \tag{3}$$

where η is the (constant) income elasticity of WTP and w is a factor that depends on all parameters of the model.

One interesting and important implication of the underlying constant-elasticity-of-substitution utility function is that the income elasticity of WTP, η, is simply the inverse of the elasticity of substitution between the consumption good and the ecosystem service, θ. This result, which has already been obtained by Kovenock and Sadka (1981) and Ebert (2003: 452–453), merits some attention. It means that $\eta > (=,<)\ 1$ if and only if $\theta < (=,>)\ 1$, that is, if and only if the consumption good and the ecosystem service are complements (Cobb-Douglas, substitutes). This, in turn, means that WTP

[2] In this "equal-preference"-model, which is standard in public economics, households are identical in terms of preferences and differ only in terms of income. This implies that if the evaluation of the ecosystem service differs between rich and poor households, such differences are caused by differences in income.

for the ecosystem service rises progressively (proportionally, regressively)[3] with income if and only if the consumption good and the ecosystem service are complements (Cobb-Douglas, substitutes).

The inverse relationship between η and θ can also explain the empirical finding of income elasticities of WTP that are smaller than one ($\eta < 1$). It reflects the fact that the subject of these studies are generally ecosystem services with locally restricted benefits, such as aesthetic or recreational values. These are perceived to be substitutes for consumption goods ($\theta > 1$). In contrast, one would expect that indispensable global ecosystem services, such as e.g. climate stability or the provision of oxygen by green plants, are complements for consumption goods ($\theta < 1$) and, hence, should display an income elasticity larger than one ($\eta > 1$). Yet, such ecosystem services have not yet been covered in CV studies.

While all households have identical preferences, represented by utility function (1), income Y is distributed unevenly over households. In particular, we assume that Y is log-normally distributed with mean μ_Y and standard deviation σ_Y. For the world income distribution, the assumption of log-normal distribution seems to be fairly valid (Pinkovskiy and Sala-i-Martin 2009). The log-normal distribution is handsome for analytical purposes, too, because it is completely determined by its first two statistical moments, μ_Y and σ_Y.

In this society, the average (over households with unequal income) total WTP for the ecosystem service at level E, μ_{WTP}, is given by

$$\mu_{\mathrm{WTP}} = \int_0^\infty f_{\ln}(Y; \mu_Y, \sigma_Y)\, \mathrm{WTP}(Y)\, dY \ , \tag{4}$$

where $f_{\ln}(Y; \mu_Y, \sigma_Y)$ is the density function of the log-normal distribution of Y with mean μ_Y and standard deviation σ_Y, and $\mathrm{WTP}(Y)$ is given by Equation (3). This yields (see Appendix A.2):

$$\mu_{\mathrm{WTP}} = w\, \mu_Y^{1/\theta} \left(1 + \frac{\sigma_Y^2}{\mu_Y^2}\right)^{\frac{1-\theta}{2\theta^2}} = w\, \mu_Y^{1/\theta} \left(1 + CV_Y^2\right)^{\frac{1-\theta}{2\theta^2}} \ , \tag{5}$$

[3] That WTP for the ecosystem service rises *progressively* (*proportionally*, *regressively*) with income Y means that $d(WTP(Y)/Y)/dY > (=<)\ 0$.

where $CV_Y = \sigma_Y/\mu_Y$ is the coefficient of variation, that is, the relative standard deviation, of income. While the standard deviation σ_Y measures the width of income distribution in monetary units, the coefficient of variation CV_Y measures the width of income distribution as a percentage of mean income.

In the following section, we study how the mean WTP for the ecosystem service in this society, μ_{WTP} (Equation 5), changes if mean income, μ_Y, and/or income inequality change. Two measures of income inequality seem plausible. First, one could simply take the standard deviation σ_Y as a measure of income inequality. This is in line with an idea of absolute poverty that is defined by some level of income, irrespective of the mean level of income in society. Second, one could take the coefficient of variation CV_Y as a measure of income inequality. This is in line with an idea of relative poverty that is defined by some fraction of mean income in society. In the following, we study the implications of both inequality measures in parallel. Changes in μ_Y and σ_Y (or CV_Y) can be interpreted as stylized outcomes of some not explicitly modelled policies for the growth and redistribution, respectively, of income.

3 Results of model analysis

In this section, we study how the mean WTP for the ecosystem service, μ_{WTP} (Equation 5), changes if mean income, μ_Y, and/or income inequality change. We do this in parallel for both measures for income inequality, coefficient of variation CV_Y (Section 3.1) and standard deviation σ_Y (Section 3.2), starting with the coefficient of variation as this yields simpler and more intuitive results.

3.1 Income inequality measured by the coefficient of variation

The first question is: how does mean WTP for the ecosystem service, μ_{WTP} (Equation 5), change if mean income, μ_Y, changes? The answer is given in the following proposition.

Proposition 1

Mean WTP for the ecosystem service increases with mean household income:

$$\frac{d\,\mu_{\mathrm{WTP}}}{d\,\mu_Y} > 0\ . \tag{6}$$

Proof. See Appendix A.3. □

The proposition states that the influence of mean household income on mean WTP is unique and straight forward: mean WTP for the ecosystem service increases with mean income.

The next question is: how does mean WTP for the ecosystem service, μ_{WTP} (Equation 5), change if income inequality, as measured by the coefficient of variation of income CV_Y, changes? And further: how does this effect depend on the level of mean income, μ_Y? The following proposition answers these two questions.

Proposition 2

1. Mean WTP for the ecosystem service decreases (increases) with income inequality, if and only if the ecosystem service and the consumption good are substitutes (complements):

$$\frac{d\,\mu_{\mathrm{WTP}}}{d\,CV_Y} \begin{cases} < 0 & \text{if and only if} \quad \theta > 1 \\ = 0 & \text{if and only if} \quad \theta = 1 \\ > 0 & \text{if and only if} \quad \theta < 1 \end{cases} . \tag{7}$$

2. $d\mu_{\mathrm{WTP}}/dCV_Y$ decreases (increases) with mean household income, if and only if the ecosystem service and the consumption good are substitutes (complements):

$$\frac{d\,\mu^2_{\mathrm{WTP}}}{d\,\mu_Y\,d\,CV_Y} \begin{cases} < 0 & \text{if and only if} \quad \theta > 1 \\ = 0 & \text{if and only if} \quad \theta = 1 \\ > 0 & \text{if and only if} \quad \theta < 1 \end{cases} . \tag{8}$$

Proof. See Appendix A.4. □

Statement 1 of the proposition shows that the influence of income inequality on mean WTP crucially depends on whether the ecosystem service and the consumption good are substitutes or complements. In the former case, a more equal distribution of income increases mean WTP. In the latter case, in contrast, a more equal distribution of income decreases mean WTP.

The rationale behind this result is as follows. Given an income elasticity of WTP below unity, individuals with lower incomes are willing to pay relatively more of their income for the ecosystem service than are individuals with higher income. This means that if an individual experiences an increase (decrease) in income, his or her WTP increases (decreases) only by less than his income. In addition, a more equal income distribution shifts probability mass from higher to lower income levels closer to the mean. Taking these two effects together explains the result, as shifting income from relatively high, but rare, income levels to lower levels reduces the WTP of the higher income levels, but it also increases the WTP of lower incomes, and the sum of increases is larger than the sum of reductions in the upper echelons of the distribution function.

The size of this effect varies with mean income in the society (Statement 2 of the proposition). In particular, in the case of substitutes the negative effect of income inequality on mean WTP is aggravated; it is diminished if mean income is high.

Finally, since both mean income, μ_Y, and income inequality, as measured by the coefficient of variation of income CV_Y, do influence mean WTP for the ecosystem service, μ_{WTP} (Equation 5), we are interested in the question: which one of the two influences is relatively stronger? This question is answered in the following proposition.

Proposition 3

Mean WTP for the ecosystem service changes more elastically with mean household income than with income inequality, except for the extreme case where the ecosystem service and the consumption are strong complements, $\theta < 1/2$, and income inequality is large, $CV_Y > \sqrt{\theta/(1-2\theta)}$. In this case, mean WTP for the ecosystem service changes less elastically with mean household income than with income inequality:

$$\left|\frac{d\,\mu_{\mathrm{WTP}}}{d\,\mu_Y}\,\frac{\mu_Y}{\mu_{\mathrm{WTP}}}\right| \left\{\begin{matrix} > \\ < \end{matrix}\right\} \left|\frac{d\,\mu_{\mathrm{WTP}}}{d\,CV_Y}\,\frac{CV_Y}{\mu_{\mathrm{WTP}}}\right|$$
$$\text{if and only if} \quad \begin{cases} \theta > \frac{1}{2} \text{ or } \left[\theta < \frac{1}{2} \text{ and } CV_Y < \sqrt{\frac{\theta}{1-2\theta}}\right] \\ \theta < \frac{1}{2} \text{ and } CV_Y > \sqrt{\frac{\theta}{1-2\theta}} \end{cases} . \tag{9}$$

Proof. See Appendix A.5. □

3.2 Income inequality measured by the standard deviation

The first question is: how does mean WTP for the ecosystem service, μ_{WTP} (Equation 5), change if mean income, μ_Y, changes? The answer is given in the following proposition.

Proposition 4

Mean WTP for the ecosystem service

1. increases with mean household income, if the ecosystem service and the consumption good are substitutes or weak complements:

$$\frac{d\,\mu_{\mathrm{WTP}}}{d\,\mu_Y} > 0 \qquad \text{if } \theta \geq 1/2 \; ; \tag{10}$$

2. decreases with mean household income below $\mu_Y^{\min} = \sqrt{1/\theta - 2}\,\sigma_Y$ and increases with mean household income above $\mu_Y^{\min}$, if the ecosystem service and the consumption good are strong complements:

$$\frac{d\,\mu_{\mathrm{WTP}}}{d\,\mu_Y} \begin{cases} < 0 & \text{for} \quad \mu_Y < \mu_Y^{\min} \\ > 0 & \text{for} \quad \mu_Y > \mu_Y^{\min} \end{cases} \qquad \text{if } \theta < 1/2 \; . \tag{11}$$

Proof. See Appendix A.6. □

The proposition states that, unless the ecosystem service and the consumption good are strong complements, the influence of mean household income on mean WTP is unique and straight forward: mean WTP for the ecosystem service increases with mean income.

The next question is: how does mean WTP for the ecosystem service, μ_{WTP} (Equation 5), change if income inequality, as measured by the standard deviation of income σ_Y, changes? And further: how does this effect depend on the level of mean income, μ_Y? The following proposition answers these two questions.

Proposition 5

1. Mean WTP for the ecosystem service decreases (increases) with income inequality, if the ecosystem service and the consumption good are substitutes (complements):

$$\frac{d\,\mu_{\text{WTP}}}{d\,\sigma_Y} \begin{cases} < 0 & \text{if} \quad \theta > 1 \\ = 0 & \text{if} \quad \theta = 1 \\ > 0 & \text{if} \quad \theta < 1 \end{cases} . \tag{12}$$

2. $d\mu_{\text{WTP}}/d\sigma_Y$ decreases with mean household income below $\tilde{\mu}_Y = \sqrt{1/\theta}\sigma_Y > \mu_Y^{\min}$ and increases with mean household income above $\tilde{\mu}_Y$, if the ecosystem service and the consumption good are substitutes or strong complements:

$$\frac{d\,\mu^2_{\text{WTP}}}{d\,\mu_Y d\,\sigma_Y} \begin{cases} < 0 & \text{for} \quad \mu_Y < \tilde{\mu}_Y \\ > 0 & \text{for} \quad \mu_Y > \tilde{\mu}_Y \end{cases} \qquad \text{if } \theta > 1 \text{ or } \theta < 1/2 \; . \tag{13}$$

   $d\mu_{\text{WTP}}/d\sigma_Y$ increases with mean household income below $\tilde{\mu}_Y$ and decreases with mean household income above $\tilde{\mu}_Y$, if the ecosystem service and the consumption good are weak complements:

$$\frac{d\,\mu^2_{\text{WTP}}}{d\,\mu_Y d\,\sigma_Y} \begin{cases} < 0 & \text{for} \quad \mu_Y > \tilde{\mu}_Y \\ > 0 & \text{for} \quad \mu_Y < \tilde{\mu}_Y \end{cases} \qquad \text{if } 1/2 < \theta < 1 \; . \tag{14}$$

   $d\mu_{\text{WTP}}/d\sigma_Y$ does not change with mean household income if $\theta = 1/2$ or $\theta = 1$.

Proof. See Appendix A.7. □

Statement 1 of the proposition shows that the influence of income inequality on mean WTP crucially depends on whether the ecosystem service and the consumption good are substitutes or complements. In the former case, a more equal distribution of income increases mean WTP. In the latter case, in contrast, a more equal distribution of income decreases mean WTP.

The rationale behind this result is as follows. Given an income elasticity of WTP below unity, individuals with lower incomes are willing to pay relatively more of their income for the ecosystem service than are individuals with higher income. This means that if an individual experiences an increase (decrease) in income, his or her WTP increases (decreases) only by less than his income. In addition, a more equal income distribution shifts probability mass from higher to lower income levels closer to the mean. Taking these two effects together explains the result, as shifting income from relatively high, but rare, income levels to lower levels reduces the WTP of the higher income levels, but it also increases the WTP of lower incomes, and the sum of increases is larger than the sum of reductions in the upper echelons of the distribution function.

The size of this effect varies with mean income in the society (Statement 2 of the proposition). In particular, in the case of substitutes the negative effect of income inequality on mean WTP is aggravated if mean income is low; it is diminished if mean income is high.

Finally, since both mean income, μ_Y, and income inequality, as measured by the standard deviation of income σ_Y, do influence mean WTP for the ecosystem service, μ_{WTP} (Equation 5), we are interested in the question: which one of the two influences is relatively stronger? This question is answered in the following proposition.

Proposition 6

Mean WTP for the ecosystem service changes more (less) elastically with mean household income than with income inequality, if the ecosystem service and the consumption good are substitutes (complements and mean household income is smaller than $\mu_Y^{\min} = \sqrt{1/\theta - 2}\,\sigma_Y$):

$$\left| \frac{d\,\mu_{\text{WTP}}}{d\,\mu_Y}\,\frac{\mu_Y}{\mu_{\text{WTP}}} \right| \left\{ \begin{matrix} > \\ < \end{matrix} \right\} \left| \frac{d\,\mu_{\text{WTP}}}{d\,\sigma_Y}\,\frac{\sigma_Y}{\mu_{\text{WTP}}} \right| \quad \text{if} \quad \begin{cases} \theta > 1 \\ \theta < 1 \text{ and } \mu_Y < \mu_Y^{\min} \end{cases} . \tag{15}$$

Proof. See Appendix A.8. □

4 Empirical analysis

Data description

In this section, we provide a case studies to illustrate the theoretical results (Section 3) about how mean WTP for ecosystem services depends on the distribution of income on a global scale. For this, we draw on the meta-study by Jacobsen and Hanley (2009), who gathered 145 WTP-estimates from 46 contingent valuation studies across six continents to scrutinize income effects regarding global WTP for biodiversity conservation. The contingent valuation studies assess WTP for different kinds of ecosystem service preservation projects, with a focus on eliciting existence values. Most studies included in the dataset are located in developed countries and the respective surveys have been conducted between 1979 to 2005.[4]

The double-log estimation with WTP per year [2006-PPP-US$] as dependent and annual household income [2006-PPP-US$] as explanatory variable (see Table 3 in Jacobsen and Hanley (2009: 145)), including 127 data pairs with household income, produces an estimate of the income elasticity of WTP of $\eta = 0.38$, with a standard error of 0.14. As there is – to our knowledge – no better estimate for an income elasticity of global WTP for ecosystem services, we treat it as a proxy for the global picture.

The income data in the sample of Jacobsen and Hanley (2009) consists of the mean incomes of the single studies and is not representative of the world distribution of household income, as the studies compiled in the dataset are over-proportionally located in developed countries. This is reflected in a small variance and high mean household income. In fact, a Kolmogorov-Smirnov test cannot reject the assumption that the mean incomes of the single studies are normally distributed. We have therefore chosen to generate an approximation of the world household income distribution that will more closely resemble the actual distribution.

[4]For a detailed summary statistics of the dataset, see Table 1 in Jacobsen and Hanley (2009: 142).

Inputs to empirical analysis

In order to quantify the impact of changes in the world distribution of household income on the mean WTP for ecosystem services, we need to specify the inputs to (Equation 5): μ_Y, σ_Y, $\theta = 1/\eta$ and w.

First, for estimating the moments of the world distribution of household income, we combine data on PPP-adjusted 2006 US$ Gross National Income (GNI) per capita values, as provided for 176 countries in the World Development Indicator Database of the World Bank (2011), with estimates from the year 2002 on average national household size (from Dorling et al. 2010). With this data, we generate a world distribution of household income in which all 176 nations enter with their mean household income. This representation of world household income still has two major deficiencies: We do not account for (1) different population sizes and (2) intra-national income inequality. A Kolmogorov-Smirnov test revealed that for this specification of the world household income distribution the null-hypothesis of log-normality cannot be rejected at common significance levels. It follows from this dataset that world average household income (μ_Y) is 38,979.83 US$, with a standard deviation (σ_Y) of 39,848.94 US$, corresponding to a coefficient of variation (CV_Y) of 1.02. Figure 1 depicts a histogram of this dataset as well as the curve of the corresponding log-normal distribution.

Second, θ is given through η as 2.63. Taking into account the standard error in η, we obtain corresponding errors in θ: $\theta_{\eta=0.52} = 1.92$, $\theta_{\eta=0.24} = 4.17$.

Third, the factor w is a function of all model parameters, including θ (cf. Equation 3). Since some of these parameters are unknown, we have obtained $\mu_{\mathrm{WTP}} = 89.51$ from the dataset of Jacobsen and Hanley (2009) and make use of Equation (5) to calculate w indirectly. The residual, calibrated factor w is thus 1.75. As w is also a function of η, with a given standard error of 0.14, we also take into account the error in η impacting w. Using a specific method for the propagation of error (see Appendix A.9), we obtain: $w_{\eta=0.52}$ =1.54 and $w_{\eta=0.24}$ =1.99. Note that an increase in η lowers w (cf. Equation 3).

Given these inputs, we can now analyze how changes in the income distribution impact the mean WTP for ecosystem services, via (hypothetically) increasing or de-

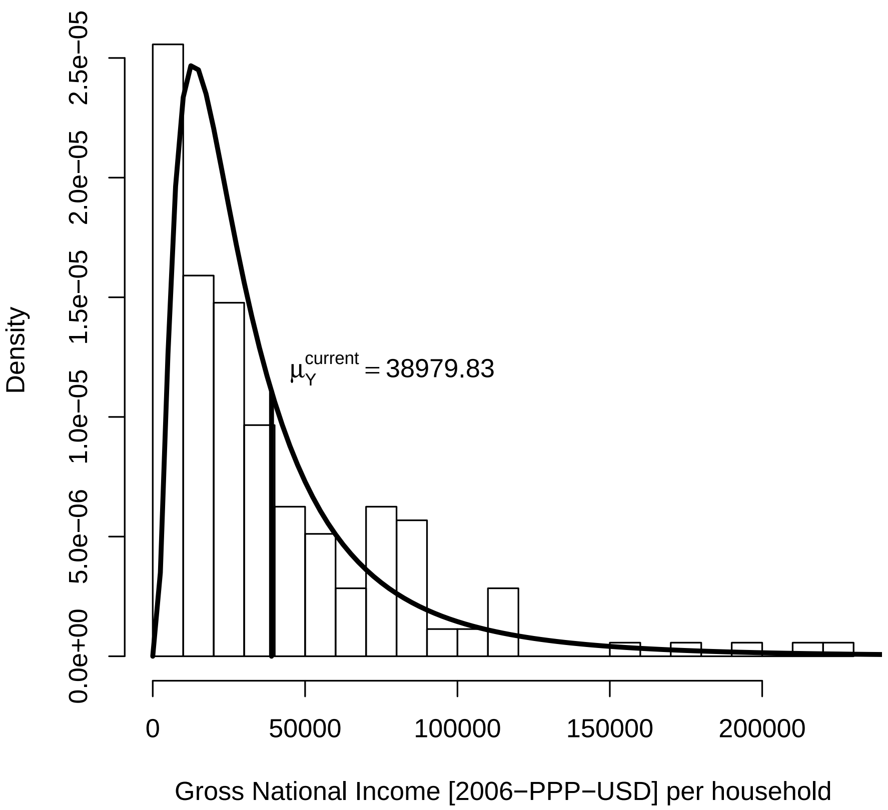

Figure 1: Histogram of the approximated distribution of world household income and related log normal distribution.

creasing μ_Y, and σ_Y or CV_Y respectively. These adjustments can be interpreted as stylized outcomes of some not explicitly modeled policies for the growth and redistribution, respectively, of income.

Results of empirical analysis

In this section, we quantify and illustrate how mean WTP for ecosystem services, μ_{WTP} (Equation 5), changes if mean income, μ_Y, and income inequality change (Propositions 1 through 6). We do this in parallel for both measures for income inequality – the coefficient of variation CV_Y and standard deviation σ_Y of world household income.

First, we examine the question of how mean WTP for ecosystem services changes with adjustments in mean income (Propositions 1 and 4). Figure 2 illustrates this relationship for the elasticity of substitution $\theta = 2.63$ ($\eta = 0.38$) of Jacobsen and Hanley (2009), with corresponding error bar, while holding CV_Y constant (Proposition 1). Mean WTP is an increasing, concave function of mean world household income. For

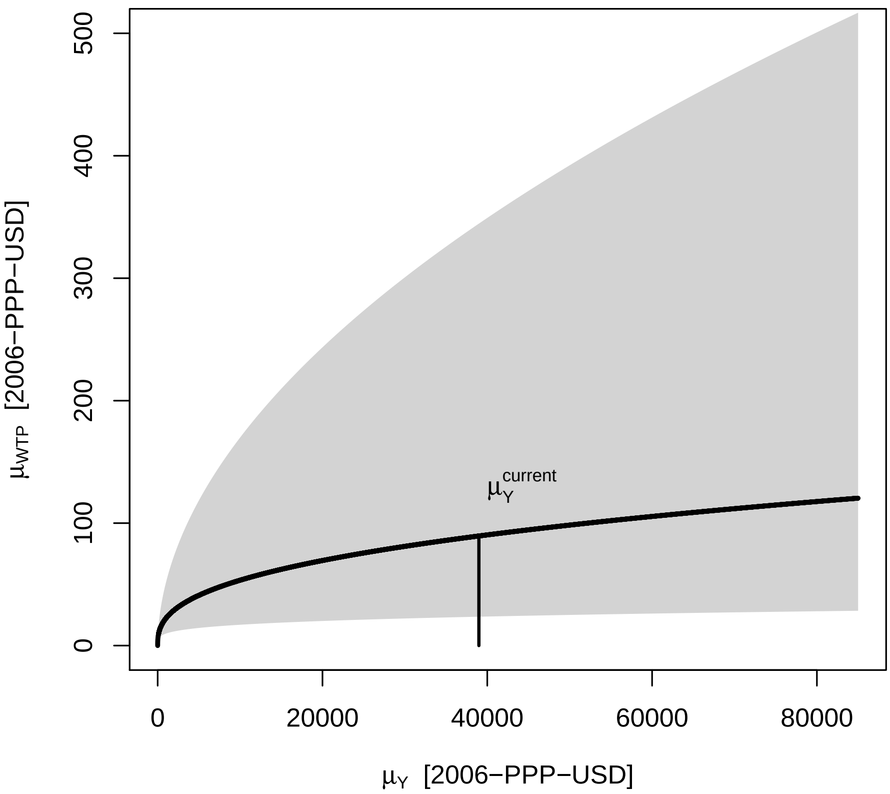

Figure 2: Relationship between global mean WTP for ecosystem services and mean world household income with error margin (shaded in grey) for a constant coefficient of variation of income.

the case of $\theta = 2.63$ (depicted as the solid black curve) mean WTP would rise by approximately 0.38% if mean world household income would increase by 1%, and by 30.13% in case of a hypothetical doubling of mean income. For the case of a constant σ_Y (Proposition 4), mean WTP would rise by approximately 0.5% if mean household income increased by 1%, and by 37.76% in case of a hypothetical doubling of mean income.

Second, we are interested in how mean WTP for ecosystem services, μ_{WTP}, changes if income inequality, as measured by CV_Y and σ_Y, respectively, changes (Propositions 2.1 and 5.1). Figure 3 illustrates this relationship for CV_Y explicitly, while the corresponding Figure for σ_Y shows exactly the same curve and error margin. Mean WTP for global ecosystem services decreases with increasing income inequality. Further increasing income inequality (both relative and absolute) by 1% would lower mean WTP by 0.12%. Compared to the current distribution of world household income, reducing income inequality to zero would lead to an increase of mean WTP for global ecosystem services by 8.79%.

Third, we are interested in whether the above-illustrated adverse effect of income inequality on mean WTP for ecosystem services depends on the level of mean income. Proposition 2.2 has shown that the relationship between mean WTP for ecosystem services and relative income inequality (as measured by CV_Y) is independent of the level of mean income. This is, however, not true for the relationship between mean WTP for ecosystem services and absolute income inequality (σ_Y). Figure 4 illustrates this relationship, derived in Proposition 5.2, with $\mu_Y^{current} \pm 30\%$ and (σ_Y). It follows that an increase of absolute income inequality by 1% lowers global mean WTP for ecosystem services by 0.08% (0.15%) for a mean world household income 30% higher (lower) than current mean income. Furthermore, for the case of lower world mean household income, reducing absolute income inequality to zero would lead to an increase of mean WTP for global ecosystem services by 12.92%, compared to 8.79% with $\mu_Y^{current}$ and 5.08% in the case of a 30% higher world household income than present.

Fourth, since both mean income, μ_Y, and income inequality (as measured by CV_Y and σ_Y, respectively) influence global mean WTP for ecosystem services, we are inter-

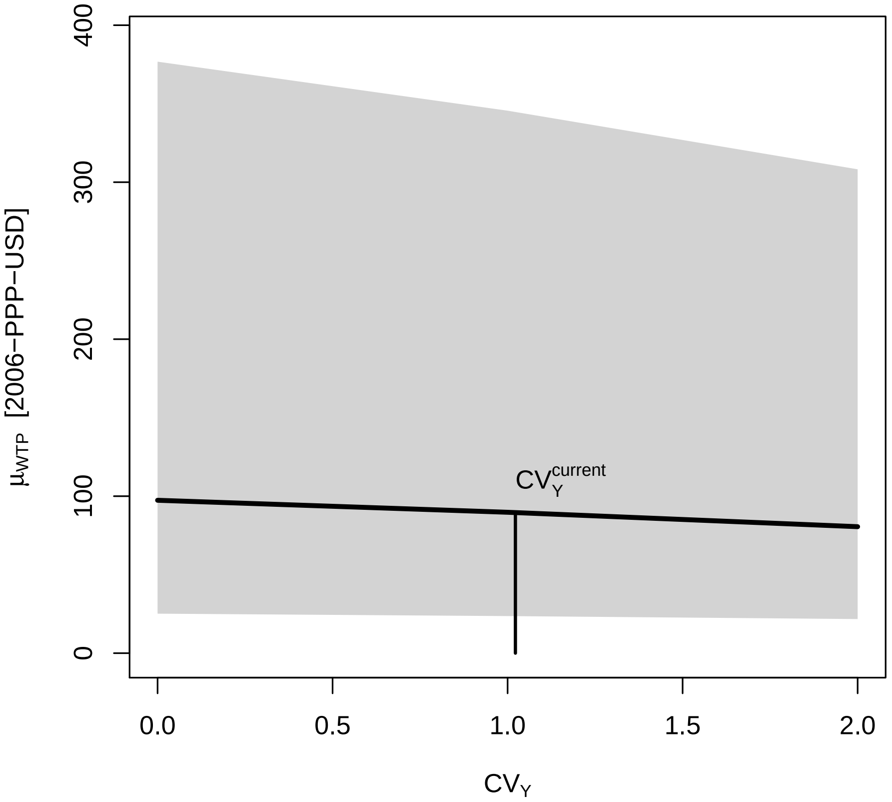

Figure 3: Relationship between global mean WTP for ecosystem services and income inequality (as measured by the coefficient of variation of world household income) with error margin.

ested in the question: which one of the two influences is relatively stronger (Propositions 3 and 6)? The elasticity of mean WTP with respect to mean income is simply the inverse of the elasticity of substitution between the composite ecosystem service and consumption good, i.e. $\eta = 0.38$. The absolute value of the elasticity of mean WTP with respect to relative income inequality (CV_Y) is 0.12 and the respective value for the elasticity of mean WTP with respect to absolute income inequality (σ_Y) is 0.24. It thus follows that for both representations of income inequality, the influence of changes in

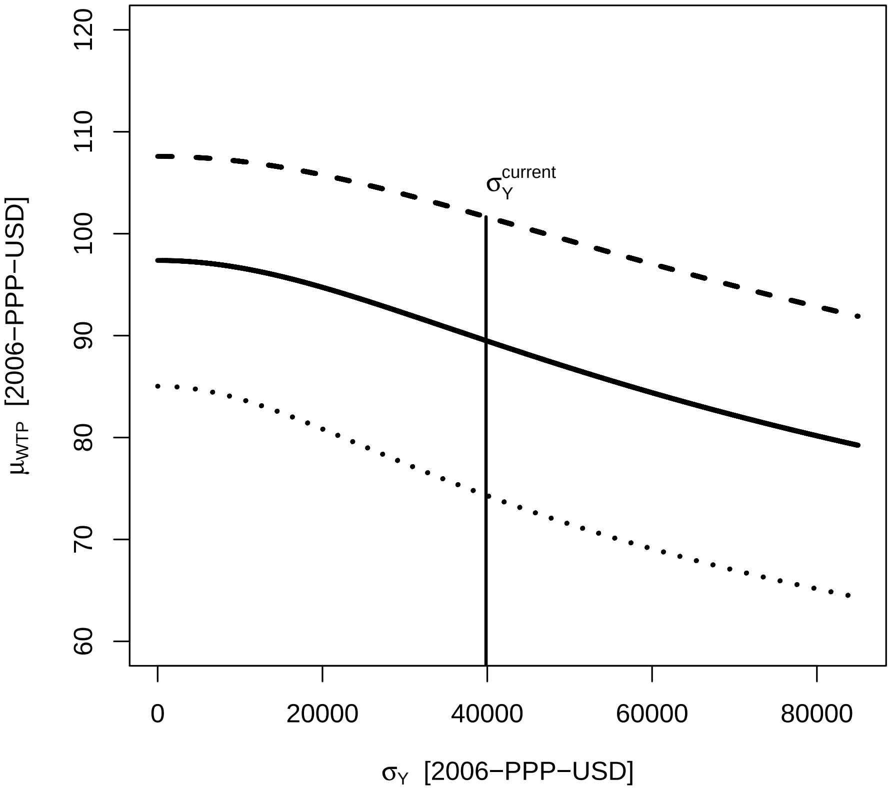

Figure 4: Relationship between global mean WTP and standard deviation of income for different (levels of) mean income. The dashed (dotted) line represents a scenario in which mean income is 30% higher (lower) than in the baseline case.

mean income is relatively stronger, while this relative effect is smaller for the case of absolute income inequality.

5 Discussion

The concepts and methods employed in this analysis limit the generality of our results. In this section, we discuss different critical issues.

First, our model applies to pure-public-goods ecosystem services only. The meta-study of Jacobsen and Hanley (2009), employed in our empirical illustration, draws on CV studies that elicit WTP for biodiversity conservation with a particular focus on existence values. Although these habitat and species preservation projects will not benefit all households equally on a global scale, existence values may be regarded as a prime example of pure-public-good-type benefits. However, that there are many ecosystem services with only a very limited spatial range of benefits, or with rivalry in consumption. Our analysis does not cover these cases of private-good ecosystem services.

Second, the CES-utility specification implies that the ecosystem service is a normal good, and not a Giffen or a luxury good. It further implies that the income elasticity of WTP is constant, an assumption that is supported by some empirical studies (e.g. Jacobsen and Hanley 2009, Broberg 2010). There is, however, also empirical evidence that the income elasticity of WTP increases with mean income (Ready et al. 2002). Again, our model does not capture this effect.

Third, we assume that households have identical preferences and differ only with respect to income. Our results also hold, however, if households have different utility functions, as long as the elasticities of substitution between ecosystem services and manufactured consumption goods are the same and the other utility-determining variables (e.g. education, social norms and relations) or parameters (e.g., the relative weight of manufacture goods to ecosystem services in utility) are not systematically correlated with the distribution of income. Thus, the crucial assumption that limits the generality of our results is that all households have an identical elasticity of substitution between ecosystem services and consumption goods.

Finally, our analysis rests on the assumption that income is log-normally distributed among members of society. While there is sound evidence that this is the case at the global level and in most countries, there are also suggestions (e.g. by Bandourian et al. 2003, Giesen et al. 2010) that actual income distributions may have a "fatter tail" than the log-normal distribution (such as the double-Pareto-log-normal, Fisk, or Weibull distributions). For such income distributions, the effects of income inequality would actually be larger than predicted by our analysis. Put the other way, employing the assumption of log-normal distribution is a conservative approach to assessing the effects of income inequality on mean WTP.

6 Conclusion

We have studied how the distribution of income among members of society, in particular mean income and income inequality, affects the average willingness to pay for public ecosystem services. We found that if exogenous income is unevenly distributed among otherwise identical households, and consumption goods and ecosystem services are substitutes, then mean WTP for ecosystem services (i) increases with mean household income and (ii) decreases with income inequality. In particular, ecosystem services are systematically undervalued by up to nine per cent, if one assumes the current grossly unequal global income distribution rather than an equal distribution. Furthermore, we find that (iii) the adverse effect of absolute income inequality (as measured by the standard deviation of income) on mean WTP for ecosystem services is the stronger, the lower mean household income; and (iv) average WTP for ecosystem services changes three times more elastically with mean household income than with relative income inequality.

Our results are relevant in several respects. First, for benefit transfer, one should correct WTP-estimates for differences in both mean household income and income inequality. Our study yields a handsome correction factor for this purpose. Second, when giving policy recommendations aimed at both allocative efficiency and distributive justice, one should correct WTP-estimates for grossly unjust income inequality, and use inequality-corrected WTP-estimates for efficiency (e.g. cost-benefit)-analysis. In the case of global WTP for biodiversity conservation this correction would lead to an increase in WTP of up to nine per cent. Third, when doing WTP-studies in poor countries one should be aware that the absolute income-inequality effect is more important in poor countries than in rich countries.

Overall, our analysis demonstrates the importance of taking into account economic inequality.

Appendix

A.1 Derivation of WTP(Y)

Total WTP for the ecosystem service at level E is given as the marginal willingness to pay ω times the number of units of E:

$$\text{WTP} = \omega\, E \tag{A.16}$$

Under the assumptions laid down in Section 2, the marginal WTP ω is implicitly defined as the virtual price that yields the ecosystem service level E as the ordinary (unconditional) Marshallian demand in the hypothetical choice problem where the ecosystem service is considered a market good. It can, hence, be derived from the agent's indirect utility function $V(p, E, Y)$ by an extension of Roy's identity (Ebert 2003: 440):

$$\omega = \frac{\partial V(p, E, Y)/\partial E}{\partial V(p, E, Y)/\partial Y}. \tag{A.17}$$

With the CES-utility function (Equation 1) this marginal WTP is then

$$\omega = p\,\frac{1-\alpha}{\alpha}\left(\frac{Y/p}{E}\right)^{\frac{1}{\theta}}. \tag{A.18}$$

Plugging this into Equation (A.16) yields

$$\text{WTP}(Y) = \frac{1-\alpha}{\alpha}(pE)^{\frac{\theta-1}{\theta}}\,Y^{1/\theta}\ . \tag{A.19}$$

A.2 Derivation of μ_{WTP}

The density function of the log-normal distribution is given by

$$f_{\ln}(Y; \mu_Y, \sigma_Y) = \frac{1}{Y\sqrt{2\pi s^2}}\exp\left(-\frac{(\ln Y - m)^2}{2s^2}\right) \tag{A.20}$$

$$\text{with}\quad m = \ln \mu_y - \frac{1}{2}\ln\left(1 + \sigma_Y^2/\mu_Y^2\right)\ , \tag{A.21}$$

$$s^2 = \ln\left(1 + \sigma_Y^2/\mu_Y^2\right)\ . \tag{A.22}$$

Equation (4) then becomes

$$
\begin{aligned}
\mu_{\text{WTP}} &= \int_0^\infty f_{\ln}(Y;\mu_Y,\sigma_Y)\,\text{WTP}(Y)\,dY \\
&\overset{\text{(A.20), (3)}}{=} \int_0^\infty \frac{w\,Y^{\eta-1}}{\sqrt{2\pi s^2}} \exp\left(-\frac{(\ln Y - m)^2}{2s^2}\right) dY \\
&\overset{\ln Y =: Z}{=} \frac{w}{\sqrt{2\pi s^2}} \int_{-\infty}^{\infty} \exp(\eta Z) \exp\left(-\frac{(Z-m)^2}{2s^2}\right) dZ \\
&= w\,\exp\left[(\eta)\left(m + \frac{\eta}{2}s^2\right)\right] \\
&\overset{\text{(A.21), (A.22)}}{=} w\,\mu_Y^{\eta} \left(1 + \frac{\sigma_Y^2}{\mu_Y^2}\right)^{\frac{\eta(\eta-1)}{2}} \\
&\overset{\eta = 1/\theta}{=} w\,\mu_Y^{1/\theta} \left(1 + \frac{\sigma_Y^2}{\mu_Y^2}\right)^{\frac{1-\theta}{2\theta^2}} .
\end{aligned}
\tag{A.23}
$$

A.3 Proof of Proposition 1

Taking the derivative of μ_{WTP} (Equation 5) with respect to μ_Y yields

$$\frac{d\,\mu_{\text{WTP}}}{d\,\mu_Y} = w\,\frac{1}{\theta}\mu_Y^{\frac{1}{\theta}-1} \left(1 + CV_Y^2\right)^{\frac{1-\theta}{2\theta^2}} , \tag{A.24}$$

which is strictly greater than zero because $\eta, w, \mu_Y, CV_Y > 0$.

A.4 Proof of Proposition 2

Ad 1. Taking the derivative of μ_{WTP} (Equation 5) with respect to CV_Y yields

$$\frac{d\,\mu_{\text{WTP}}}{d\,CV_Y} = w\,\frac{1-\theta}{\theta^2}\,\mu_Y^{\frac{1}{\theta}}\,CV_Y \left(1 + CV_Y^2\right)^{\frac{1-\theta-2\theta^2}{2\theta^2}} . \tag{A.25}$$

Because $\theta, w, \mu_Y, CV_Y > 0$, the sign of $d\mu_{\text{WTP}}/dCV_Y$ is determined by the sign of $1-\theta$:

$$\frac{d\,\mu_{\text{WTP}}}{d\,CV_Y} \begin{cases} < 0 & \text{if and only if} \quad 1-\theta < 0 \quad \Leftrightarrow \quad \theta > 1 \\ = 0 & \text{if and only if} \quad 1-\theta = 0 \quad \Leftrightarrow \quad \theta = 1 \\ > 0 & \text{if and only if} \quad 1-\theta > 0 \quad \Leftrightarrow \quad \theta < 1 \end{cases} . \tag{A.26}$$

Ad 2. The cross derivative of average WTP (Equation 5) is obtained by taking the derivative of (A.25) with respect to μ_Y:

$$\frac{d^2\,\mu_{\text{WTP}}}{d\,\mu_Y\;d\,CV_Y} = w\,\frac{1-\theta}{\theta^3}\,\mu_Y^{\frac{1}{\theta}-1}\,CV_Y\,\left(1+CV_Y^2\right)^{\frac{1-\theta-2\theta^2}{2\theta^2}}\quad. \tag{A.27}$$

Because $\theta, w, \mu_Y, CV_Y > 0$, the sign of $d^2\mu_{\text{WTP}}/d\mu_Y dCV_Y$ is determined by the sign of $1-\theta$:

$$\frac{d^2\,\mu_{\text{WTP}}}{d\,\mu_Y\;d\,CV_Y}\begin{cases} <0 & \text{if and only if} \quad 1-\theta<0 \quad \Leftrightarrow \quad \theta>1 \\ =0 & \text{if and only if} \quad 1-\theta=0 \quad \Leftrightarrow \quad \theta=1 \\ >0 & \text{if and only if} \quad 1-\theta>0 \quad \Leftrightarrow \quad \theta<1 \end{cases}\quad. \tag{A.28}$$

A.5 Proof of Proposition 3

to be completed ...

A.6 Proof of Proposition 4

Taking the derivative of μ_{WTP} (Equation 5) with respect to μ_Y yields

$$\frac{d\,\mu_{\text{WTP}}}{d\,\mu_Y} = \eta\,w\,\mu_Y^{\eta-1}\left(1+\frac{\sigma_Y^2}{\mu_Y^2}\right)^{\frac{\eta(\eta-1)}{2}}\left[1-(\eta-1)\,\frac{\sigma_Y^2/\mu_Y^2}{1+\sigma_Y^2/\mu_Y^2}\right]\quad. \tag{A.29}$$

Because $\eta, w, \mu_Y, \sigma_Y > 0$ this implies that

$$\frac{d\,\mu_{\text{WTP}}}{d\,\mu_Y}\begin{cases} >0 & \text{if} \quad \eta<2+\mu_Y^2/\sigma_Y^2 \\ <0 & \text{if} \quad \eta>2+\mu_Y^2/\sigma_Y^2 \end{cases}\quad. \tag{A.30}$$

This means that for income elasticities $\eta < 2$, i.e. elasticities of substitution $\theta > 1/2$, $d\mu_{\text{WTP}}/d\mu_Y$ is always positive. In the case of strong substitutability ($\theta < 1/2$), $d\mu_{\text{WTP}}/d\mu_Y$ attains a unique minimum at the income level $\mu_Y^{\min} = \sqrt{\eta-2}\,\sigma_Y$. In this case, μ_{WTP} falls with mean income for income levels below $\mu_Y^{\min}$ and increases with mean income above $\mu_Y^{\min}$.

A.7 Proof of Proposition 5

Taking the derivative of μ_{WTP} (Equation 5) with respect to σ_Y yields

$$\frac{d\,\mu_{\mathrm{WTP}}}{d\,\sigma_Y} = \eta\,(\eta-1)\,w\,\mu_Y^{\eta}\left(1+\frac{\sigma_Y^2}{\mu_Y^2}\right)^{\frac{\eta(\eta-1)}{2}-1}\frac{\sigma_Y}{\mu_Y^2}\,. \tag{A.31}$$

Because $\eta, w, \mu_Y, \sigma_Y > 0$ it follows directly that

$$\frac{d\,\mu_{\mathrm{WTP}}}{d\,\sigma_Y}\begin{cases} < 0 & \text{if} \quad \eta < 1 \quad \Leftrightarrow \quad \theta > 1 \\ > 0 & \text{if} \quad \eta > 1 \quad \Leftrightarrow \quad \theta < 1 \end{cases}\,. \tag{A.32}$$

This establishes the first parts of Proposition **??**.

The cross derivative of average WTP (5) is given as

$$\frac{\partial^2\,\mu_{\mathrm{WTP}}}{\partial\,\sigma_Y\;\partial\,\mu_Y} = \eta\,(\eta-1)\;w\,\mu_Y^{\eta-1}\,\sigma_Y\left(1+\frac{\sigma_Y^2}{\mu_Y^2}\right)^{\frac{\eta(\eta-1)}{2}-1}\left[\eta-2+[2-\eta\,(\eta-1)]\,\frac{\sigma_Y^2/\mu_Y^2}{1+\sigma_Y^2/\mu_Y^2}\right] \tag{A.33}$$

Setting this derivative equal to zero and simplifiying gives

$$(\eta-1)\left[(\eta-2)-(\eta\,(\eta-1)-2)\,\frac{\sigma_Y^2/\mu_Y^2}{1+\sigma_Y^2/\mu_Y^2}\right]=0 \tag{A.34}$$

and

$$(\eta-2)=\eta(\eta-2)\frac{\sigma_Y^2}{\mu_Y^2}, \tag{A.35}$$

which finally yields a unique solution at

$$\mu_Y = \sqrt{\eta}\,\sigma_Y. \tag{A.36}$$

The slope of this derivative depends on the level of η or θ, respectively, where three cases have to be considered.

$\theta > 1$: **Substitutes** This implies $\eta < 1$, from which it follows that both $\eta - 1$ in equation (A.34) and $\eta - 2$ in equation (A.35) are negative, hence we have

$$\frac{\partial^2\,\mu_{\mathrm{WTP}}}{\partial\,\sigma_Y\;\partial\,\mu_Y}\begin{cases} < 0 & \text{if} \quad \mu_Y < \sqrt{\eta}\,\sigma_Y \quad \Leftrightarrow \quad \mu_Y < \sqrt{1/\theta}\,\sigma_Y \\ > 0 & \text{if} \quad \mu_Y > \sqrt{\eta}\,\sigma_Y \quad \Leftrightarrow \quad \mu_Y > \sqrt{1/\theta}\,\sigma_Y \end{cases} \tag{A.37}$$

$\theta < 1$: **Complements** This implies $\eta > 1$, from which it follows that $\eta - 1$ in equation (A.34) is positive. Furthermore, it has to be distinguished whether $\eta \gtrless 2$, i.e. $\theta \gtrless 1/2$. Hence we have

$1/2 < \theta < 1$: **Weak complements** In this case, $\eta - 2 < 0$ in equation (A.35), hence

$$\frac{\partial^2 \mu_{\mathrm{WTP}}}{\partial \sigma_Y \, \partial \mu_Y} \begin{cases} > 0 & \text{if} \quad \mu_Y < \sqrt{\eta}\, \sigma_Y \quad \Leftrightarrow \quad \mu_Y < \sqrt{1/\theta}\, \sigma_Y \\ < 0 & \text{if} \quad \mu_Y > \sqrt{\eta}\, \sigma_Y \quad \Leftrightarrow \quad \mu_Y > \sqrt{1/\theta}\, \sigma_Y \end{cases} \tag{A.38}$$

$\theta < 1/2$: **Strong complements** In this case, $\eta - 2 > 0$ in equation (A.35), hence

$$\frac{\partial^2 \mu_{\mathrm{WTP}}}{\partial \sigma_Y \, \partial \mu_Y} \begin{cases} < 0 & \text{if} \quad \mu_Y < \sqrt{\eta}\, \sigma_Y \quad \Leftrightarrow \quad \mu_Y < \sqrt{1/\theta}\, \sigma_Y \\ > 0 & \text{if} \quad \mu_Y > \sqrt{\eta}\, \sigma_Y \quad \Leftrightarrow \quad \mu_Y > \sqrt{1/\theta}\, \sigma_Y \end{cases} \tag{A.39}$$

Taken together, equations (A.37) - (A.39) establish the second part of Proposition 5.

A.8 Proof of Proposition 6

to be completed ...

A.9 Error propagation

to be completed ...

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