University of Warsaw
Faculty of Economic Sciences

Working Papers
No. 7/2015 (155)

EDWARD B. BARBIER
MIKOŁAJ CZAJKOWSKI
NICK HANLEY

Is the income elasticity of the willingness to pay for pollution control constant?

Warsaw 2015

Is the income elasticity of the willingness to pay for pollution control constant?

EDWARD B. BARBIER
Department of Economics & Finance
University of Wyoming
e-mail: ebarbier@uwyo.edu

MIKOŁAJ CZAJKOWSKI
Faculty of Economic Sciences
University of Warsaw
e-mail: miq@wne.uw.edu.pl

NICK HANLEY
School of Geography and Sustainable Development
University of St Andrews
e-mail: ndh3@st-andrews.ac.uk

Abstract

This paper explores both theoretically and empirically whether or not the willingness to pay (WTP) for pollution control varies with income. Our model indicates that the income elasticity of the marginal WTP for pollution reduction is only constant under very restrictive conditions, which are not necessary for an environmental Kuznets curve relationship between pollution and income. Our empirical analysis tests the null hypothesis that the elasticity of the WTP for pollution control with respect to income is constant, employing a multi-country contingent valuation study of eutrophication reduction in the Baltic Sea. Our findings reject this hypothesis, and estimate an income elasticity of the WTP for eutrophication control of 0.1 - 0.2 for low-income respondents and 0.6 - 0.7 for high-income respondents. Thus, our empirical results suggest that the elasticity is not constant and always less than one.

Keywords:

Baltic Sea, benefit transfer, environmental Kuznets curve, eutrophication, income elasticity of willingness to pay, non-market valuation.

JEL:

Q51; Q53; Q56

Acknowledgements

The data collection was funded by the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning, Swedish Environmental Protection Agency, four Finnish Ministries Ministry of Agriculture and Forestry, Ministry of Environment, Ministry of Transport and Communications and Ministry of Finance), the Danish Strategic Research Council, and the German Federal Environment Agency. We would like to thank the BalticSTERN Secretariat and team consisting of researchers from all the nine Baltic Sea states for joint work in data collection and the willingness to share the data. The second author gratefully acknowledges the support of the Polish Ministry of Science and Higher Education and the Foundation for Polish Science.

Working Papers contain preliminary research results.
Please consider this when citing the paper.
Please contact the authors to give comments or to obtain revised version.
Any mistakes and the views expressed herein are solely those of the authors.

Introduction

Since the seminal study by Kriström and Riera (1996), economists have continued to debate whether or not the willingness to pay (WTP) for environmental improvement varies with respect to income, and what the likely magnitude of that income elasticity might be. There is evidence from consumer expenditure surveys that environmental quality could be a luxury good, implying that the income elasticity of demand is higher than one (Ghalwash 2008). In contrast, studies that directly estimate the income elasticity of WTP for environmental improvement find that this elasticity may in fact be less than one (Czajkowski and Ščasný 2010; Hökby et al. 2003; Jacobsen and Hanley 2009; Kriström and Riera 1996; Ready et al. 2002). Others have shown that the relationship between elasticity of demand and income elasticity of WTP is not straightforward for environmental public goods, and knowledge of the one does not necessarily provide information on the other (Flores and Carson 1997; Ebert 2003).

The issue as to whether the elasticity of the WTP for environmental improvement with respect to income is constant has also yet to be resolved. There is a growing theoretical literature suggesting that the elasticity is unlikely to be constant (Ebert 2003; Flores and Carson 1997; Hökby and Söderqvist 2003). Similarly, some theoretical explanations of the environmental Kuznets curve (EKC) are consistent with the marginal WTP for reducing pollution varying with income (Andreoni and Levinson 2001; Israel and Levinson 2004; McConnell 1997; Stokey 1998). In contrast, recommended guidance principles for transferring estimated WTP values for environmental improvement to other sites are often based on the assumption that the income elasticity of these WTP values must be constant (Bateman et al. 2011; Ready and Navrud 2006).

The purpose of the following paper is to explore both theoretically and empirically whether or not the WTP for pollution control varies with income. Thus, the contribution which this paper makes to the literature is to present for the first time an integrated theoretical and empirical investigation of how the income elasticity of WTP for more of an environmental good - or less of an environmental bad - varies with income.

Following Andreoni and Levinson (2001), Israel and Levinson (2004), McConnell (1997) and Stokey (1998), we first develop a theoretical model to demonstrate the conditions under which the elasticity of the marginal WTP for reducing pollution with respect to income is likely to be constant. However, in contrast to these models, in which environmental quality is controlled in a social planner's problem, the model developed here is based on a representative agent's decision whether or not to contribute some portion of income to overall pollution reduction in an economy. This enables comparison with theoretical explorations in the environmental valuation literature that distinguish the income elasticity of WTP from the demand for environmental quality with respect to income (Ebert 2003; Flores and Carson 1997; Hökby and Söderqvist 2003). Our model indicates that the income elasticity of the marginal WTP for pollution reduction is only constant under very restrictive conditions, and moreover, confirms that a constant elasticity is not necessary for generating an environmental Kuznets curve relationship between pollution levels and income per capita.

The aim of our empirical analysis is to test the null hypothesis that the elasticity of the WTP for pollution control with respect to income is constant. To do this, we make use of a large multi-country dataset from a contingent valuation study of the benefits of meeting nutrient reduction targets for the Baltic Sea (Ahtiainen et al. 2014). The survey was aimed at estimating the WTP for reducing eutrophication in the Baltic Sea, with respondents drawn from 9 littoral countries - Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. Due to the large differences in respondents' income levels among these countries, the dataset provides a unique opportunity to examine income elasticity of WTP for reducing eutrophication across a very wide range of household income levels – from less than 500 to over 5000 euros (€) per month. We employ the Box-Cox model to test our null hypothesis, which is rejected. We find that the income elasticity of the WTP for eutrophication control is increasing and concave, and that it behaves similarly irrespectively of the model specification. It takes values of 0.1 - 0.2 for low-income respondents and reaches 0.6 - 0.7 for the highest income levels observed in our dataset. This result is consistent with previous findings (Ready et al. 2002; Czajkowski and Ščasný 2010).

The outline of our paper is as follows. The next section develops our theoretical model of the willingness to pay for pollution reduction, which we use to derive the conditions under which the income elasticity of this WTP is constant. Next, we discuss the implications of this model for deriving an environmental Kuznets curve relationship between pollution levels and income per capita and for non-marginal pollution reductions. The subsequent sections of the paper develop our Box-Cox regression model for testing the null hypothesis that the elasticity of the marginal WTP for pollution control with respect to income is constant, and apply this model to our case study of eutrophication control in Baltic Sea countries. We conclude by discussing our theoretical and empirical results, and their implications for future research.

Theoretical Model

Assume that there are N individuals in an economy, who may be willing to pay for a specific improvement in environmental quality, such as reducing the water pollution associated with eutrophication of a nearby coastal sea. Eutrophication is disliked because it accelerates growth of algae in water bodies, diminishes enjoyment of seaside recreation and disrupts aquatic ecosystems. In addition, the water pollution causing eutrophication consists of nutrient, phosphorous and nitrogen emissions, which are directly linked to the total levels of production and consumption in the economy. However, assuming a feasible technology for abating these emissions, individuals may be willing to forego some of their income that would otherwise be spent on consumption in order to contribute to overall pollution abatement.

Thus the utility function of a representative agent in the economy is

$$U = U\left(c, P\right), \quad U_c > 0, U_{cc} < 0, U_P < 0, U_{PP} < 0, \; U_{cP} \leq 0 \, , \tag{1}$$

where c is per capita consumption and P is the overall water pollution level associated with eutrophication. Let y denote the individual's given level of per capita income. The choice is to allocate a share $\omega \in [0, \overline{\omega}]$ of this income to pollution control, with the remainder $1-\omega$ spent on consumption. However, there is a minimal level of consumption that ensures an upper limit $\overline{\omega}$ on the individual's allocation of income to pollution abatement, i.e. $c = \left(1-\overline{\omega}\right)y = \overline{c}$.

If $\alpha\left(N\omega y\right)$ is the reduction in pollution through all individuals' expenditures on pollution control, then overall emissions generated in the economy is

$$P = \left[cN - \alpha\left(\omega y N\right)\right] = \left(1-\omega\right)y - \alpha\left(\omega y\right), \; N = 1 \tag{2}$$

where normalizing the number of individuals maintains the focus on the representative agent's decision (e.g. P can now be thought of as per capita pollution levels). The abatement technology is governed by

$$\alpha'\left(\omega y\right) > 0, \; \alpha\left(0\right) = 0, \; \alpha'\left(0\right) = 0, \; \alpha\left(\overline{\omega} y\right) = \overline{\alpha}, \quad \alpha'\left(\overline{\omega} y\right) = \beta < \infty \, . \tag{3}$$

For a given income level, pollution abatement is an increasing function of expenditure allocated to pollution control. Abatement cannot occur if no money is allocated to reducing pollution, abatement is finite if the maximum amount is allocated to control, and the rate of increase in pollution abatement at the upper limit on control is bounded above by β.

The representative agent's problem is

$$\max_{\omega \in \left[0, \overline{\omega}\right]} U\left(\left(1-\omega\right)y, \left(1-\omega\right)y - \alpha\left(\omega y\right)\right) \; . \tag{4}$$

For the given level of income y, the optimal allocation share for reducing pollution ω^* satisfies

$$\begin{aligned} -U_C y - U_P\left(1+\alpha'\right) \leq 0, \quad & \omega \geq 0 \\ -U_C y - U_P\left(1+\alpha'\right) \geq 0, \quad & \omega \leq \overline{\omega} \end{aligned} \; . \tag{5}$$

For the corner solution $\omega = 0$, the marginal benefit of pollution abatement $-U_P\left(1+\alpha'\right)$ is less than the cost $U_C y$, and thus the individual will not contribute any income to emission reduction. All of the agent's income will be devoted to consumption, and thus pollution will be at its maximum $P = c = y$. For the other corner solution $\omega = \overline{\omega}$, the marginal benefit of pollution abatement exceeds the cost, and the individual will allocate the maximum amount of income to pollution reduction. As this corner solution is not important for what follows, for simplicity it will be assumed that $\omega > \overline{\omega}$.

The marginal willingness to pay (WTP) for pollution reduction w_P is therefore

$$w_p = -\frac{U_P}{U_c} \leq \frac{1}{1+\alpha'}, \qquad \omega \geq 0 \ . \tag{6}$$

The WTP is defined by the marginal rate of substitution between less pollution and consumption. In the case of the interior solution, this marginal rate of substitution must also equal $1/1+\alpha'$, the opportunity cost of less pollution in terms of foregone consumption.

For the corner solution case when the representative agent allocates no income to pollution reduction and thus $\omega = 0$, it follows from (6) that

$$\frac{\partial w_P}{\partial y} = \frac{-U_{PP} - U_{cc} - 2U_{cP}}{\left[U_c\right]^2} > 0, \quad \varepsilon_P \equiv \frac{\partial w_P}{\partial y} \cdot \frac{y}{w_P} = \frac{-U_{PP} - U_{cc} - 2U_{cP}}{-U_c U_P} y > 0 \ . \tag{7}$$

The marginal WTP for pollution control increases with income, and the elasticity of w_P with respect to income is also positive. Because the terms in the denominator of ε_P in (7) are a function of per capita income, this elasticity is not constant.

For the interior optimum, changes in w_P correspond to changes in the opportunity cost of reduced pollution. It follows that

$$\frac{\partial w_P}{\partial y} = \frac{-\alpha''\omega}{\left[1+\alpha'\right]^2}, \quad \varepsilon_P \equiv \frac{\partial w_P}{\partial y} \cdot \frac{y}{w_P} = \frac{-\alpha''}{1+\alpha'} \omega y . \tag{8}$$

In this case, how the marginal WTP for reduced pollution changes with income depends on the abatement technology $\alpha\left(\omega y\right)$ as governed by (3). If this technology is increasing and convex, and thus $\alpha'' > 0$, then as income increases w_P falls. However, if abatement technology is increasing and concave so that $\alpha'' < 0$, then w_P rises as income increases. There is no change in w_P if abatement increases linearly with pollution reduction expenditure ($\alpha'' = 0$). Similarly, the income elasticity of the marginal WTP for pollution reduction also varies with abatement technology, i.e. $\varepsilon_P \overset{>}{\underset{<}{=}} 0$ if $\alpha'' \overset{<}{\underset{>}{=}} 0$. Unless abatement technology is linear so that $\varepsilon_P = 0$, for different per capita income levels, the income elasticity of WTP is not constant.

Finally, as (7) indicates, even if the individual allocates no income to pollution control, the agent's marginal WTP for pollution reduction rises with per capita income. If income arises above some threshold level $\hat{y}$, the interior solution is reached. It follows that the conditions for optimal abatement, pollution levels and marginal willingness to pay for pollution reduction can be restated as

$$\alpha\left(\omega^*\left(y\right)y\right) = 0, \quad P = c = y, \quad w_q = \frac{-U_P}{U_c}, \quad y \leq \hat{y} \tag{9}$$

$$\alpha\left(\omega^*\left(y\right)y\right) > 0, \quad P = \left(1 - \omega^*\left(y\right)\right)y - \alpha\left(\omega^*\left(y\right)y\right), \quad w_q = \frac{1}{1 + \alpha'\left(\omega^*\left(y\right)y\right)}, \quad y > \hat{y}. \tag{10}$$

As per capita income rises to $\hat{y}$, pollution increases by the same amount. It must reach its maximum at $\hat{y}$, because for income beyond this threshold, emissions declines at the rate $\partial P / \partial y = -\omega\left(1 + \alpha'\right) < 0$.

Discussion

Figure 1 summarizes the key results. The upper diagram shows the change in the marginal willingness to pay for pollution reduction as per capita income increases, and the bottom diagram indicates the resulting pollution-income relationship. Because the top figure is drawn in *c*-*P* space, the marginal rate of substitution relationship in (6) is transformed to $U_c / -U_P \geq 1 + \alpha'$. The corresponding indifference curves are depicted as solid lines, and the increasing and convex production possibility frontiers for different pollution-consumption combinations are the dotted lines. Although the latter frontiers are drawn through the origin, for a given level of income, there is always a minimal level of pollution given by $\overline{P} = \overline{c} - \alpha\left(\overline{\omega}y\right)$.

Assume that the initial level of per capita income y_0 is well below the threshold level $\hat{y}$. This corresponds to a corner solution at point A, where the marginal WTP for pollution reduction is defined by the marginal rate of substitution between less pollution and consumption (see condition (6) above). As income increases, w_P rises although pollution continues to increase as $P = c = y$. At point B, income attains the threshold level, and although still a corner solution, pollution reaches its peak $\hat{P}$. If income increases above the threshold level, the marginal WTP for pollution reduction and its elasticity with respect to income depends on the opportunity cost of pollution reduction, which in turn is dictated by the abatement technology. Point C represents one such interior optimum. Figure 1 indicates the case where the abatement technology is increasing but concave with respect to pollution control expenditures, i.e. $\alpha''\left(\omega y\right) < 0$. The income elasticity of the marginal WTP for pollution reduction is positive, but as income increases, pollution declines more slowly with income (i.e., the slope of the pollution-income relationship beyond $\hat{y}$ becomes flatter).

These results confirm, as Flores and Carson (1997) and Ebert (2003) have shown, that the demand for environmental quality with respect to income does not indicate the actual income elasticity for the WTP for pollution reduction. Similarly, a constant elasticity is not necessary for an environmental Kuznets curve relationship between pollution levels and income per capita (McConnell 1997; Israel and Levinson 2004). Although in the corner solution, there is no demand for reduced pollution and emissions increase exactly with income and consumption, $P = c = y$, the WTP income elasticity is positive and increasing with income. Above the threshold $\hat{y}$, pollution always declines with increased income, but the income elasticity ε_P could be increasing, decreasing or constant.

Although the derived pollution-income relationship in this model is similar to that in Stokey (1998), the conditions leading to this relationship differ. Stokey (1998) assumes that pollution increases with income at low per capita income levels in an economy because it is too poor to modify the "dirtiest" emissions technology. Here, the key determinant is whether or not the average individual is willing to allocate some income to pollution reduction expenditures. If the representative agent is not willing to spend any income on control, then pollution increases with income. Once some income is allocated to reduce emissions, abatement technology influences not only how pollution declines with income but also the sign and magnitude of the income elasticity of the WTP for pollution control. This role of abatement technology in affecting any pollution-income relationship is consistent with Andreoni and Levinson (2001), who show that the returns to scale in pollution control is key to an environmental-Kuznets curve for pollution.

Note also that, if the elasticity of the WTP for a *marginal* reduction in pollution with respect to income is not constant, then the income elasticity of the WTP for a *non-marginal* pollution reduction is also unlikely to be constant. For example, the WTP by an individual for a non-marginal reduction in water pollution from P_0 to P_1 is by definition

$$W(P) = -\int_{P_0}^{P_1} w_p(y)\,dp, \quad P_1 < P_0 \ , \tag{11}$$

which is the area under the marginal WTP curve bounded by the pollution levels P_0 to P_1. It follows that the effects of a change in income on the WTP for a non-marginal reduction in pollution is $\frac{\partial W(P)}{\partial y} = -\int_{P_0}^{P_1} \frac{\partial w_p}{\partial y} dp$ and the corresponding income elasticity is

$$\varepsilon_W = \frac{\partial W\left(P\right)}{\partial y} \cdot \frac{y}{W\left(P\right)} = \frac{y \int_{P_0}^{P_1} \frac{\partial w_p}{\partial y} dp}{\int_{P_0}^{P_1} w_p\left(y\right) dp}. \qquad (12)$$

Unless $\partial w_P \big/ \partial y = 0$, the income elasticity of the WTP for a non-marginal pollution reduction, ε_W, is not constant. As already shown above, $\partial w_P \big/ \partial y > 0$ for the corner solution and is only equal to zero under for the interior optimum if the abatement technology is linear (i.e., $\alpha'' = 0$).

To summarize, the results derived from our theoretical model indicate that the elasticity of the marginal WTP of individuals for pollution reduction is only constant under very restrictive conditions. Nor is a constant elasticity necessary to derive an environmental Kuznets relationship between pollution and income. Determining how this elasticity varies with income, and its magnitude at different income levels, is therefore an empirical issue that requires further investigation.

Empirical Strategy

Our empirical analysis explores further the relationship between consumers' WTP for improving environmental quality (i.e. reducing pollution) and income. We investigate this relationship econometrically using the Box-Cox model extended for use with multi-variate data (Andrews et al. 1971; Box and Cox 1964). In particular, we adopt the following functional form of the Box-Cox model, which has become an accepted standard in econometric studies in the cases when determination of the functional relationship between some variables of interest cannot be based on a priori economic rationale (Sakia, 1992)

$$y_i^{(\lambda_0)} = \beta_0 + \sum_{k=1}^{K} x_{ki}^{(\lambda_k)} \beta_k + \varepsilon_i. \qquad (13)$$

Note that, in the above specification, the dependent and each of the explanatory variables can be transformed with a different parameter. These transformations incorporate a wide range of functional forms, nesting linear ($\lambda = 1$), logarithmic ($\lambda = 0$), unit root and many others, and as such allow for a great flexibility. As a result, estimations based on (13) have been extensively used for uncovering a wide range of non-linear relationships in economics.[1]

In what follows we apply this approach for modelling the income elasticity of the WTP for controlling pollution. There are two main reasons for this – firstly, it incorporates a wide range of functional forms which allows us to investigate the a priori unknown form of non-linearity of the relationship (and correct for the natural skewedness in the data). Secondly, since it includes logarithmic transformation as a special case, it provides a convenient way to test the restriction that the transformation parameters of WTP (dependent variable) for pollution control and income (one of the explanatory variables) are both equal to zero, which is equivalent of the log-log relationship and results in the income elasticity of WTP being constant.[2] That is, the purpose of our empirical analysis in employing the Box-Cox model is to test the null hypothesis that the elasticity of the marginal WTP for pollution control with respect to income is constant.

To take into account the possibility that the that the maximum likelihood estimation of the Box-Cox transformed regression model may not be robust to heteroskedascity (Zarembka 1974), we allow for multiplicative variance heterogeneity of the following form

$$\varepsilon_i \sim f\left(0, \sigma^2 \exp\left(\mathbf{z}_i \boldsymbol{\gamma}\right)^2\right), \qquad (14)$$

[1] For example, recent empirical applications include the functional form of cost functions (Berbeka et al. 2012), modelling price changes (Milon et al. 1984; Mishili et al. 2011; Karaman and Yavuz 2014), portfolio choice (Garlappi and Skoulakis 2011), the economic effects of invasive species (Horsch and Lewis 2009), elasticities of demand and supply (Bessler et al., 1984; Czajkowski et al., 2010), and various health economics applications (Manning 2013).

[2] To test this hypothesis we use asymptotic distribution of the likelihood ratio, which have been shown to have good power properties in this case (Doksum and Wong 1983).

where $\mathbf{z}$ is a vector of explanatory variables of variance and $\boldsymbol{\gamma}$ – a vector of the associated parameters estimated simultaneously with linear and transformation parameters of the model.[3]

Case Study

We empirically explore the relationship between WTP for pollution control and income using a large dataset from a contingent valuation study of the benefits of meeting nutrient reduction targets for the Baltic Sea. The survey was aimed at estimating respondents' WTP for reducing eutrophication (one of the most prominent threats to the Baltic Sea) and its environmental effects on water clarity, blue-green algal blooms, underwater meadows, fish species composition and deep sea bottoms (Ahtiainen et al., 2014).

The study was conducted in 9 littoral countries of the Baltic Sea: Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden, with the adult population in these countries totaling over 230 million people. Due to the large differences in the income levels between these countries, the dataset provides unique opportunity to examine income elasticity of WTP for reducing eutrophication across a very wide range of income levels – from less than 500 to over 5000 euros (€) per month.

The study used a payment card as a WTP elicitation format (Rowe et al., 1996). The bids were country specific, based on the WTPs observed in the pilot studies, however the payment cards were otherwise constructed using the same methodology – the range was designed so that neither the lower nor the upper end of the bid distribution would be truncated (Roach et al., 2002). In what follows, we use the mid-point of each respondent's selected interval as an estimate of his or her individual maximum WTP.

[3] The estimation package allowing for independent Box-Cox transformations of all model variables, multiplicative heteroskedascity and imposing restrictions was written in Matlab and is available for download at http://czaj.org/ under a Creative Commons Attribution 4.0 License.

The contingent scenario and the survey were designed following state-of-the-art standards for contingent valuation studies (Bateman et al., 2004; Champ et al., 2004; Carson et al., 2005; Dillman et al., 2014). Identical questionnaires, translated into national languages, were used to collect the data. See Ahtiainen et al. (2014) for the details regarding the study, the results and their policy relevance.

The survey was designed in 2010–2011 and implemented in October-December 2011. The primary data collection method was Computer Assisted Web Interviews (CAWI), Computer Assisted Personal Interviews (CAPI) were, however, used in the countries where the internet coverage was low, thus not warranting representativeness of a web-based sample (Latvia, Lithuania and Russia; Poland implemented both methods simultaneously). Both CAPI and CAWI were conducted by professional survey companies. Samples were randomly drawn and stratified to represent national population data on, gender, age and regional location.

In total, 10,564 surveys were collected across the nine countries of which 10,396 were complete enough to be used in this analysis. Table 1 presents socio-demographic characteristics of the survey sample vs. general population in each country. The samples exhibited reasonable properties in terms of representativeness, with possibly larger households, lower net income and higher education levels compared to the official statistics.

Results

We apply the Box-Cox regression model (13) to the data collected in the empirical Baltic Sea study described above. Since our primary interest is in estimating the relationship of respondents' WTP for eutrophication reduction and income levels, we estimated the model employing the following specification

$$WTP_i^{(\lambda_0)} = \mathbf{x}_i \boldsymbol{\beta} + income_i^{(\lambda_1)} \beta_{income} + \varepsilon_i \,, \tag{15}$$

where (λ_0) and (λ_1) refer to separate Box-Cox transformation parameters. In order to account for likely differences between the countries' average WTP levels we used fixed-effect type of treatment – the $\mathbf{x}_i$ vector includes dummy variables for each of the countries. We tested if our results are robust across several specifications, such as including additional respondent specific controls in $\mathbf{x}_i$ (sex, age, education level and household size), allowing for heteroskedascity (the error term variance to be country-specific, as specified in (14)) or both.

The results of these modelling approaches are presented in Table 2.[4] Country-specific fixed effects were a substantial and statistically significant improvement to our models, and in addition, some of the country-specific constants were statistically different from each other, indicating differences in mean WTP levels. Respondents' net income was also a highly significant explanatory variable of WTP for eutrophication reduction. Most of the respondent-specific control variables were also significant; male respondents were willing to pay consistently less than others, and respondents who were better educated and who lived in higher-income households were willing to pay more. The explanatory variables of the error term variance (not reported) were all highly significant and substantially improved the model fit. These results are consistent across all model specifications.

The Box-Cox transformation parameters associated with the variables *WTP* and *income* in (15) are both significantly different from zero. This is an indication that, at least in the case of our dataset, lognormal transformation of WTP and income is not superior to other functional forms, and hence the elasticity of WTP for pollution control with respect to income is not constant. Thus, it appears that our null hypothesis can be rejected.

To formally test this hypothesis, in Table 3 we present the results of the models in which both Box-Cox transformation parameters were constrained to zero, resulting in the log-log relationship between WTP for eutrophication reduction and income. The estimated (constant) income elasticity is in the range of 0.23 to 0.29 (depending on the model specification), which is in line with the evidence from studies which used a similar specification (e.g., Kriström et al., 1996; Ready et al.,

[4] Both WTP and income levels were converted to euros (€) using Purchasing Power Parity (PPP) corrected exchange rates.

2002; Hökby et al., 2003; Jacobsen et al., 2009). We note, however, that this specification is outperformed by a more flexible functional form, and therefore, the restriction unjustified. Since the two models are nested, we are able to test this using the likelihood ratio test the results of which are presented in Table 4. The critical value for the test statistic (Chi-squared with 2 degrees of freedom) is 5.99 and therefore, we can easily reject the restrictions – income elasticity of WTP is not constant for our Baltic Sea dataset.

Finally, to provide an insight into the dynamics of the changes of the income elasticity of WTP for eutrophication reduction, we calculate its values for different levels of income. Following from our Box-Cox regression model specification (15), the elasticity is

$$\psi = \frac{\frac{dWTP}{WTP}}{\frac{dincome}{income}} = \frac{\partial \log\left(WTP\right)}{\partial \log\left(income\right)} = \frac{\beta_{income} income^{\lambda_1}}{\lambda_0 \left(\mathbf{x}\ \boldsymbol{\beta} + \beta_{income} \frac{income^{\lambda_1} - 1}{\lambda_1}\right) + 1} \ . \quad (16)$$

Figures 2-5 present the resulting elasticity estimates for different levels of income observed in our data with the accompanying 95% confidence intervals[5]. We find that the income elasticity is increasing and concave, and that it behaves similarly irrespectively of the model specification. It takes values of 0.1 - 0.2 for low-income respondents and reaches 0.6 - 0.7 for the highest income levels observed in our dataset. This result is consistent with previous findings the elasticity is less than one (Hökby et al. 2003; Jacobsen and Hanley 2009; Kriström and Riera 1996; Lindhjem and Tuan 2012), and varies with income (Ready et al. 2002; Czajkowski and Ščasný 2010).

[5] The confidence intervals were simulated numerically (Krinsky and Robb 1986). We used 10^6 draws from multivariate normal distribution given by the vector of parameters and the associated variance-covariance matrix of each model and for each set of parameters drawn in this way calculated the resulting elasticity (for each income level). The lower and upper bound of the 95% confidence interval is approximated with the 0.025 and 0.975 quantiles of the resulting empirical distribution.

Conclusion

Our analysis demonstrates both theoretically and empirically that the income elasticity of the WTP for environmental improvement is unlikely to be constant. We confirm that one cannot infer the income elasticity for the WTP for pollution reduction from the demand for environmental quality with respect to income, and *vice versa* (Flores and Carson 1997; Ebert 2003). In addition, a constant elasticity is not necessary for an environmental Kuznets curve relationship between pollution levels and income per capita (McConnell 1997; Israel and Levinson 2004). In fact, we show that the elasticity of the marginal WTP of for pollution reduction is only constant under very restrictive conditions.

Overall, these results should finally put to rest the "folklore myth" that an environmental Kuznets curve for pollution control implies that the environment is a luxury good (Kriström and Riera 1996), or that one can determine the magnitude of the income elasticity of the WTP for environmental improvement from such an "EKC" relationship.

Our empirical investigation of the relationship between WTP for eutrophication reduction and income based on a large multi-country dataset for the Baltic Sea also leads to rejection of the null hypothesis that the elasticity of the WTP for pollution control with respect to income is constant. We find that this relationship is most likely to be concave, taking values of 0.1 - 0.2 for low-income respondents and reaching 0.6 - 0.7 for the highest income levels observed in our dataset.

Our finding that the willingness to pay (WTP) for environmental improvement varies with respect to income is directly relevant to the growing interest in transferring environmental values estimated at one study site to other locations, countries and even regions to aid environmental decision-making (Johnston and Rosenberger 2010). Recommended guidance principles for transferring estimated WTP values for environmental improvement to other sites are often based on the assumption that the income elasticity of these WTP values must be constant

(Bateman et al. 2011; Ready and Navrud 2006). If this elasticity varies significantly with income levels, as our Baltic Sea case study application suggests, then assuming a constant elasticity will lead to significant errors in the WTP estimates based on these value transfers. Clearly, what is needed is robust estimation of a range of income elasticities of the WTP for environmental improvement, as we have developed here, to ensure that the correct functional form of the WTP-income elasticity relationship is estimated as the basis of any value transfer application.

References

Ahtiainen, H., Artell, J., Czajkowski, M., Hasler, B., Hasselström, L., Huhtala, A., Meyerhoff, J., Smart, J. C. R., Söderqvist, T., Alemu, M. H., Angeli, D., Dahlbo, K., Fleming-Lehtinen, V., Hyytiäinen, K., Karlõševa, A., Khaleeva, Y., Maar, M., Martinsen, L., Nõmmann, T., Pakalniete, K., Oskolokaite, I., and Semeniene, D., 2014. Benefits of meeting nutrient reduction targets for the Baltic Sea – a contingent valuation study in the nine coastal states. *Journal of Environmental Economics and Policy*:1-28.

Andreoni, J. and A. Levinson. 2001. "The Simple Analytics of the Environmental Kuznets Curve." *Journal of Public Economics* 80:269-286.

Andrews, D. F., Gnanadesikan, R., and Warner, J. L., 1971. Transformations of Multivariate Data. *Biometrics*, 27(4):825-840.

Bateman, I. J., Carson, R. T., Day, B., Hanemann, M. W., Hanley, N., Hett, T., Jones-Lee, M., Loomes, G., Mourato, S., Özdemiroğlu, E., Pearce, D. W., Sudgen, R., and Swanson, J., 2002. Economic Valuation with Stated Preference Techniques: A Manual. Edward Elgar, Northampton, MA.

Bateman, I. J., Brouwer, R., Ferrini, S., Schaafsma, M., Barton, D. N., Dubgaard, A., Hasler, B., Hime, S., Liekens, I., Navrud, S., De Nocker, L., Ščeponavičiūtė, R., and Semėnienė, D. 2011. Making Benefit Transfers Work: Deriving and Testing Principles for Value Transfers for Similar and Dissimilar Sites

Using a Case Study of the Non-Market Benefits of Water Quality Improvements Across Europe. *Environmental and Resource Economics*, 50(3):365-387.

Berbeka, K., Czajkowski, M., and Markowska, A., 2012. Municipal wastewater treatment in Poland – efficiency, costs and returns to scale. *Water Science and Technology*, 66(2):394-401.

Bessler, D. A., Weaver, R. D., Wohlgenant, M. K., Challant, J. A., King, G. A., and Gallant, A. R., 1984. Estimating functional forms with special reference to agriculture. *American Journal of Agricultural Economics*, 66(2):204-224.

Box, G. E. P., and Cox, D. R., 1964. An Analysis of Transformations. *Journal of the Royal Statistical Society. Series B (Methodological)*, 26(2):211-252.

Carson, R. T., and Hanemann, W. M., 2005. Contingent Valuation. In: *Handbook of Environmental Economics*, K. G. Mäler and J. R. Vincent, eds., Elsevier, Amsterdam.

Champ, P. A., Boyle, K. J., and Brown, T. C., 2004. A Primer on Nonmarket Valuation. Kluwer Academic Publishers, Dordrecht.

Chang, H.-s., 1977. Functional Forms and the Demand for Meat in the United States. *The Review of Economics and Statistics*, 59(3):355-359.

Czajkowski, M., and Ščasný, M., 2010. Study on benefit transfer in an international setting. How to improve welfare estimates in the case of the countries' income heterogeneity? *Ecological Economics*, 69(12):2409-2416.

Dillman, D. A., Smyth, J. D., and Christian, L. M., 2014. Internet, Phone, Mail, and Mixed-Mode Surveys: The Tailored Design Method. 4 Ed., Wiley.

Doksum, K. A., and Wong, C.-W., 1983. Statistical Tests Based on Transformed Data. *Journal of the American Statistical Association*, 78(382):411-417.

Ebert, U. (2003), Environmental goods and the distribution of income, *Environmental and Resource Economics* 25(4): 435–459.

Flores, N. E., and Carson, R. T., 1997. The Relationship between the Income Elasticities of Demand and Willingness to Pay. *Journal of Environmental Economics and Management*, 33:287-295.

Garlappi, L., and Skoulakis, G., 2011. Taylor series approximations to expected utility and optimal portfolio choice. *Mathematics and Financial Economics*, 5(2):121-156.

Ghalwash, T., 2008. Demand for Environmental Quality: An Empirical Analysis of Consumer Behavior in Sweden. *Environmental and Resource Economics*, 41(1):71-87.

Han, A. K., 1987. Non-parametric analysis of a generalized regression model: The maximum rank correlation estimator. *Journal of Econometrics*, 35(2–3):303-316.

Hinkley, D., 1985. Transformation Diagnostics for Linear Models. *Biometrika*, 72(3):487-496.

Hökby, S., and Söderqvist, T., 2003. Elasticities of Demand and Willingness to Pay for Environmental Services in Sweden. *Environmental and Resource Economics*, 26(3):361-383.

Horsch, E. J., and Lewis, D. J., 2009. The Effects of Aquatic Invasive Species on Property Values: Evidence from a Quasi-Experiment. *Land Economics*, 85(3):391-409.

Israel, D. and A. Levinson. 2004. "Willingness to Pay for Environmental Qualtiy: Testable Empirical Implications of the Growth and Environment Literature." *Contributions to Economic Analysis & Policy* 3(1), Article 2, pp. 1-29, http://www.bepress.com/bejeap/contributions/vol3/iss1/art2

Jacobsen, J. B., and Hanley, N., 2009. Are There Income Effects on Global Willingness to Pay for Biodiversity Conservation? *Environmental and Resource Economics*, 43(2):137-160.

Johnston R. and Rosenberger R. 2010. Methods, trends and controversies in contemporary benefits transfer. *Journal of Economic Surveys* 24:479-510.

Karaman, S., and Yavuz, F., 2014. Hedonic price analysis of the quality characteristics of the Anatolian Hard Red Wheat. *Agricultural Economics*, 60(10):469-478.

Kemp, G. C. R., 1996. Scale equivariance and the Box-Cox transformation. *Economics Letters*, 51(1):1-6.

Khan, M. S., and Ross, K. Z., 1977. The functional form of the aggregate import demand equation. *Journal of International Economics*, 7(2):149-160.

Krinsky, I., and Robb, A. L., 1986. On approximating the statistical properties of elasticities. *The Review of Economics and Statistics*, 68(4):715-719.

Kriström, B., and Riera, P., 1996. Is the income elasticity of environmental improvements less than one? *Environmental and Resource Economics*, 7(1):45-55.

Lindhjem, H. and Tuan, T.H. 2012. "Valuation of species and nature conservation in Asia and Oceania" *Environmental Economics and Policy Studies* 14: 1-22.

Manning, W., 2013. Dealing with skewed data on costs and expenditures. In: *The Elgar Companion to Health Economics*, A. M. Jones, ed., 473-480.

McConnell, K.E. 1997 "Income and the demand for environmental quality." *Environment and Development Economics* 2:383-399.

Milon, J. W., Gressel, J., and Mulkey, D., 1984. Hedonic Amenity Valuation and Functional Form Specification. *Land Economics*, 60(4):378-387.

Mishili, F. J., Temu, A., Fulton, J., and Lowenberg-DeBoer, J., 2011. Consumer Preferences as Drivers of the Common Bean Trade in Tanzania: A Marketing Perspective. *Journal of International Food & Agribusiness Marketing*, 23(2):110-127.

Ready, R. C., Malzubris, J. N., and Senkane, S., 2002. The relationship between environmental values and income in a transition economy: surface water quality in Latvia. *Environment and Development Economics*, 7(1):147-156.

Ready R.C. and Navrud S. 2006. "International benefits transfer: methods and validity tests" Ecological Economics, 60: 429-434.Roach, B., Boyle, K. J., and Welsh, M. P., 2002. Testing Bid Design Effects in Multiple Bounded Contingent Valuation. *Land Economics*, 78(1):121-131.

Rowe, R. D., Schulze, W. D., and Breffle, W. S., 1996. A Test for Payment Card Biases. *Journal of Environmental Economics and Management*, 31(2):178-185.

Sakia, R. M., 1992. The Box-Cox Transformation Technique: A Review. *Journal of the Royal Statistical Society. Series D (The Statistician)*, 41(2):169-178.

Stokey, N.L. 1998. "Are There Limits to Growth?" *International Economic Review* 39:1-31.

Zarembka, P., 1974. Transformation of variables in econometrics. In: *Frontiers of Econometrics*, P. Zarembka, ed., Academic Press, New York, 81-104.

Figure 1. Marginal willingness to pay and pollution as a function of income

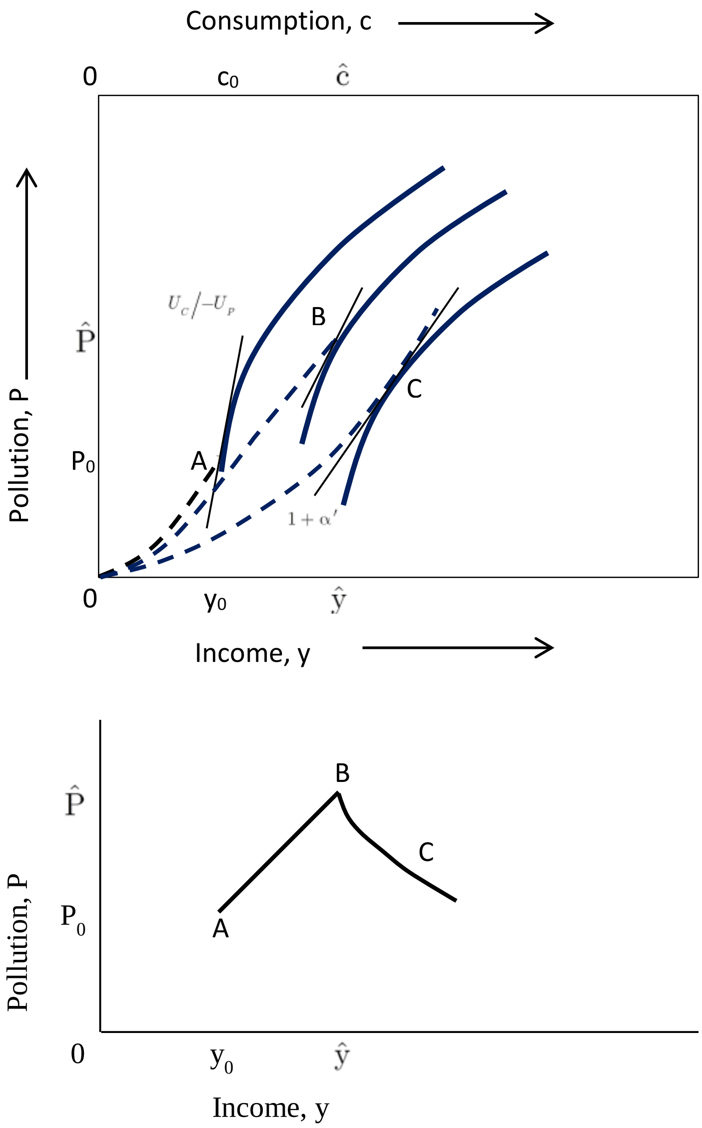

Table 1. Socio-demographic characteristics of the survey samples by country (corresponding characteristics for relevant population in parentheses)

Country	Sample size	Response rate (%)	Mean age	Gender (% male)	Household size	Higher education (%)	Mean net monthly income (€)
Denmark	1,061	38.2	50 (46)	57 (50)	2.2 (2.1)	48 (25)	2,275 (2,385)
Estonia	505	42.1	38 (44)	50 (47)	2.9 (2.2)	55 (31)	583 (542)
Finland	1,645	39.4	51 (45)	49 (49)	2.3 (2.1)	32 (29)	1,890 (2,031)
Germany	1,495	32.5	42 (43)	50 (49)	2.5 (2.1)	39 (25)	1,641 (1,827)
Latvia	701	45	44 (45)	55 (47)	2.8 (2.5)	25 (23)	311 (428)
Lithuania	617	60.5	43 (42)	49 (46)	2.8 (2.5)	22 (24)	205 (387)
Poland	2,029	36[6]	39 (39)	50 (49)	3.3 (2.6)	32 (18)	495 (492)
Russia	1,508	69.3	44 (39)	55 (46)	3.0 (2.6)	44 (23)	338 (462)
Sweden	1,003	34	54 (41)	54 (50)	2.2 (2.0)	50 (33)	1,858 (2,024)

[6] Response rate for CAWI surveys only.

Table 2. Box-Cox regression results of the non-constant elasticity relationship between WTP and income

	Baseline model		Model with heteroskedascity		Model with controls		Model with controls and heteroskedascity	
	Linear coef.	Trans. coef.	Linear coef.	Trans. coef.	Linear coef.	Trans. coef.	Linear coef.	Trans. coef.
WTP		0.1515*** (0.0037)		0.1407*** (0.0068)		0.1518*** (0.0037)		0.1410*** (0.0068)
Denmark	4.4416*** (0.0710)		4.3494*** (0.0865)		4.1825*** (0.1272)		4.1311*** (0.1298)	
Estonia	4.0166*** (0.0927)		3.9180*** (0.1026)		3.6077*** (0.1451)		3.5630*** (0.1440)	
Finland	4.5821*** (0.0616)		4.4859*** (0.0763)		4.3705*** (0.1250)		4.3088*** (0.1255)	
Germany	3.9847*** (0.0697)		3.9086*** (0.0680)		3.6888*** (0.1266)		3.6537*** (0.1182)	
Latvia	2.2323*** (0.0965)		2.1674*** (0.0761)		1.9198*** (0.1489)		1.9008*** (0.1307)	
Lithuania	2.9415*** (0.1095)		2.8521*** (0.0920)		2.5600*** (0.1567)		2.5253*** (0.1421)	
Poland	3.0380*** (0.0632)		2.9675*** (0.0745)		2.6506*** (0.1314)		2.6299*** (0.1300)	
Russia	2.9606*** (0.0621)		2.8843*** (0.0801)		2.5772*** (0.1346)		2.5536*** (0.1366)	
Sweden	5.5041*** (0.0740)		5.3680*** (0.1041)		5.1842*** (0.1351)		5.0984*** (0.1457)	
income	0.5260*** (0.0344)	0.5589*** (0.1341)	0.4786*** (0.0340)	0.6062*** (0.1316)	0.4219*** (0.0362)	0.5368*** (0.1658)	0.3912*** (0.0355)	0.5884*** (0.1608)
male					-0.2006*** (0.0399)		-0.1764*** (0.0381)	
age					0.0008 (0.0014)		0.0003 (0.0013)	
edu2					0.1050 (0.0813)		0.1039 (0.0739)	
edu3					0.3034*** (0.0818)		0.2759*** (0.0760)	
edu4					0.4792*** (0.0782)		0.4284*** (0.0732)	
hhsize					0.0335** (0.0160)		0.0320** (0.0152)	
sigma	1.9611*** (0.0255)		1.9962*** (0.0703)		1.9543*** (0.0254)		1.9774*** (0.0695)	
LL	-47,897.1751		-47,801.5856		-47,851.3664		-47,761.3722	
Pseudo-R2	0.2144		0.2160		0.2152		0.2166	
AIC/n	9.2170		9.2002		9.2094		9.1936	
n (obs.)	10,396		10,396		10,396		10,396	
k (param.)	13		21		19		27	

***, **, * represent significance at 0.01, 0.5, 0.1 level, respectively

Table 3. Box-Cox regression results of the constant-elasticity relationship between WTP and income

	Baseline model		Model with heteroskedascity		Model with controls		Model with controls and heteroskedascity	
	Linear coef.	Trans. coef.	Linear coef.	Trans. coef.	Linear coef.	Trans. coef.	Linear coef.	Trans. coef.
WTP		0 (fixed)		0 (fixed)		0 (fixed)		0 (fixed)
Denmark	3.3324*** (0.0458)		3.3369*** (0.0424)		3.1678*** (0.0855)		3.1675*** (0.0783)	
Estonia	3.0677*** (0.0636)		3.0626*** (0.0556)		2.7995*** (0.0993)		2.8066*** (0.0894)	
Finland	3.4341*** (0.0367)		3.4381*** (0.0253)		3.3033*** (0.0834)		3.2969*** (0.0718)	
Germany	3.1004*** (0.0464)		3.1032*** (0.0283)		2.9048*** (0.0856)		2.9118*** (0.0714)	
Latvia	1.8018*** (0.0554)		1.7920*** (0.0565)		1.6036*** (0.0957)		1.5885*** (0.0908)	
Lithuania	2.3811*** (0.0679)		2.3669*** (0.0558)		2.1280*** (0.1031)		2.1147*** (0.0919)	
Poland	2.2995*** (0.0331)		2.2967*** (0.0726)		2.0531*** (0.0853)		2.0560*** (0.1025)	
Russia	2.2672*** (0.0386)		2.2613*** (0.0524)		2.0259*** (0.0903)		2.0245*** (0.0909)	
Sweden	3.9269*** (0.0414)		3.9301*** (0.0307)		3.7255*** (0.0884)		3.7299*** (0.0774)	
income	0.2942*** (0.0209)	0 (fixed)	0.2824*** (0.0193)	0 (fixed)	0.2336*** (0.0222)	0 (fixed)	0.2254*** (0.0209)	0 (fixed)
male					-0.1185*** (0.027)		-0.1301*** (0.0248)	
age					0.0000 (0.0010)		0.0006 (0.0009)	
edu2					0.0667 (0.0548)		0.0638 (0.0475)	
edu3					0.2079*** (0.0546)		0.1801*** (0.0491)	
edu4					0.3264*** (0.0532)		0.2745*** (0.0462)	
hhsize					0.0197* (0.0108)		0.0224** (0.0102)	
sigma	1.3392*** (0.0075)		1.1378*** (0.0195)		1.3334*** (0.0074)		1.1233*** (0.0192)	
LL	-48,598.3857		-48,119.3229		-48,553.5376		-48077.1279	
Pseudo-R2	0.2030		0.2108		0.2037		0.2115	
AIC/n	9.3516		9.2609		9.3441		9.2540	
n (obs.)	10,396		10,396		10,396		10,396	
k (param.)	11		19		17		25	

***, **, * represent significance at 0.01, 0.5, 0.1 level, respectively

Table 4. Likelihood ratio test results of the non-linear vs. constant income elasticity of WTP

	Baseline model	Model with heteroskedascity	Model with controls	Model with controls and heteroskedascity
LL	-47,897.1751	-47,801.5856	-47,851.3664	-47,761.3722
LL (rescricted)	-48,598.3857	-48,119.3229	-48,553.5376	-48,077.1279
LR test statistic	1,402.4212	635.4745	1,404.3424	631.5114
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001

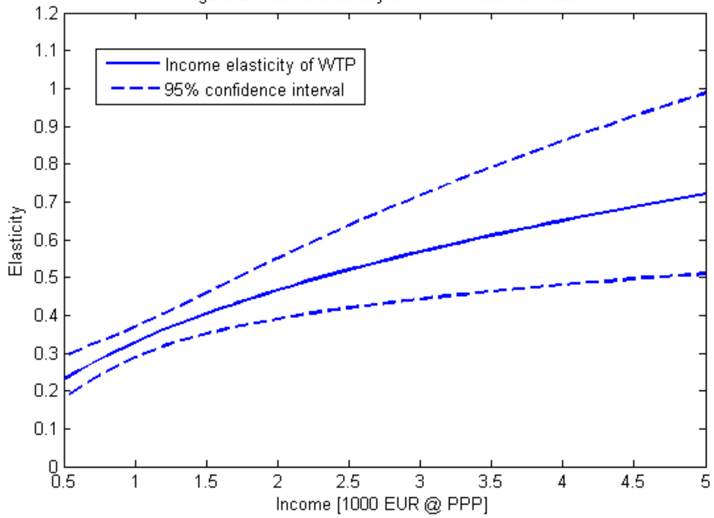

Figure 2. Income elasticity of WTP -- baseline model

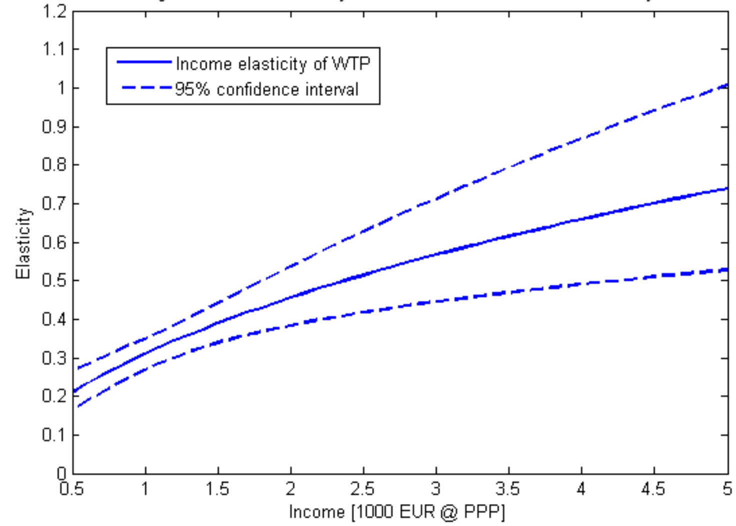

Figure 3. Income elasticity of WTP -- model with heteroskedascity

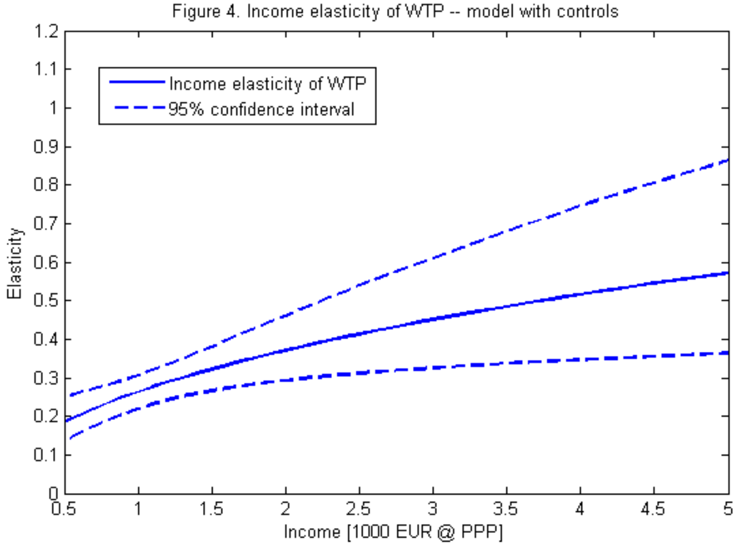

Figure 4. Income elasticity of WTP -- model with controls

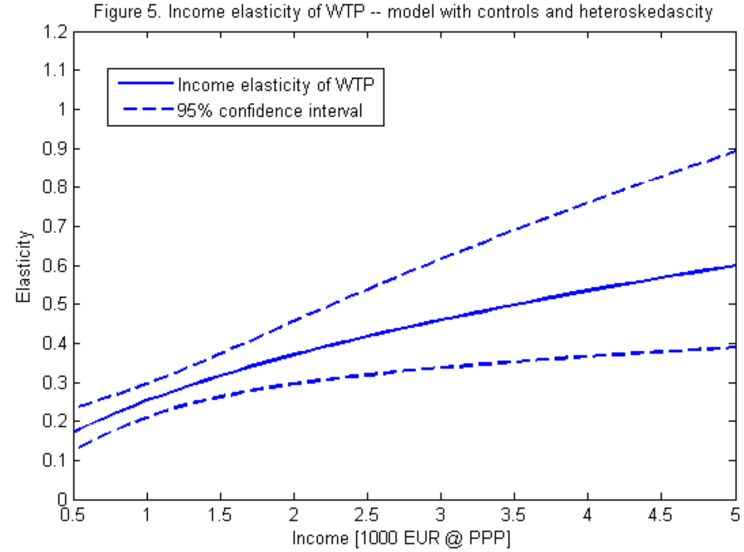

Figure 5. Income elasticity of WTP -- model with controls and heteroskedascity

Faculty of Economic Sciences
University of Warsaw
44/50 Długa St.
00-241 Warsaw
www.wne.uw.edu.pl