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Moritz A. Drupp, Zachary M. Turk, Ben Groom, Jonas Heckenhahn

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Abstract

While the global economy continues to grow, ecosystem services tend to stagnate or decline. Economic theory has shown how such shifts in relative scarcities can be reflected in project appraisal and environmental-economic accounting, but empirical evidence has been sparse to put theory into practice. To estimate the relative price change in ecosystem services that can be used for making such adjustments, we perform a global meta-analysis of contingent valuation studies to derive income elasticities of willingness to pay (WTP) for ecosystem services to proxy the degree of limited substitutability. Based on 861 income-WTP pairs from more than 400 studies, we estimate an income elasticity of WTP of around 0.8. Combined with estimates of good-specific growth rates, we estimate relative price change of ecosystem services of around 2.2 percent per year. In an application to natural capital valuation of forest ecosystem services by the World Bank, we show that public forest natural capital should be uplifted by around 60 percent. Our assessment of aggregate public natural capital yields a larger value adjustment of between 100 and 170 percent, depending on the discount rate. We discuss implications for policy appraisal and for improving estimates of natural capital in comprehensive wealth accounts.

JEL-Codes: D610, H430, Q510, Q540, Q580.

Keywords: willingness to pay, ecosystem services, income elasticity, limited substitutability, growth, relative prices, contingent valuation, forests, natural capital.

Moritz A. Drupp
Department of Economics
University of Hamburg / Germany
Moritz.Drupp@uni-hamburg.de

Zachary M. Turk
Department of Economics
Cork University Business School,
University College Cork / Ireland
zacharyturk@yahoo.com

Ben Groom
Department of Economics, University of Exeter
Business School / United Kingdom
B.D.Groom@exeter.ac.uk

Jonas Heckenhahn
Faculty of Management and
Economics, Ruhr University
Bochum / Germany
Jonas.Heckenhahn@ruhr-uni-bochum.

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1 Introduction

Measuring economic progress towards sustainability requires addressing the limited substitutability among the various constituents of comprehensive wealth (Smulders and van Soest, 2023). Potential limits to substitution imply that society must strike a balance between the two opposing paradigms of Weak and Strong Sustainability (e.g., Neumayer, 2003; Hanley et al., 2015; Dasgupta, 2021). Many contemporary measures of economic progress and wealth have explicitly or implicitly followed a Weak Sustainability approach. In doing so, they consider natural capital and ecosystem services as largely substitutable—sometimes even perfectly substitutable—with human-made capital stocks. In light of the continued growth of human-made capital and the stagnation or degradation of many natural capital stocks (IPBES, 2019), the Weak Sustainability approach is increasingly being called into question. From a theory perspective, we should consider some degree of imperfect substitutability when estimating shadow prices. This is relevant both for natural capital that serves as an intermediate input to various production processes and for public natural capital as a direct source of utility (see, e.g. Smulders and van Soest, 2023; Zhu et al., 2019). A common constraint to implementation, however, has been a lack of sufficient empirical evidence on the limits of substitutability of ecosystem services and natural capital to inform the computation of shadow prices (e.g., Cohen et al., 2019; Drupp, 2018; Drupp et al., 2024; Rouhi Rad et al., 2021).

This paper makes a step towards closing this important empirical evidence gap by characterising the limited degree of substitutability of ecosystem services in utility via a global meta-analysis of environmental valuations tudies. Doing so allows changes in the relative scarcity of ecosystem services to be properly valued in policy appraisal and environmental-economic accounting. The evidence is drawn from the largest global meta-analysis to date that estimates the degree of limited substitutability of ecosystem services vis-a-vis market goods, proxied via the income elasticities of WTP for ecosystem services. Knowing the income elasticity of WTP, and good-specific growth rates that we estimate as well, allows computing the relative price changes of ecosystem services. We then propose an approach to deriving adjustments to natural capital accounts, which we demonstrate using our empirical estimates in the context of forest ecosystem service values in the World Bank's *Changing Wealth of Nations (CWON)* program as well as for a general generic adjustment of public natural capital values.

There are two general approaches to reflecting limited substitutability of ecosystem services in Cost-Benefit Analysis (CBA) or the assessment of comprehensive wealth, to take two examples. One can either apply differentiated discount rates—often a lower discount rate for non-market ecosystem services—or account for increasing relative scarcity by adjusting our valuation (accounting price) of ecosystem services throughout the horizon of the evaluation (e.g. Baumgärtner et al., 2015; Drupp, 2018; Gollier, 2010; Hoel and Sterner, 2007; Traeger, 2011; Weikard and Zhu, 2005). Several studies have already shown the importance of accounting for the adverse effects of climate change on ecosystem services, biodiversity and environmental amenities (e.g. Hoel and

Sterner, 2007; Sterner and Persson, 2008). More recently Drupp and Hänsel (2021) and Bastien-Olvera and Moore (2021) examined how the increasing scarcity and limited substitutability of non-market ecosystem services each affect optimal climate policy through good-specific discount rates or relative price changes. Drupp and Hänsel (2021), for instance, estimate that limited substitutability leads to relative prices of non-market goods increasing by around 2 to 4 percent per year. Incorporating this scale of adjustment leads to estimates of the social cost of carbon that are more than 50 percent higher compared to the case where goods are assumed to be perfectly substitutable. Accounting for relative price changes of non-market goods is thus crucial to the appraisal of climate policy. Perhaps more importantly, relative price changes need to be accounted for properly in the appraisal of projects, regulations and policies to better account for the impact of ecosystem services on well-being. Furthermore, when using environmental-economic accounting, e.g. within the UN System of Environmental Economic Accounting-Experimental Ecosystem Accounting (SEEA-EEA) or *CWON*, valuations that account for limited substitutability are critical to the assessment of sustainability.

Practically speaking, two components are needed to estimate the trajectory of relative prices for ecosystem services: i) the elasticity of substitution between market and non-market goods; and, ii) their respective growth rates. Previous empirical studies have estimated the elasticity of substitution indirectly using the inverse of the income elasticity of willingness to pay (WTP) from non-market valuation studies (Baumgärtner et al., 2015; Drupp, 2018; Heckenhahn and Drupp, 2024). Good-specific growth rates have been estimated either using historical time series data (e.g., Baumgärtner et al., 2015; Heckenhahn and Drupp, 2024) or as endogenous outcomes in global integrated climate-economy assessment models (e.g. Drupp and Hänsel, 2021). The rate of change of relative prices is then approximated by the income elasticity of WTP multiplied by the difference between the growth rates of marketed and non-marketed goods. Baumgärtner et al. (2015) were the first to estimate relative price changes in this way. Yet, the study drew on an estimate of the elasticity of substitution for just one ecosystem service: global biodiversity conservation, based on a small meta-analysis of 46 contingent valuation (CV) studies by Jacobsen and Hanley (2009). Heckenhahn and Drupp (2024) provide the first country-specific evidence, estimating growth rates for 15 separate ecosystem services, along with their degree of substitutability. Yet, their meta-analysis was focused solely on Germany and built on just 36 WTP studies. There is thus clear room for improvement in the estimates of growth and substitutability of ecosystem services so that welfare effects and sustainability can be more accurately evaluated.

These gaps in and limitations of the empirical evidence—the absence of both a general default for generic ecosystem services as well as country- and ecosystem service-specific estimates of income or substitution elasticities and growth rates—mean that guidelines for government appraisal and environmental-economic accounting seldom address the issue of limited substitutability of non-market goods (Groom et al., 2022). Where environmental discounting or relative price changes have been integrated into governmental policy guidance they are operationalised using estimates of growth and elasticities at the global level (Groom and Hepburn, 2017). For instance, The Netherlands consider a general default relative price change of 1 percent per annum for ecosystem services of all kinds in their discounting guidance, following Baumgärtner et al. (2015).[1] In other cases, the uniform treatment makes sense. The UK Department for Environment, Food and Rural Affairs used to reflect relative price adjustments for the health benefits of pollution reductions by 'uplifting' the damage costs by 2 percent per year. The underlying assumption here is that WTP for avoiding the health consequences of pollution grows in line with predicted income (Treasury, 2021). Indeed, health benefits in general are discounted using a discount rate that is 2 percentage points lower in the UK for related reasons.[2] For the environment in general, where the guidelines do reflect changing valuations over time or lower discount rates, e.g. in the Asian Development Bank and Canadian guidelines, again rather generic rules of thumb are used that do not distinguish ecosystem services (Groom et al., 2022). Finally, where guidelines exist for natural capital valuation, such as the most recent *CWON* report by the World Bank, they apply to a minimal basket of non-market goods and capital stocks, and fail to account for changing relative prices. For instance, in the CWON forest ecosystem services are valued using a meta-regression and benefit transfer by Siikamäki et al. (2015), yet maintain constant real prices over time.[3]

From a policy perspective, not accounting for limited substitutability of ecosystem services and market goods, either via relative price changes or in discount rates, means that ecosystem services will be seriously undervalued in public appraisal of policy or natural capital, particularly if relative scarcity is rising. The underlying—often implicit—assumption in such cases is that ecosystem services are perfectly substitutable with market goods. Yet, even in the unusual cases where adjustments have been made, the advice is too generic to properly reflect sustainability and the welfare associated with different ecosystem services over time. For practical purposes then, more accurate estimates are needed, ideally differentiated across ecosystem services in case sizable heterogeneities manufest themselves. Only then will governments feel comfortable including such adjustments in their guidance.

Against this background, we provide the first systematic global empirical evidence basis to inform relative price adjustments of ecosystem services. These estimates can be applied to public appraisal of public investment and regulatory change as well as to natural capital valuation such as the *CWON* programme and the SEEA-EEA. Our main focus is on improving the estimation of limited substitutability of non-market ecosystem services vis-a-vis market goods. To this end, we perform a meta-analysis of environmental values derived using the CV method to estimating the income elasticity

[1] The guidance allows specific deviations from 1% if growth or substitution possibilities deviate from the default assumptions, e.g. if the ecosystem service is deemed no-substitutable.

[2] Another rationale for this practice stems from the use of Quality Adjusted Life Years in UK public appraisal. Since QALYs are masured in utility, so the argument goes, they should only be discounted using the pure rate of time preference

[3] The assumption is that per-hectare monetary values are constant over time (correcting for inflation). Note, Siikamäki et al. (2015) find positive and large GDP elasticities of WTP.

of WTP—a key parameter also for benefit transfer across space (Baumgärtner et al., 2017; Smith, 2023). Our meta-analysis contains a sample of over 1000 articles and builds on a large-scale keyword-based search strategy and an in-depth analysis of the known population of peer-reviewed CV studies. Our full sample includes 861 mean income and WTP estimates, including recurring covariates, sourced from 402 peer-reviewed contingent valuation studies.

Our centralestimates suggest an income elasticity of WTP for ecosystem services of 0.8, with a 95 confidence interval extending from around 0.6 to 1.0. This estimate is fairly stable across different ecosystem service types. Using estimates of good-specific growth rates, we compute relative price changes of ecosystem services of around 2.2 percent per year on aggregate. Relative price changes are smaller for forest ecosystem services (1.6 percent), primarily due to a lower rate of de-growth of forest area. These estimates can be employed to adjust WTP estimates for project appraisal or environmental-economic accounting. In an application on natural capital valuation, taking the *CWON* 2021 report by the World Bank (2021), we show that adjusting natural capital estimates for non-timber ecosystem services for relative price changes results in uplifting the present value over a 100-year time period by 57 percent (95 CI: 35 to 86 percent), materially elevating the role of public natural capital. The results echo work on the importance of limited substitutability in climate policy appraisal (Bastien-Olvera and Moore, 2021; Drupp and Hänsel, 2021; Sterner and Persson, 2008). Our estimates for adjustments to the value of aggregate public natural capital are more substantial, amounting to between 100 and 170 percent for our main estimate, depending on the discount rate. We close by discussing the results and limitations of our empirical analysis and by summarizing insights for project appraisal, accounting and sustainability more generally.

2 Theoretical background

To provide the theoretical background for our empirical analysis, we consider a simple model in which intertemporal well-being is derived from both human-made goods, C_t and non-market environmental goods or ecosystem services, E_t. In the general case of imperfect substitutability, ecosystem services feature explicitly in the instantaneous utility function representing preferences over market-traded consumption goods and non-market goods, $U(C_t, E_t)$. A standard form of the time-discounted Utilitarian social welfare function is given by:

$$W = \int_{t=0}^{\infty} U(C_t, E_t) e^{-\delta t} dt \, . \quad (1)$$

The theory of dual discounting or relative price changes has shown that there are two approaches to addressing the intertemporal appraisal of non-market goods (e.g., Baumgärtner et al., 2015; Gollier, 2010; Traeger, 2011; Weikard and Zhu, 2005):

1. Explicitly consider how the relative price of non-market goods vis-a-vis market-traded consumption goods changes over time. Then, compute comprehensive consumption equivalents at each point in time and use a single consumption discount rate to on future comprehensive consumption equivalents.

2. Use differentiated, good-specific consumption discount rates, i.e. one for market goods, r_C, and another for non-market goods, r_E.

In the first approach, we compute the value of non-market goods in terms of the market good numeraire. This value is given by the marginal rate of substitution (MRS), U_{E_t}/U_{C_t}, which is the implicit price of non-market goods. The MRS tells us by how much the consumption of market goods would need to increase in response to a marginal decrease in non-market goods to hold utility constant. The RPC_t measures the change in the MRS between non-market and market goods over time, i.e. the relative change in the valuation of non-market goods (Hoel and Sterner, 2007):

$$RPC_t = \frac{d}{dt}\left(\frac{U_{E_t}}{U_{C_t}}\right)/\left(\frac{U_{E_t}}{U_{C_t}}\right). \tag{2}$$

Future expected non-market values can then be adjusted using the RPC_t and a single SDR can then be used to discount future flows of private and non-market consumption.

In the second approach, we compute good-specific (dual) discount rates as:

$$r_{C_t} = \delta + \eta_{CC_t} g_{C_t} + \eta_{CE_t} g_{E_t} \tag{3}$$

$$r_{E_t} = \delta + \eta_{EE_t} g_{E_t} + \eta_{EC_t} g_{C_t} \tag{4}$$

where g_E and g_C are the growth rates, η_{CC_t} (η_{EE_t}) is the elasticity of marginal utility of private-good (non-market good) consumption with respect to private-good (non-market good) consumption, and η_{CE_t} (η_{EC_t}) denotes the cross-elasticity of marginal utility of private-good (non-market good) consumption with respect to non-market good (private-good) consumption (see, e.g., Baumgärtner et al., 2015). Expanding their applicability, these dual rates can also be used in cases where non-market goods are not evaluated in monetary units such as satellite accounts in national accounting and biophysical impact assessments. It is important to stress that this approach also implies that we have to adjust the 'standard' discount rate for private consumption with an addition to the Simple Ramsey Rule by a substitutability effect ($\eta_{CE_t} g_{E_t}$), to account for how changes in the physical availability of the non-marketed good affect the utility obtained from the private-good. This is unnecessary when using the RPC approach because non-marketed goods are valued in terms of private goods and the RPC effect captures substitutabuility.

To make this concrete and applicable, let us consider the workhorse constant-elasticity-of-substitution (CES) utility function, capturing various degrees of substitutability:

$$U(C_t, E_t) = \left(\alpha C_t^{\frac{\sigma-1}{\sigma}} + (1-\alpha)\, E_t^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}\ , \tag{5}$$

$0 < \sigma < +\infty$, is the constant elasticity of substitution between the two goods, and $0 < \alpha < 1$ is the utility share parameter for private consumption. The utility function given by equation 5 is strictly concave, represent homothetic preferences, and both the private good, C_t, and non-market good, E_t, are normal. It turns out that with CES preferences and imperfect complements, i.e. $\sigma > 0$, we get the following straightforward equivalence between the dual discounting and RPC approaches (Weikard and Zhu, 2005):

$$RPC_t \;=\; \frac{1}{\sigma}\left[g_{C_t} - g_{E_t}\right] \;=\; r_{C_t} - r_{E_t}. \tag{6}$$

Accordingly, the choice of whether one adjusts the numerator via a relative price effect adjustment or the denominator via the use of dual discount rates is not of theoretical importance in intertemporal valuation exercises. In the setting of CES preferences, Ebert (2003) has shown that the constant elasticity of substitution between a market good and a non-market good is directly and inversely related to the income elasticity of WTP, ξ, of the non-market good (cf. Baumgärtner et al., 2017). We can thus write the RPC as:

$$RPC_t \;=\; \xi\left[g_{C_t} - g_{E_t}\right]. \tag{7}$$

Note that the income elasticity of WTP, ξ, can thus also be denoted as the elasticity of complementarity between market goods and non-market ecosystem services.

We can further decompose the RPC into two constituent parts: An income effect, $\xi \times g_{C_t}$, which captures the increase in relative prices due to rising incomes over time, and a scarcity effect, $-\xi \times g_{E_t}$, which captures the change in relative prices due to changing absolute scarcities of ecosystem services. While it is common practice to adjust future WTP estimates for the income effect for selected types of other non-market goods, such as for health or travel time savings, policy and accounting guidelines typically do not yet feature scarcity effects (e.g., Drupp et al., 2024).

3 Empirical strategy

We build on previous work to estimate income elasticities of WTP for ecosystem services based non-market valuation studies (e.g., Jacobsen and Hanley, 2009; Heckenhahn and Drupp, 2024; Subroy et al., 2019; Richardson and Loomis, 2009; Barrio and Loureiro, 2010). Our meta-analysis collects mean WTP and mean income estimates at the valuation exercise scale, which are then used to estimate income elasticities of WTP and, on their basis, to determine the elasticities of substitution or complementarity between ecosystem services and market goods via their indirect relationship (cf. Baumgärtner et al., 2015; Ebert, 2003; Heckenhahn and Drupp, 2024). In this section, we first discuss the meta-analysis and subsequently the empirical strategy to derive estimates of ξ. Finally, we discuss the computation of growth rates of ecosystem services.

3.1 Meta-analysis of mean WTP-income value pairs

The data basis for our analysis is a meta-analysis of existing WTP studies.The entire process of dataset creation began in spring 2022 and concluded in early 2023. In the first phase, we identifed potentially relevant non-market valuation studies through a keyword-based search string provided in Appendix A.1. In particular, here, we built on the authors' experience (e.g., Heckenhahn and Drupp, 2024; Moore et al., 2024) and beta testing. To ensure better comparability of ecosystem service valuation estimates, we focused our search on contingent valuation (CV) studies that were published in peer-reviewed, English-language literature since the year 2000. The keyword-based search resulted in a preliminary data set where each row is a peer-reviewed journal article in which we expect to find relevant (mean) WTP estimates and income data. Generally, the employed search string was intended to cast a wide net. That is, we expected to later drop several studies due to irrelevance and informational shortcomings.

The data was then evaluated using the exclusion criteria reported in Appendix A.2. After application of the first exclusion criterion—including whether each article has been cited at least once in SCOPUS—2,174 articles remained. The next exclusion criteria step is an abstract screening to check whether the articles potentially report new, CV-based WTP estimates at all. Strictly theoretical papers as well as reviews, secondary source estimates, and those focused on benefit transfer were excluded to avoid double-counting estimates. Naturally, whether we could access the articles was important but rarely proved to be an issue. At this stage, 1,165 studies remained on which to conduct a detailed screening and subsequent data harvesting.

From the data set of 1,165 WTP studies, we selected a random sample of 100 studies as the basis to fine-tune the screening and coding processes and improve consistency between our two independent coders. Each paper was carefully scrutinized for appropriate WTP and income data (see Appendix A.2 for details). A recurring issue was that several papers do not report whether income data is net of taxes or gross income. We have subsequently contacted each paper's corresponding author in search of clarification, with a response rate of around 40 percent, dropping the ambiguous remaining observations. The review of each paper and harvesting of relevant data was a particularly time-intensive process. However, we found it easier to first screen for the inclusion of both mean WTP and mean income estimates—or the information necessary to derive such estimates—before harvesting all relevant data. We also found that there is an important distinction between CV estimates presented on a timescale basis versus per-use estimates. Namely, without data on frequency of use at the respondent scale, per-use estimates are not comparable to estimates based on timescales, which is why we chose to set them aside. We further constrained our data set to peer-reviewed studies that survey respondents on values based on timescales such as annually, monthly, etc. and convert estimates to an annual scale.

Our main analysis builds on studies surviving our exclusion criteria and containing at least the minimum necessary information—a mean WTP estimate and mean respon-

Table 1: Prepared data set description

Variable	Context	Value
Countries represented	Count	74
Continent	Observations	
North America		101
South America		45
Africa		37
Europe		290
Asia		380
Australia		8
Study year	Mean (s.d.)	2010 (6.7)
Income	Mean annual, 2020 USD (s.d.)	36,586 (27,046)
WTP	Mean annual, 2020 USD (s.d.)	155 (496)
Survey sample size	Mean (s.d.)	608 (810)
Respondent age	Mean (s.d.)	43 (6.5)
Respondent household size	Mean (s.d.)	4.1 (1.5)
Forest-relevant estimates	Share of observations	0.29

Notes: s.d. is the standard deviation of the data referenced. Based on N=861 WTP-income pairs contained in 402 unique studies.

dent income estimate. An unfortunate but necessary result of our focus on comparability is a substantially reduced number of studies contributing to the end result. Of the 1,165 studies passing the first two rounds of screening, 402 studies containing 861 distinct WTP-income pairs are of use. Table 1 provides summary statistics of our sample. Appendix B includes graphical illustrations of the meta-analysis data. Appendix E provides the full list of included studies and their respective references.

3.2 Estimation strategy

Our main result is based on a log-log specification of mean WTP and mean income values while accounting for the structure of our data, and clustering standard errors at the study level. We suspect that a number of covariates affect the estimated coefficient on income if omitted. These variables would have a direct effect on WTP and as such should be included in the model. Importantly, the income (and WTP) data is not always consistent on a household level, but sometimes elicited at an individual level. We, therefore, rely as a default on the multivariate estimate that contains controls for these differences across estimates. Our main model specification thus becomes:

$$ln(WTP_{ij}) = \alpha + \xi\, ln(INC_{ij}) + \sum_{k=1}^{n} \beta_k x_{ij} + \epsilon_i \quad (8)$$

where $\sum_{k=1}^{n} \beta_k x_{ij}$ is our list of n covariates. These include potentially relevant factors about the survey environment (survey year,), respondent incomes (income and WTP per-person or household, gross or net income), WTP terms (annual, monthly, repeated), and survey methods (elicitation format, data collection method).

We conduct a sensitivity analysis on our coefficient of interest by estimating a large set of models with different variations of covariates included in our main model in Equation 8. So, we estimate an $2^{13} = 8,192$ versions of our main log-log specification. Furthermore, as study sample size also varies substantially—note a mean sample size of 608 with a standard deviation of 810—the result of alternative observation weights are compared. However, our preferred weighting approach is to apply the square-root of the sample size used at the WTP estimate scale. This implies that we put some weight on sample size but avoid the risk that a few studies with particularly large sample sizes drive our result entirely. In an additional analysis, we investigate numerous specifications that have been used in the literature so far to estimate income elasticity of WTP: From simple OLS, to random effects (e.g. Jacobsen and Hanley, 2009; Heckenhahn and Drupp, 2024), fixed effects, to clustered random regression as used here with sample size, inverse of square root of sample size (cf. Subroy et al., 2019) to our main specification that uses the square root of sample size to weigh estimates.[4] Finally, note that we apply robust standard errors throughout.

We separately explore heterogeneities in income elasticites. First, we compare study differences across ecosystem service types. To this end, we prepared a set of indicator variables for ecosystem service types based on the ecosystem services listed in the Millenium Ecosystem Assessment (MEA, 2005). These indicators are at the WTP estimate-level as some papers report estimates specific to certain service types. Second, we test how income elasticities differ across continents. Third, we test for differences across time time periods (for example, pre- and post-2010). Finally, we explore whether income elasticity estimates differ along the income distribution, by comparing different segments of the income distribution.

3.3 Growth rates

We assemble growth rates of ecosystem services to obtain a proxy for a global measure of the shift in the relative scarcity of ecosystem services vis-a-vis human-made goods. These estimates extend and update prior work by Baumgärtner et al. (2015), who found that ecosystem services have overall declined by half a percent in the last decades. We focus on non-market (and non-rivalrous) ecosystem services, i.e. we do not consider provisioning services but capture regulating and cultural services. In a first step, we

[4] We report the sensitivity of the estimated income elasticity to these methodological choices concerning models and weighting schemes in Figures 6 and 7 in the Appendix.

Table 2: Components and data sources for estimates of growth rates

Component	Unit of measurement	Data source
Forest area	Hectare	WorldBank (2023)
Living Planet Index (LPI)	Dimensionless	Zoological Society of London, and WWF 2022
Red List Index (RLI)	Various	IUCN RedList (2023), based on Butchart et al. (2010)
Air quality (mean annual PM2.5)	Micrograms per m^3	WorldBank (2023)
Climate regulation	Degrees Celsius	NOAA (2023)
GDP per capita	US dollars	WorldBank (2023)

update the data sources employed by Baumgärtner et al. (2015), notably: Forest cover, Living Planet Index (LPI), and IUCN's Red List Index (RLI). We complement this with two additional measures for regulating services that capture highly salient aspects of environmental quality: air quality regulation and climate regulation. We proxy the former by the negative of changes in PM2.5 emissions, i.e. counting reductions in emission as an improvement in air quality. We proxy for the latter with the change in the 2C global mean temperature budget—the upper target of the UN Paris Agreement. Table 2 shows the individual components, units of measurement, and data sources.

Within regulating (forest, LPI, RLI, PM2.5, temperature) and cultural services (forest, LPI, RLI) as well as aggregate ecosystem services we take the arithmetic mean of relevant individual components. To calculate growth rates, we use the time span with the longest comparable data across all indicators (1993 to 2016) and estimate exponential growth rates, including standard errors. We use the largest standard error of the individual growth rate components—climate for regulating and aggregate services, and the living planet index for cultural services—when aggregating standard errors. Akin to estimating growth rates of ecosystem services, we also estimate the growth rate of global GDP per capita. In contrast to Baumgärtner et al. (2015), we do not subtract provisioning services as we do not examine it as a separate ecosystem service category, and measure economic growth including its standard error.[5]

[5] All time series show a clear trend except for air quality, which deteriorates from 1990 to 2010 and improves again thereafter. We thus also redo the analysis of growth rates for the time frame 2010 to 2016.

4 Results

We now present here estimates of income elasticities of WTP, ξ, for ecosystem services globally as well as select regions. We also estimate income elasticities based on subcategories of ecosystem services as well as different time frames. We subsequently couple the estimates of income elasticities with estimates of good-specific growth rates to compute relative price changes of ecosystem services.

4.1 Income elasticity of WTP for ecosystem services

We first estimate the income elasticity of WTP for aggregate ecosystem services on our full sample with key controls (different permutations of Equation 8).[6] Our central estimate of the income elasticity of WTP amounts to 0.79 (95-CI: 0.60 to 0.97).[7] We develop a specification graph to investigate the sensitivity of our estimate to various combinations of control variables. The result of 8,192 alternative specifications represented in Figure 5 of Appendix D and shows that the univariate estimate falls at the lower end of these alternative specifications. Our main estimate (with controls) maps into a mean value for the elasticity of substitutability between ecosystem services and market goods of 1.27 (95-CI: 1.03 to 1.66).

Table 3: Income elasticity of WTP for aggregate ecosystem services

ln(INCOME)	S.E.	N	Adj. R^2
0.79***	0.09	861	0.89

Notes: Multivariate regression. The set of controls includes the study year, sample size, income information (gross/net, individual/household), payment type and elicitation method. Significance levels: * p<0.1, ** p<0.05, *** p<0.01

Estimates on subsets allow us to investigate the extent of heterogeneities. We consider different sub-types of ecosystem services, and potential differences across continents and time frames. Table 4 reports income elasticities of WTP across different sub-types of ecosystem services: regulating and cultural services as well as key subcategories. We find little variation in income elasticities, noting that oftentimes projects

[6] Note that for our data the Breusch and Pagan Lagrange multiplier test clearly rejects a model with equal effects (p = 0.000, n = 861, j = 402). Further, note that Ramsey's Regression Specification Error Test yields the following results: Log-log model: chi-squared: 108.68 (p = 0.000), linear model: chi-squared = 16.64 (p = 0.000), quadratic model: chi-squared = 25.96 (p = 0.000), semi-log model: chi-squared = 9.74 (p = 0.0018). These results indicate that the log-log specification we apply provides the best fit for our data.

[7] By contrast, a univariate regression yields an estimate of the income elasticity of WTP for ecosystem services of 0.62 (95-CI: 0.41 to 0.84), see Table 7. The difference is almost entirely attributable to the inclusion of an indicator of whether the income measure is at the household or individual level. Respondent measures of income potentially overlook the dynamics around household size or multiple streams of income resulting in seemingly more elastic estimates of the income elasticity of willingness to pay for ecosystem services. As such, we select the coefficient from the multivariate estimation as our main result.

Table 4: Heterogeneity of income elasticities of WTP across ecosystem service types

	ln(INCOME)	S.E.	N	Adj. R^2
Climate regulation	0.80***	0.18	189	0.93
Air quality regulation	0.79***	0.14	258	0.92
Water regulation	0.85***	0.13	286	0.89
Erosion regulation	0.84***	0.12	195	0.86
Regulating Services	0.79***	0.12	541	0.93
Spiritual and religious values	0.84***	0.12	121	0.64
Aesthetic values	0.72***	0.10	423	0.89
Recreation and ecotourism	0.69***	0.16	361	0.85
Biodiversity preservation	0.80***	0.10	411	0.89
Cultural Services	0.74***	0.10	574	0.87
Forest ecosystem services	0.81***	0.13	246	0.87
Non-forest ecosystem services	0.78***	0.12	614	0.89

Notes: Multivariate regressions. Significance levels: * p<0.1, ** p<0.05, *** p<0.01

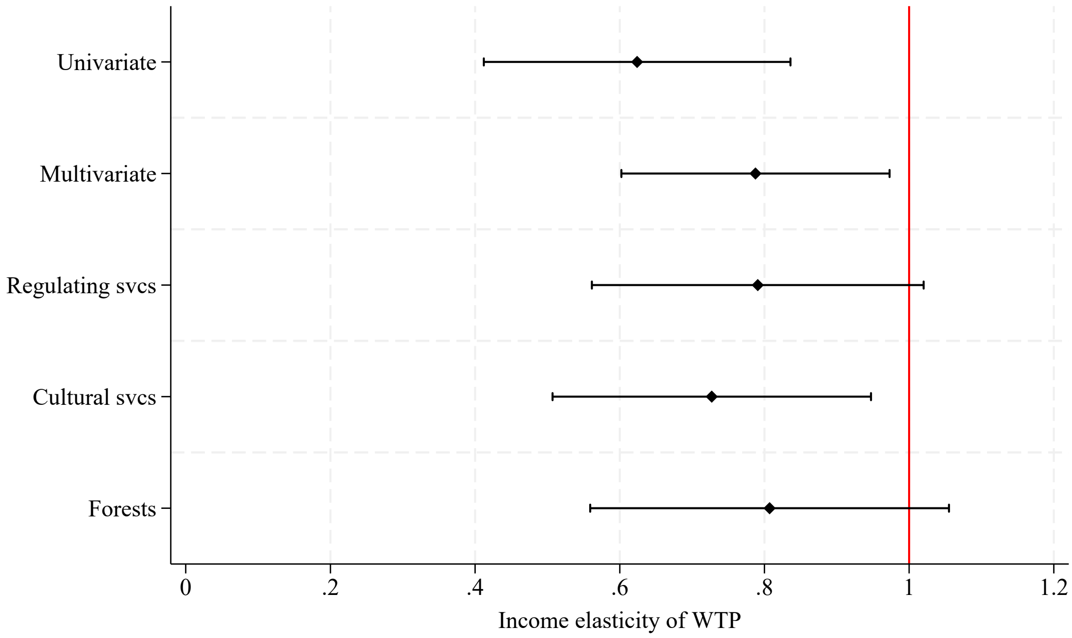
valued in CV studies encompass contributions to multiple services. Only the estimate of the income elasticity for recreation and ecotourism is lower—the category closest to being rivalrous. We also split the sample into forest and non-forest ecosystem services, as this serves as a key input to our application on natural capital accounting in the *CWON* example in Section 5. We find that the income elasticity of forest ecosystem services is slightly higher than the aggregate estimate, but far from significantly so. While the 95 CI for our main aggregate estimate does not include the CObb-Douglas case (ξ = 1), the 95 CI for forest ecosystem services overlaps into the complements domain. For comparison, we present the univariate and choice set of control estimates alongside key subgroups to be discussed in Figure 1.

We next divide our sample by the continent on which the CV study has been undertaken, and report the results in Table 5. We note that the estimates are mostly concentrated in Asia, followed by Europe, with much fewer estimates from other world regions.[8] In terms of income elasticities, we find insignificant or only marginally significant estimates in the Americas, while values in Asia, Europe, and Africa fall close to our main estimate of around 0.8.

The largest prior comparable meta-analysis on the income elasticity of WTP (for biodiversity conservation only) was conducted by Jacobsen and Hanley (2009). Their main result was an income elasticity of WTP estimate of 0.38, but published more than a decade ago. It is, thus, interesting to investigate how our estimate of the income elasticity of WTP relates in a more comparable time frame and in comparison to the

[8]Several studies from Africa involve day trips and other per-use scenarios and are excluded here.

Figure 1: Estimates of the income elasticity of WTP for select models and service types.



Notes: Estimates are the coefficients on $ln(INCOME)$ from the main and univariate specifications in Table 7 as well as estimates based on subsets of observations on regulating services, and cultural services, and forests using the main model. 95 percent confidence interval estimates are included around the point estimates.

Table 5: Heterogeneity of income elasticities of WTP across continents

	ln(INCOME)	S.E.	N	Adj. R^2
North America	0.60**	0.28	100	0.96
South America	-0.34	0.63	45	0.90
Africa	0.78***	0.15	37	0.98
Europe	0.85***	0.15	290	0.81
Asia	0.71***	0.13	380	0.92

Notes: Multivariate regressions. Significance levels: * p<0.1, ** p<0.05, *** p<0.01

most recent decade. In Table 5 we break down the sample by sampling year. We conduct this analysis based on our multivariate estimation strategy. First, we consider estimates from publications based on samples collected up to and including the year 2010 and find an income elasticity of 0.88 in our full model with controls. In contrast, the income elasticity for 2011 onwards is somewhat lower, at 0.74 (see Table 6). Thus, overall, our analysis does not suggest that the income elasticity may have declined over time.[9]

[9]Two other difference in the meta-analysis by Jacobsen and Hanley (2009) and ours concern the ecosystem service type under consideration (biodiversity in their case) and whether also grey-literature was included in the analysis. On the first, we do not find evidence that income elasticities are different for

Table 6: Heterogeneity of income elasticities of WTP across decades

	ln(INCOME)	S.E.	N	Adj. R^2
pre-2011	0.88***	0.16	429	0.85
2011-2021	0.74***	0.10	431	0.92

Notes: Multivariate regressions. Significance levels: * p<0.1, ** p<0.05, *** p<0.01

Finally, we examine whether income elasticity estimates differ across income levels. Previous work by Barbier et al. (2017) and Ready et al. (2002) had suggested that estimates of income elasticities might increase along income levels by examining data in primary CV studies. Here, we now test how estimates of income elasticity differ across income levels in our aggregate-level data set.

Table 7: Income elasticity of WTP for ecosystem services across income brackets

Sample	ln(INCOME)	S.E.	N	Adj. R^2
Below median				
	0.83***	0.12	431	0.89
Above median				
	0.51	0.36	429	0.91
Bottom 25%				
	0.70***	0.25	215	0.85
Top 25%				
	1.27	0.88	214	0.94

Notes: Multivariate regressions. The set of controls including the study year, sample size, income information (gross/net, individual/household), payment type and elicitation method. Significance levels: * p<0.1, ** p<0.05, *** p<0.01

To this end, we first consider a median split. Below the median income level, we find an estimate for the income elasticity of WTP that is close to our main estimate. Above the median income level, we find an estimate that is substantially smaller and insignificant. We explored further ways of cutting the data, using thirds, quartiles and quintiles as well. For instance, when comparing the bottom with top quartiles, we find that our income elasticity is almost twice as large in the top (but insigificantly different from zero) as compared to the bottom quartile. Overall, we thus do not find any robust indication of a systematic relationship between income levels and estimates of the income elasticity of WTP.

biodiversity-related CV studies (see Table 4). On the latter, Heckenhahn and Drupp (2024) find a larger income elasticity estimate when focusing on peer-reviewed literature only in their German case study.

4.2 Growth rates

Table 8 reports estimates on the growth rates of ecosystem service categories and their standard errors, alongside the growth rate of GDP per capita. Growth metrics are estimated based on data for the longest common time frame, for the years 1993 to 2016.

Table 8: Good-Specific Growth Rates

Indicator	Growth rate (S.E.)
Forest area	-0.11% (0.00%)
Living planet index	-2.84% (0.06%)
Red list index	-0.42% (0.01%)
Air quality (PM2.5)	-0.16% (0.17%)
Climate regulation	-1.50% (0.14%)
Aggregate Ecosystem Services	-1.01% (0.17%)
GDP per capita	1.82% (0.02%)

We find substantial heterogeneity in growth rates. The Living Planet Index and climate regulation metrics show the largestnegative rates, while the change in forest area and air quality metrics show the lowest rates of change.[10] Our estimate of aggregate ecosystem service change is -1.01 percent (CI: -1.34 to -0.68), while GDP per capita has increased by 1.82 percent (CI: 1.78 to 1.86) over the same period. This amounts to a sizable shift in the relative scarcity of ecosystem services vis-a-vis market goods. Ecosystem services have thus become relatively scarcer by 2.83 percent per year.

4.3 Relative price changes of ecosystem services

We can now combine the two critical pieces—the income elasticity and growth rate estimates—to compute relative price changes (*RPC*). Table 9 reports our estimates of *RPCs* both in the aggregate and for different ecosystem service categories.

Our central estimate for the *RPC* of aggregate ecosystem services is 2.24 percent (CI: 1.98 to 2.49). That is, the value of ecosystem services is increasing by around 2.2 percent per year relative to market goods. This is more than twice as large as the estimate reported in Baumgärtner et al. (2015). The *RPC* estimate for regulating services is only slightly higher than that for cultural services, which is qualitatively similar to what Heckenhahn and Drupp (2024) find for a German case study. While the income elasticity for forest ecosystem services is higher than for ecosystem services on aggregate, the rate of decline of forest area is considerably smaller; in combination, the *RPC* of forest ecosystem services (1.57 percent) is smaller than that of aggregate ecosystem services.

[10] Results are qualitatively similar when constraining the analysis to the most recent trend data, except for air quality regulation which shows a positive development in the current trend data (2010 to 2016), improving by 1.78% per year. In contrast, the decline rate for climate regulation is more strongly negative. Overall, we find a somewhat smaller rate of de-growth of -0.73 percent for the time period 2010 to 2016.

Table 9: Relative price changes (RPC) of ecosystem services

Sample	$\xi = 1/\sigma$ (S.E.)	$g_C - g_E$ (S.E.)	RPC (C.I.)
Regulating Services	0.79 (0.12)	2.83% (0.17%)	2.24% (1.92% to 2.56%)
Cultural Services	0.74 (0.10)	2.95% (0.09%)	2.18% (1.91% to 2.45%)
Aggregate Services	0.79 (0.09)	2.83% (0.17%)	2.24% (1.98% to 2.49%)
Forest Services	0.81 (0.13)	1.94% (0.07%)	1.57% (1.25% to 1.89%)

Notes: RPC 95% confidence interval estimates based on $\xi(g_C - g_E) \pm 1.96 \times \sqrt{\left(\frac{S.E.(\xi)}{\xi}\right)^2 + \left(\frac{S.E.(g_C - g_E)}{g_C - g_E}\right)^2}$.

Finally, we conduct a quantitative cross-validation to verify our findings of considerable *RPCs* over time. Specifically, we analyzed the role of the study year as an explanatory variable for ln(WTP), interpreting *RPCs* as the annual percentage increase required in ecosystem services' WTP values. Across the full study sample, we observe a coefficient of 0.025 (p=0.057) for study year, indicating a potential *RPC* of 2.5 percent per year. This closely aligns with our calculated aggregate *RPC* of 2.24 percent per year, affirming the consistency and robustness of our results and further strengthening the evidence for positive and notable *RPCs*.

5 Application to Environmental-Economic Accounting

Relative price adjustments of ecosystem services are relevant for both policy appraisal and environmental-economic accounting. Here, we explore implications for accounting, considering the *CWON* 2021 report by the World Bank (2021) as a prominent case to illustrate the approach and its importance with a focus on forest natural capital.[11] We afterwards illustrate implications also for our aggregate measure of ecosystem services.

CWON, like most measures of comprehensive wealth, only features selected natural capital stocks, predominantly relating to fossil energy resources and other provisioning services that are traded on markets. *CWON*, however, also considers non-timber forest benefits as part of its natural capital accounting. Non-timber forest benefits are currently estimated to be around 12 percent of the total value of natural capital (World Bank, 2021). Non-timber ecosystem service values in the year 2018, in WTP per hectare, were based on a meta-regression analysis drawing on 270 estimates from non-market valuation studies of non-timber forest benefits by (Siikamäki et al., 2021). Per-hectare

[11] We have subsequently also applied the approach to proposing adjustments for assessing changes to ecosystem services in benefit-cost analysis (Drupp et al., 2024)

values are assumed to be constant over time and only adjusted for inflation by using country-specific GDP deflators (World Bank, 2021). The capitalized value of non-timber ecosystem services is calculated as the present value of annual services, discounted over a 100-year time horizon at a constant discount rate of 4 percent. This implies that no adjustment for *RPCs* is factored in despite forest de-growth, particularly in comparison to GDP per capita. Implicitly, this carries the assumption that WTP does not increase with income and—in the setting of our model—that ecosystem services are considered perfect substitutes to market goods.[12]

Taking our estimated growth rates for forest area and for GDP per-capita as best estimates of growth rates for the 100 year time horizon in question (see Panel (a) in Figure 2), we compute *RPCs* for forest ecosystem services using our disentangled estimate on the income elasticities of WTP for forest ecosystem services (see Panel (b) in Figure 2). We use the *RPC* of 1.57 percent to adjust future WTP estimates for increasing income and changing real scarcities of forest ecosystem services, and contrast these yearly adjusted WTPs with the *CWON* default which considers constant real WTPs over the time horizon (see Panel (c) in Figure 2). Real WTP in 30 (100) years, for instance, would be 85% (677%) higher as compared to the current *CWON*, which does not consider relative price changes. Finally, we compute the discounted present value of non-timber forest natural capital, using *CWON*'s discount rate of 4 percent, and compare it to the unadjusted value from *CWON*. In Panel (d) of Figure 2, we depict the estimated increase in the non-timber forest natural capital value (in %), relative to the *CWON*'s current estimate, as a function of the degree of complementarity between forest ecosystem services and market goods, measured by the income elasticity of WTP for forest ecosystem services. For instance, Cobb-Douglas substitutability ($\sigma = \xi = 1$) would imply uplifting the present value of non-timber forest ecosystem services by 79 percent. In comparison, a prominent assumption in applied modelling of an elasticity of substitution of 0.5 (c.f., Sterner and Persson, 2008), i.e. an elasticity of complementarity of 2 (off the chart here), would translate into uplifting the public natural capital value by around 330 percent.

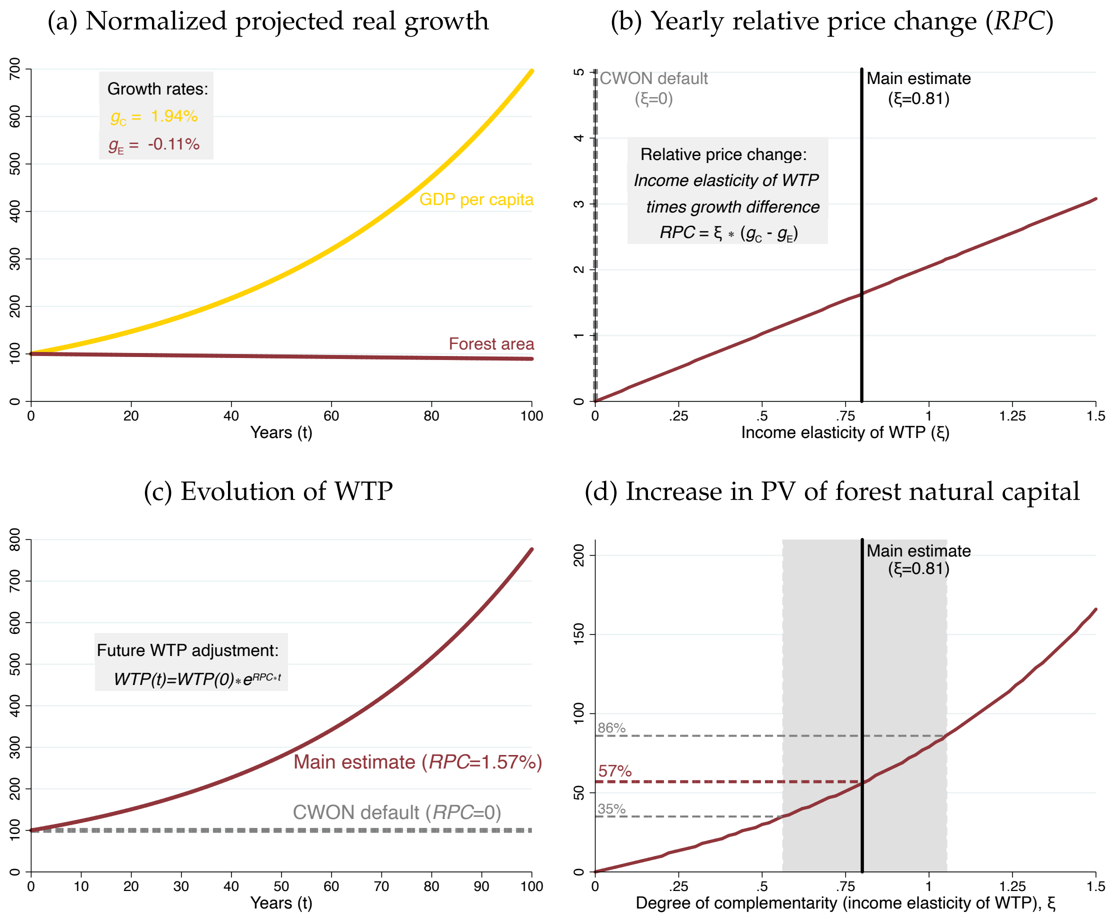
For our central estimate of the *RPC* of forest ecosystem services, we find that the value of non-timber forest natural capital should be uplifted by 57 percent, with a 95 percentile confidence interval around the income elasticity resulting in a range of uplift-factors of 35 to 86 percent (see Panel (d) in Figure 2).

Considering the limited degree of substitutability and shifts in relative scarcity by performing *RPC* adjustments in computing the natural capital value of non-timber forest services makes a material difference to natural capital accounting in *CWON*. The 57 percent increase in non-timber forest value would lead to an increase of the overall natural capital value in *CWON* of around 6.6 percent (CI: 4.0 to 10.0 percent).

Beyond the *CWON* case study, we illustrate implications also for our aggregate measure of ecosystem services. Using, the *RPC* of aggregate ecosystem services, which draws on a slightly lower income elasticity of WTP but a larger difference in growth

[12] Siikamäki et al. (2021) report positive and significant GDP elasticities of WTP for recreation and habitat/species conservation, for instance, but these are not considered in the *CWON* natural capital valuation.

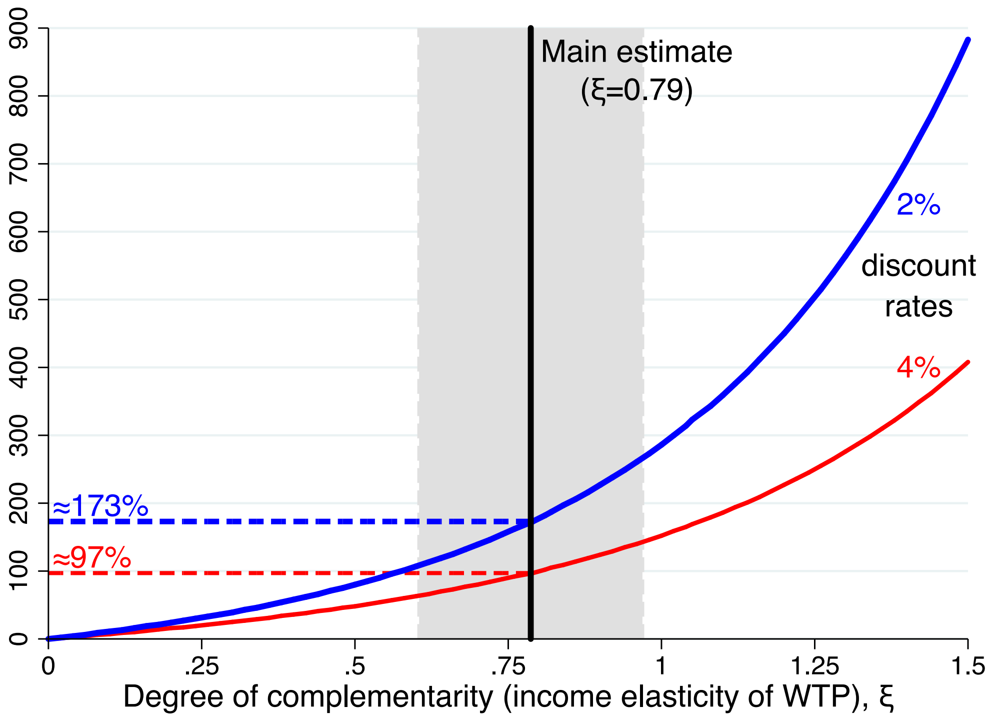
Figure 2: Accounting for public forest natural capital with changing relative prices.



Notes: Panel (a): Relative to growth in market goods (or real income, reflected by GDP per capita), global forest area has been decreasing, which we here project forward. Initial values are normalized to 100 in year 0. Panel (b): The relative price change (*RPC*) rule maps growth rates of GDP per capita and of ecosystem services into yearly relative price adjustments against the rate at which WTP for ecosystem services changes with income. Panel (c): Future WTP adjustment when applying our main estimate for the RPC for forest ecosystem services. Panel (d) shows the estimated increase in The Changing Wealth of Nations' (*CWON*) non-timber forest natural capital value (in %), relative the *CWON*'s current estimate, as a function of the degree of complementarity between forest ecosystem services and market goods, measured by the income elasticity of WTP (see the maroon line). The vertical black line indicates the central estimate of the income elasticity of WTP for forest ecosystem services while the grey-shaded area indicates its 95 confidence interval. Horizontal, dashed helplines indicate the corresponding increase in the public natural capital values (in %).

rates, due to a stringer decline in aggregate ecosystem services, we obtain a central uplift-factor for public natural capital of 97 percent (see Figure 3), which amounts to a 70 percent increase as compared to the *CWON* uplift factor. When changing the discount rate from *CWON*'s 4 percent to a rate of 2 percent, as per current guidance in US Circular A-4 and as recommended by most experts (Drupp et al., 2018), we find that the public natural capital value should be uplifted by around 173 percent according to our main estimate for the income elasticity of WTP (see Figure 3).

Figure 3: Increase in public natural capital values along the degree of complementarity.



Notes: Estimated increase in public natural capital values for our aggregate assessment of ecosystem services (in %), relative to a case where relative price changes are not considered, as a function of the degree of complementarity between ecosystem services and market goods, measured by the income elasticity of WTP for ecosystem services. The red and blue lines illustrate effects for different discount rates of 4% (red, as in CWON guidance) and 2% (blue, as in US Circular A-4). The vertical black line indicates the central estimate of the income elasticity of WTP for our aggregate assessment of ecosystem services while the grey-shaded area indicates its 95 confidence interval. Horizontal, dashed helplines indicate the corresponding increase in the public natural capital value (in %).

6 Discussion

Estimating the trajectory of shadow prices for ecosystem services requires a theoretical structure in order to project into the future. Furthermore, the use of the income elasticity of WTP as a proxy for the degree of limited substitutability rests on particular assumptions regarding social preferences. On the empirical side, our study identifies the degree of complementarity via the income elasticity of WTP for ecosystem services based on a meta-analysis of the peer-reviewed literature. 861 unique (mean) income-WTP pairs are considered across studies and geographical contexts over a 20 year time frame. Given these data, assumptions are also required to allow the aggregation of ecosystem services and the computation of ecosystem growth rates across the study samples. The assumptions are discussed here. We argue that our estimates of relative price increases could well be conservative, but point to areas for further research in the pursuit of greater generality for policy purposes.

With regard to the data, our analysis is subject to concerns on the underlying data quality of contingent valuation studies, including hypothetical bias etc., which has been discussed at length in the literature (e.g., Kling et al., 2012). Schläpfer (2008), for instance, argues that (too) small income effects in contingent valuation studies may be an artefact of anchoring biases, but we are not aware of a clear empirical test of this hypothesis. If this were the case, we might under estimate income elasticities and hence the degree of complementarity. If this were the case, our estimates of the appropriate upward-adjustment of natural capital values would be conservative.

Second, besides the specific concerns associated with contingent valuation, our approach to identifying the (aggregate) income elasticity of WTP —while building on the state of the art in the literature— is somewhat coarse, and rests on a very heterogeneous, imbalanced panel. Broadly speaking, our new sample contains studies that reflect both methodological refinements that have been introduced over time that have arguably deflated WTP estimates (Barrio and Loureiro, 2010), and an increasing share of studies from Asia and lower-income countries over time. Ideally, we'd like to identify the income elasticity of WTP based on a sample that is not subject to methodological revisions or major changes in its geographical composition. While a few test-retest investigations exist that draw repeatedly from the same sample (see Skourtos et al., 2010, for an overview), these typically concern shorter time frames and have not been designed to investigate income effects. Evidence to date suggests that mean WTP estimates are relatively constant over time frames of up to five years, but that this is not the case for longer time frames (Skourtos et al., 2010). In our meta-analsyis, we find that the year of data sampling is positively and significantly associated with ln(WTP). Yet, we find that the income elasticity of WTP appears relatively stable across decades.

Third, our approach of relying on a direct relationship between the income elasticity of WTP and the elasticity of substitution or complementarity holds under a very common but still very specific assumption on preferences, specifically that preferences are represented by a CES utility function (e.g., Ebert, 2003; Baumgärtner et al., 2017). We are not aware of studies trying to systematically test the relative goodness-of-fit of CES versus other utility specifications,[13] but note that extensions exist in the applied theoretical literature. One interesting case is an extension of preferences that consider critical thresholds in the form of subsistence needs (Baumgärtner et al., 2017; Drupp, 2018; Heal, 2009). If there exists some critical level of ecosystem services, $\overline{E} > 0$, then the degree of substitutability becomes endogenous to the level of the ecosystem service over and above the critical level, and the RPC equation is adjusted to (cf. Drupp, 2018):[14]

$$RPC_t = \xi \left[g_{C_t} - g_{E_t} \frac{E_t}{E_t - \overline{E}} \right]. \tag{9}$$

[13]Some applied literature has documented non-constant income elasticities of WTP (e.g., Barbier et al., 2017), but no systematic evidence to date suggest a clear direction of non-constancy.

[14]WTP estimates are typically assumed to be a function of the ecosystem service level themselves (Baumgärtner et al., 2017). Empirical evidence, however, is mixed—Barrio and Loureiro (2010) and others find, for instance, that WTPs decrease with forest cover, while Taye et al. (2021) find that WTPs increase with forest cover—as it's often challenging to isolate the pure effect of the level of the ecosystem service.

Such an extension implies higher relative price changes that increase substantially as one gets close to the critical basic need threshold given exogenous growth rates (Drupp, 2018). It would lead to an upward revision of the natural capital values adjustment discussed in Section 5. However, if growth rates are endogenous and optimally managed, ensuring that we will not get close to such critical subsidence levels, relative prices changes are not substantially affected (Drupp and Hänsel, 2021).

Finally, we assume that preferences elicited primarily on small scale projects aimed at improving ecosystem service conditions scale up to the global level. However, services may be perceived as complements (substitutes) at the local level, but as substitutes (complements) at a global scale. This issue may be more pronounced when the focus is relatively more on local public goods as compared to global public goods. We cannot directly test for this, but a comparison of the income elasticity of WTP for recreational services versus other services may serve as a proxy for this idea. Indeed, we find that the income elasticity for recreational services is smaller than the estimate for the other ecosystem services, but also that there is more variation around the income elasticity of WTP for recreational services.

We have further updated and extended the *"Herculean task"* (Baumgärtner et al., 2015, p. 278) of assembling a proxy for the aggregate growth rates of ecosystem services. There exists no accepted standard for how to aggregate various measures of environmental quality, and also the data sources we draw on have to be considered imperfect proxies themselves. We have followed Baumgärtner et al. (2015) in using the unweighted arithmetic mean of the growth rates for the different types of ecosystem services. This assumes that the elasticity of substitution between different ecosystem services is equal to one (Cobb-Douglas), which implies that WTPs would be the same for all types of ecosystem services if their quantities were similar, an assumption we cannot properly test. We note that there are other conceivable means of aggregation, using different weightings to different degrees of substitutability. We leave a systematic exploration of this issue to future work; the same holds for exploring the role of uncertainty around projecting past growth estimates into the future (Gollier, 2010) as well as the potential convergence of ecosystem service and human-made goods growth rates, as the scarcity and limited substitutability of ecosystem services as intermediate inputs to production may manifest itself as a drag on growth (Zhu et al., 2019).

7 Conclusion

We present the largest global database to estimate the degree of complementarity of ecosystem services vis-a-vis human-made goods, via the income elasticity of WTP for ecosystem services, in order to compute relative price changes of ecosystem services. We estimate an income elasticity of WTP of around 0.8, which is relatively stable across ecosystem service subtypes, time frames and continents. The 95 confidence interval borders the Cobb-Douglas case, but overall suggest a mildly substitutive relationship between ecosystem services and market goods. For our aggregate assessment of ecosystem services, including estimates of growht rates, we find relative price changes of ecosystem services of around 2.2 percent per year. Relative price changes are smaller (1.6 percent) for forest ecosystem services as these show a slower rate of de-growth as compared to other ecosystem service components. We also developed a simple approach for how these estimates can be employed to adjust future WTP estimates and present values to be used in project appraisal or environmental-economic accounting (subsequently used in Drupp et al., 2024). In an application on natural capital valuation, taking the Changing Wealth of Nations (CWON) 2021 report by the World Bank (2021) as a case study, we show that adjusting natural capital estimates for non-timber ecosystem services for relative price changes results in uplifting the present value over a 100 year time period by around 60 percent, materially elevating the role of public natural capital. The corresponding estimates for relative price adjustments for our aggregate assessment of public natural capital are more substantial, amounting to between 100 and 170 percent for our main estimate of the income elasticity, depending on the discount rate. This echoes work on the importance of limited substitutability in climate policy appraisal (Bastien-Olvera and Moore, 2021; Drupp and Hänsel, 2021; Sterner and Persson, 2008).

The adjustment techniques we present are generally applicable for environmental-economic appraisal and accounting, while the specific numerical inputs, such as on growth rates, need to be adjusted on a case-by-case basis. Our results suggest that the case for making relative price adjustments is reasonably robust and that more countries and institutions than present (Groom et al., 2022) should consider making such adjustments to correct the current mis-valuation of non-market goods in public policy appraisal (Drupp et al., 2024) and of public natural capital values in comprehensive wealth accounting.

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Appendix

Appendix A Selection of relevant valuation studies

A.1 Search string

Our focus is on values for regulating ecosystem services and cultural ecosystem services (not provisioning services) that have been elicited using the contingent valuation method. The search string has three components (1) focus on ecosystem services, (2) focus on WTP estimates, (3) focus on the contingent valuation method.

(TITLE-ABS-KEY (environment* OR natur* OR ecosystem OR biodiversity OR biologic* OR ecologic* OR habitat* OR forest* OR species OR protected OR conserv* OR endangered OR ″national park*″ OR landscape* OR terrestrial OR pollination OR tree* OR tropic* OR vegetation OR peatland* OR grassland* OR dryland* OR pastoral OR soil OR animal* OR bird* OR wild* OR air OR water OR aquatic OR marine OR coast* OR water* OR fish* OR wetland* OR mangrove* OR reef* OR marsh* OR floodplain* OR river* OR climate OR storm* OR erosion OR pest* OR hazard* OR recreat* OR touris* OR "urban green" OR sacred OR spirit* OR sanctuary OR "natural heritage" OR aesthetic*)

AND TITLE-ABS-KEY (wtp OR willingness-to-pay OR ″willingness to pay*″ OR ″willing to pay*″ OR ″shadow price*″ OR ″shadow value*″ OR ″implicit price*″ OR ″implicit value*″)

AND TITLE-ABS-KEY (″contingent valuation*″ OR cvm OR ″contingent choice*″))

AND (LIMIT-TO (SRCTYPE , ″j″)) AND (LIMIT-TO (DOCTYPE , ″ar″)) AND (LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2013) OR LIMIT-TO (PUBYEAR , 2012) OR LIMIT-TO (PUBYEAR , 2011) OR LIMIT-TO (PUBYEAR , 2010) OR LIMIT-TO (PUBYEAR , 2009) OR LIMIT-TO (PUBYEAR , 2008) OR LIMIT-TO (PUBYEAR , 2007) OR LIMIT-TO (PUBYEAR , 2006) OR LIMIT-TO (PUBYEAR , 2005) OR LIMIT-TO (PUBYEAR , 2004) OR LIMIT-TO (PUBYEAR , 2003) OR LIMIT-TO (PUBYEAR , 2002) OR LIMIT-TO (PUBYEAR , 2001) OR LIMIT-TO (PUBYEAR , 2000)) AND (LIMIT-TO (LANGUAGE , ″English″))

A.2 Exclusion and selection criteria

A.2.1 Paper exclusion criteria

Citations: We excluded all studies that had not been cited (in SCOPUS).

Abstract screening: We excluded non-topical publications based on abstract-screening that do not report new primary WTP estimates. Specifically, we excluded: Theory, reviews, comments, non-primary valuation (such as benefit transfer), as well as WTPs for non-environmental goods, WTPs for provisioning services, WTPs derived from valuation approaches other than CV

PDFs obtainable: We excluded studies where we could not access the PDFs.

Paper screening: We excluded non-topical publications based on abstract-screening that do not report new primary WTP estimates. Specifically, we excluded: Theory, reviews, comments, non-primary valuation (such as benefit transfer), as well as WTPs for non-environmental goods, WTPs for provisioning services, WTPs derived from valuation approaches other than CV PLUS XYZ

A.2.2 Data selection criteria

In the following, we detail our approach for selecting WTP and income values, which constitute the key variables for our analyses.

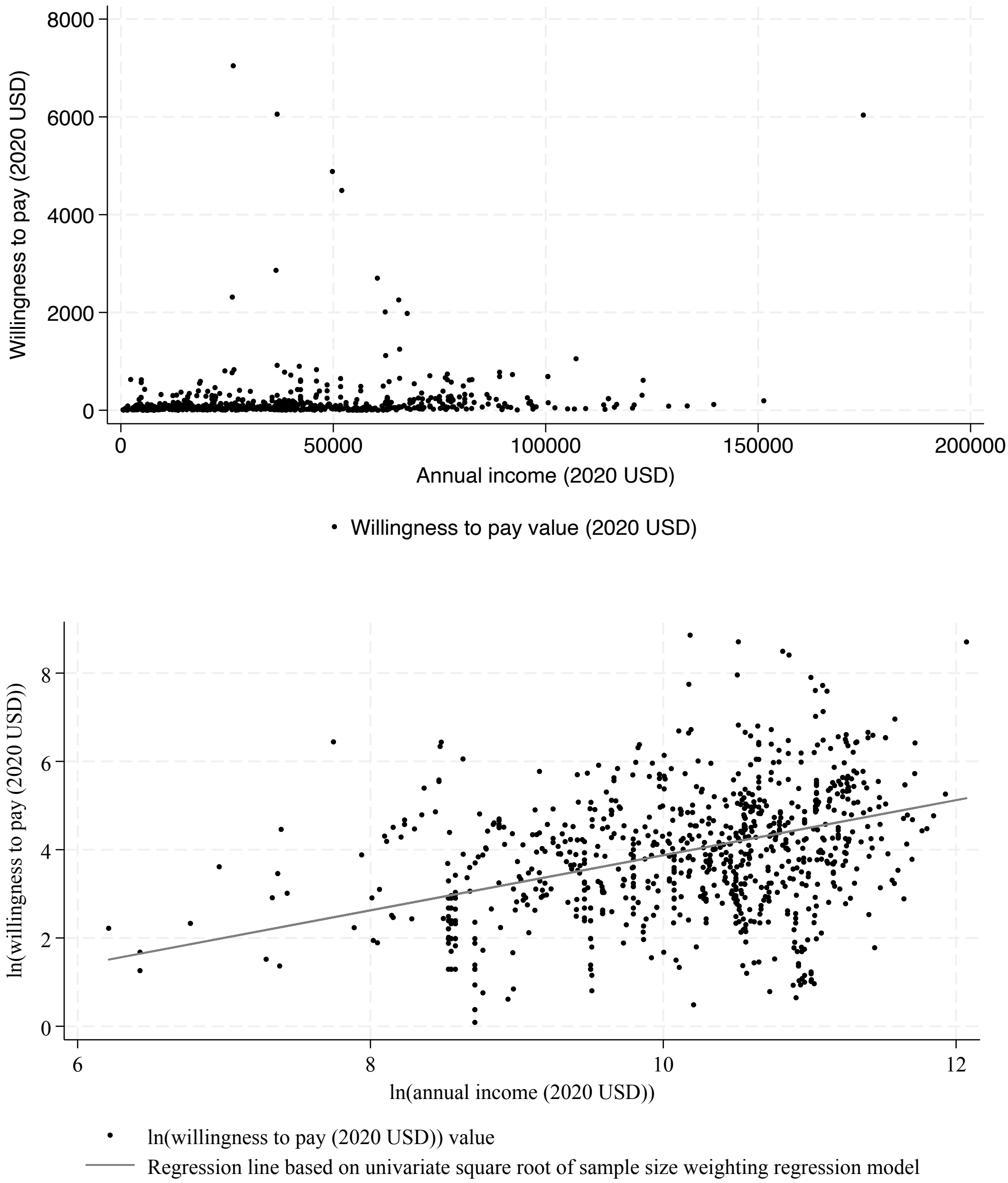
WTP data selection: We exclude median WTP values, WTP values derived from multiplying marginal WTP estimates, WTP values resulting from the addition of preceding WTP values, WTP values based on pretests, WTP values based on subsamples when overall mean values are provided, and negative WTP values. When different results are presented based on different models, we include only the WTP values from the standard model. If no standard model is indicated, we average the relevant model results. When multiple mean WTP estimates are provided (e.g., including or excluding outliers and zero bids), we include the estimate marked as the authors' preferred estimate. If no preference is indicated, we include the unmodified estimate. When WTP values are provided for different subsamples, we assign the WTP values to the corresponding subsample income values. When WTP values refer to a monthly payment, we multiply these values by 12 to obtain annual values. WTP values referring to yearly payments and one-time payments are included as they are. When WTP results are divided among different quantities (supply levels) of the same ecosystem service, we take the average of these values. If WTP results consider participants' response uncertainty, we average these values. When WTP results are split among different subsamples without overall mean WTP values or subsample-specific income values, we take the average of the subsample WTP values, using weighted averages if subsample sizes are available.

Income data selection: We include studies regardless of whether they provide net or gross income data, while we contacted study authors when articles did not provide specific information on that. We also included studies regardless of whether the respective income data refers to the household or personal level. If a study only provides percentage shares of income categories instead of a mean income value, we derive the mean income value by calculating the midpoints of the income categories and multiplying them by their respective percentage shares. For the category open towards the bottom, we multiply the upper bound (the lower bound of the lowest income category) by 0.75 to find the midpoint, and for the category open towards the top, we multiply the lower bound (the higher bound of the highest income category) by 1.5. We then sum these products and divide by the sum of the percentage shares to estimate the mean income. For income values split among different subsamples, we average these values to attain overall mean income values, using weighted averages if subsample sizes are available.

Appendix B Graphical presentation of the meta-analysis data

Figure 4 visualizes the meta-analysis data using the original, untransformed income and WTP data in the upper panel. Here, each dot represents a WTP value. In contrast, the lower panel presents both WTP and income data in their logarithmic forms, which we consistently use throughout our main analysis to calculate income elasticities. Here, each dot represents a ln(WTP) value. The lower panel also includes a regression line based on the univariate version of our preferred square root of sample size weighting regression model.

Figure 4: Visualization of mean income and WTP data (original and ln-transformed)



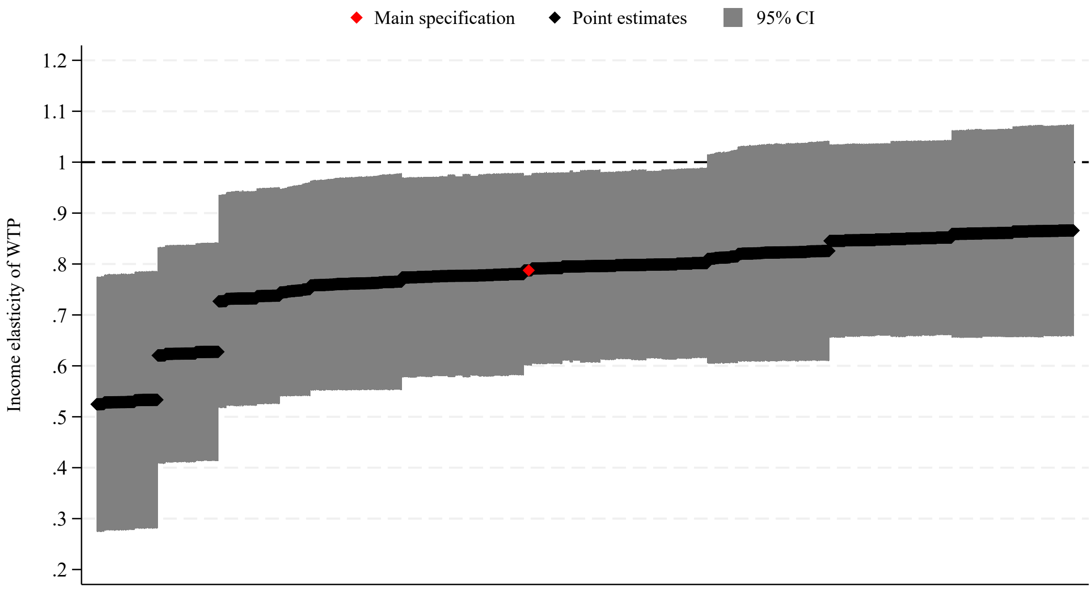
Appendix C Inflation and currency conversion

All monetary values were converted to 2020 US Dollar by first inflating the respective national consumer price index and then applying purchasing-power-parity (PPP) conversion. The relevant year for the inflation of the values was the year of study data collection. When the authors did not provide the study year, we estimate the average lag between study and publication years based on the studies where both pieces of information is available. The difference is approximately 4.0 years on average. We use this to estimate the study year when missing. When historical inflation data for years far in the past were unavailable, we utilized the most recent year's inflation data as an estimate for these years' inflation rates.

Appendix D Alternative specification results

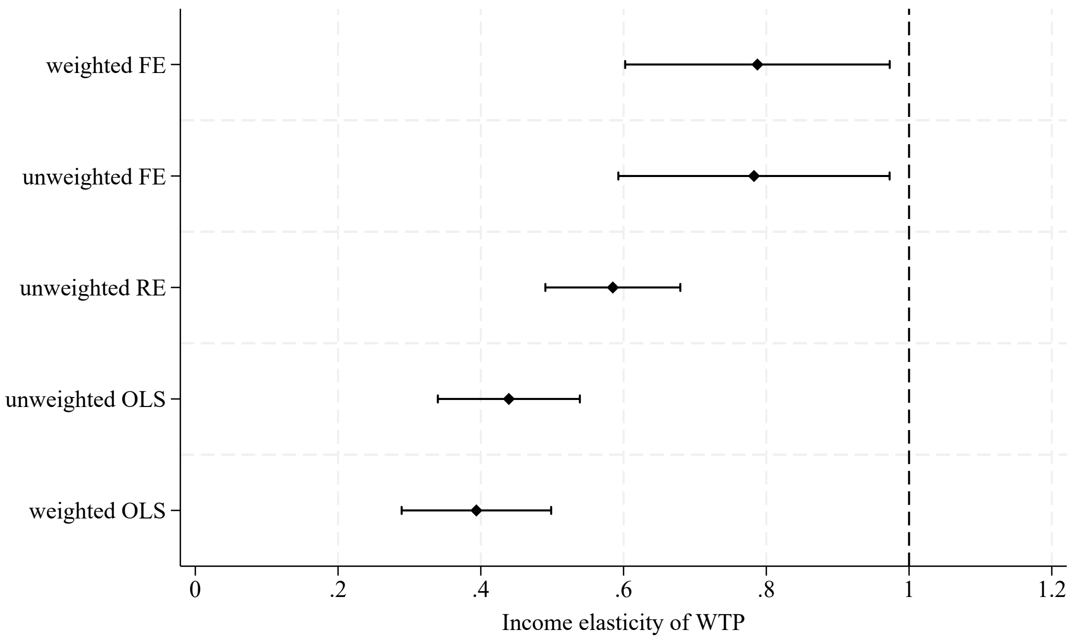
This section presents a specification graph that suggests the robustness of our results to the inclusion or exclusion of covariates. We also present results based on alternative statistical models to suggest the robust of our results to model selection.

Figure 5: Income elasticity of WTP estimates based on alternative model specifications.



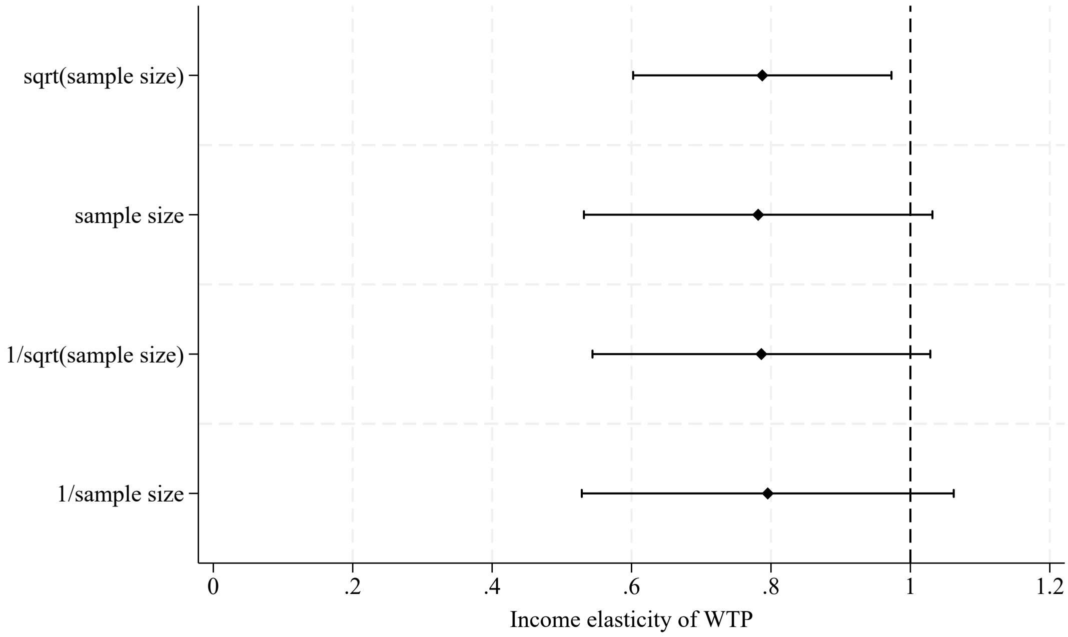
Notes: Estimates are the result of $2^{13} = 8,192$ alternative specifications of Equation 8. The main specification is based on Equation 8 which is at the 44th percentile ranking of our income elasticity coefficient estimates from smallest to largest. The 95 percent confidence interval estimates are included and results are plotted from smallest (0.53) to largest (0.87) coefficient estimate on $ln(INCOME)$.

Figure 6: Income elasticity of WTP estimates based on alternative statistical models.



Notes: The main result is based on a fixed-effects (FE) model at the study level and weighted by the square root of the sample size. Some frequent alternatives to this approach include unweighted fixed effects and random effects models and weighted and unweighted OLS estimates. While a Hausman test suggests FE model is most appropriate, we provide these alternative estimates.

Figure 7: Income elasticity of WTP estimates by weight selection.



Notes: The main result is derived with weights based on the square root of the sample size. Some alternatives that are more or less reasonable are to use the sample size, inverse of the sample size, and inverse of the square root of the sample size. Inverse sample sizes will tend to place more weight on studies with smaller sample sizes and squared sample size weights will tend to bias estimates toward studies with substantially larger samples.

Appendix E

This Appendix first provides the list of the WTP studies included in the meta-analysis, along with the study year, the country where the study took place, and the number of WTP estimates the respective study provided for our meta-analysis. Second, the Appendix provides the full references for all the included studies. Note that for the creation of the Table and the study references, we used ChatGPT as support.

List of WTP Studies

Table 10: List of included WTP studies

Short reference	Study year	Study country	Provided WTP estimates
Aadland et al. (2012)	2006	United States	2
Abate et al. (2020)	2018	Norway	1
Acharya et al. (2021)	2018	Nepal	96
Adams et al. (2008)	2004	Brazil	2
Adams et al. (2020)	2016	United States	1
Adhikari et al. (2017)	2013	United States	1
Ahlheim et al. (2006)	2004	Philippines	2
Ahlheim et al. (2013)	2009	China	5
Ahlheim et al. (2015)	2009	China	1
Ahtiainen et al. (2014)	2011	Denmark, Finland, Sweden, Germany, Estonia, Poland, Russia, Latvia, Lithuania	9
Akhtar et al. (2017)	2016	Pakistan	1
Akinyemi & Mushunje (2017)	2014	South Africa	1
Akinyemi & Mushunje (2020)	2016	South Africa	2
Al-Amin et al. (2020)	2015	Malaysia	1
Al-Assaf (2015)	2012	Jordan	1
Albaladejo-García et al. (2021)	2018	Spain	1
Alberini et al. (2005)	2002	Italy	1
Aldrich et al. (2007)	1997	United States	2
Amare et al. (2016)	2014	Ethiopia	1
Ami et al. (2011)	2006	France	1
Ami et al. (2014)	2011	France	2

Continued on next page

Short reference	Study year	Study country	Provided WTP estimates
Amiri et al. (2015)	2011	Iran	1
Amirnejad et al. (2006)	2004	Iran	1
Aoun (2015)	2011	Lebanon	2
Arabomen et al. (2019)	2015	Nigeria	1
Aravena et al. (2012)	2008	Chile	2
Ardiansyah et al. (2019)	2018	Indonesia	1
Arega & Tadesse (2017)	2014	Ethiopia	1
Arowolo et al. (2014)	2011	Nigeria	1
Asciuto et al. (2015)	2012	Italy	2
Atkinson et al. (2012)	2006	United Kingdom	2
Azlina et al. (2018)	2016	Malaysia	2
Bandara & Tisdell (2004)	2001	Sri Lanka	1
Bandara & Tisdell (2005)	2001	Sri Lanka	1
Banna et al. (2016)	2012	Malaysia	1
Baral et al. (2007)	2004	Nepal	1
Barrena et al. (2014)	2012	Chile	3
Barton (2002)	1997	Costa Rica	2
Bederli Tümay & Brouwer (2007)	2001	Turkey	2
Belhaj (2003)	1995	Morocco	1
Bernath & Roschewitz (2008)	2004	Switzerland	1
Bernstein et al. (2013)	2010	United States	1
Berrens et al. (2004)	2000	United States	4
Bhat & Sofi (2021)	2018	India	1
Bigerna et al. (2019)	2016	Italy	1
Blaine & Smith (2006)	2003	United States	2
Bliem & Getzner (2012)	2007	Austria	4
Bonnichsen & Olsen (2016)	2008	Denmark	1
Börger (2013)	2012	Italy	1
Bostan et al. (2020)	2016	Iran	1
Bowman et al. (2009)	2004	United States	1
Bowman et al. (2012)	2009	United States	1
Brandli et al. (2015)	2011	Brazil	1
Braun et al. (2016)	2013	Germany	2
Broadbent et al. (2015)	2012	United States	3
Broberg & Brännlund (2008)	2004	Sweden	1
Brouwer (2006)	2002	Netherlands	2
Brouwer (2008)	2003	Netherlands	1

Continued on next page

Short reference	Study year	Study country	Provided WTP estimates
Brouwer (2012)	2006	Netherlands	1
Brouwer & Martín-Ortega (2012)	2007	Spain	1
Brouwer et al. (2008)	2003	Netherlands	6
Brouwer et al. (2016)	2006	Netherlands	4
Bueno et al. (2016)	2014	Philippines	1
Bundal et al. (2018)	2014	Philippines	1
Carandang et al. (2013)	2009	Philippines	2
Carlsson & Johansson-Stenman (2000)	1996	Sweden	1
Carlsson & Martinsson (2001)	1996	Sweden	1
Carlsson et al. (2012)	2009	United States, Sweden, China	9
Carlsson et al. (2013)	2009	Sweden, China	4
Castro et al. (2011)	2008	Spain	5
Cerda et al. (2014)	2009	Chile	1
Chambers & Whitehead (2003)	2001	United States	2
Chaudhry et al. (2007)	2002	India	5
Chaudhry et al. (2008)	2002	India	5
Chen (2015)	2013	China	2
Chen & Han (2018)	2018	Taiwan	1
Chen & Jim (2010)	2007	China	1
Chen & Jim (2012)	2009	Hong Kong	1
Chen & Liaw (2012)	2006	Taiwan	5
Chen et al. (2021)	2017	Taiwan	2
Cheng et al. (2017)	2016	Hong Kong	10
Cheng et al. (2021)	2019	China	1
Chien et al. (2005)	1996	Taiwan	2
Chigamba et al. (2021)	2019	Malawi	1
Choi (2013)	2009	South Korea	2
Choi (2015)	2012	Australia	2
Choi et al. (2016)	2015	South Korea	1
Choi et al. (2020)	2019	South Korea	1
Choi et al. (2021)	2016	South Korea	1
Colby & Orr (2005)	2001	United States	1
Collins & Rosenberger (2007)	2004	United States	1

Continued on next page

Short reference	Study year	Study country	Provided WTP estimates
Cook et al. (2018a)	2010	Iceland	3
Cook et al. (2018b)	2016	Iceland	2
Corrigan et al. (2008)	2004	United States	1
Dare et al. (2015)	2011	Nigeria	1
De Melo Travassos et al. (2018)	2011	Brazil	1
De Salvo et al. (2021)	2020	Italy	2
Denstadli & Veisten (2020)	2017	Norway	1
Dogan & Muhammad (2019)	2015	Turkey	1
Donfouet et al. (2015)	2011	Cameroon	3
Dong & Zeng (2018)	2016	China	1
Dong et al. (2011)	2009	China	1
Dribek & Voltaire (2017)	2008	Tunisia	2
Du & Mendelsohn (2011)	2009	China	1
Du Preez et al. (2010)	2005	South Africa	1
Duan et al. (2014)	2010	China	4
Dupont (2004)	1995	Canada	4
Eisen-Hecht & Kramer (2002)	1998	United States	1
Endalew & Assefa Wondimagegnhu (2019)	2017	Ethiopia	1
Endalew et al. (2020)	2018	Ethiopia	1
Eregae et al. (2021)	2020	Kenya	3
Ezebilo et al. (2015)	2007	Sweden	1
Fattahi Ardakani et al. (2017)	2015	Iran	8
Ferreira et al. (2017)	2014	Portugal	1
Ferrini et al. (2014)	2008	United Kingdom	2
Francisco (2015)	2011	Philippines	2
Fujino & Kuriyama (2019)	2016	Japan	3
Gauthier (2004)	1996	France	1
Getzner (2012)	2011	Austria	6
Giaccaria et al. (2016)	2007	Italy	3
Giannelli et al. (2018)	2014	Spain	1
Giraud et al. (2001)	1996	United States	1
Giraud et al. (2002)	2000	United States	2
Goh & Matthew (2021)	2018	Malaysia	2
Gómez-Valenzuela et al. (2020)	2019	Dominican Republic	1

Continued on next page

Short reference	Study year	Study country	Provided WTP estimates
Gordillo et al. (2019)	2017	Ecuador	3
Grala et al. (2012)	2004	United States	1
Grazhdani (2015)	2012	Albania	1
Gregg & Wheeler (2018)	2016	Australia	1
Guo et al. (2014)	2010	China	2
Guo et al. (2020)	2016	China	3
Haefele et al. (2018)	2016	United States, Mexico	8
Haefele et al. (2019)	2016	United States, Canada, Mexico	3
Haile & Slangen (2009)	2005	Netherlands	1
Halkos & Matsiori (2012)	2008	Greece	1
Halkos & Matsiori (2014)	2010	Greece	1
Halkos & Matsiori (2017)	2013	Greece	1
Halkos & Matsiori (2018)	2014	Greece	1
Halkos et al. (2019)	2015	Greece	1
Hammitt et al. (2001)	1993	Taiwan	2
Hamuna et al. (2018)	2018	Indonesia	1
Han & Lee (2008)	2005	South Korea	1
Han et al. (2011)	2009	China	1
Harper (2015)	2014	United States	1
He et al. (2015)	2012	China	2
He et al. (2017)	2013	Canada	1
Herriges et al. (2010)	2003	United States	5
Hidano et al. (2005)	2000	Japan	2
Hörnsten & Fredman (2000)	1998	Sweden	1
Huang et al. (2013)	2008	China	1
Huenchuleo et al. (2012)	2004	Chile	1
Huhtala (2004)	1999	Finland	1
Hwang et al. (2020)	2018	South Korea	1
Hynes & O'Donoghue (2020)	2012	Ireland	1
Hynes et al. (2011)	2008	Ireland	1
Imandoust & Gadam (2007)	2004	India	1
Jain et al. (2017)	2013	India	5
Jalilov (2018)	2016	Philippines	2
Janku et al. (2014)	2014	Czech Republic	1
Jaunky et al. (2021)	2016	Mauritius	1
Jenkins et al. (2002)	1999	United States	6
Jin et al. (2008)	2005	Macao	2

Continued on next page

Short reference	Study year	Study country	Provided WTP estimates
Jin et al. (2010)	2005	Thailand, China, Vietnam, Philippines	4
Jin et al. (2018)	2012	China	1
Jin et al. (2019)	2017	China	1
Jin et al. (2020)	2019	South Korea	1
Jørgensen et al. (2013)	2009	Denmark	2
Jung & Lee (2021)	2018	South Korea	1
Kaffashi et al. (2011)	2009	Iran	1
Kaffashi et al. (2013)	2010	Iran	1
Kaffashi et al. (2015)	2009	Iran	1
Kalfas et al. (2020)	2017	Greece	1
Khai & Yabe (2014)	2013	Vietnam	1
Kim & Petrolia (2013)	2009	United States	1
Kim & Yoo (2020)	2019	South Korea	1
Kim et al. (2012)	2010	South Korea	2
Kim et al. (2015)	2012	South Korea	2
Kim et al. (2016)	2014	South Korea	1
Kim et al. (2017a)	2015	South Korea	1
Kim et al. (2017b)	2016	South Korea	1
Kim et al. (2018a)	2017	South Korea	1
Kim et al. (2018b)	2017	South Korea	1
Kim et al. (2019a)	2017	South Korea	1
Kim et al. (2019b)	2018	South Korea	1
Kim et al. (2019c)	2016	South Korea	1
Kim et al. (2020)	2016	South Korea	1
Kim et al. (2020)	2018	South Korea	1
Kim et al. (2021a)	2019	South Korea	1
Kim et al. (2021b)	2017	South Korea	1
Kniivilä et al. (2002)	2000	Finland	1
Kobayashi et al. (2010)	2005	United States	1
Kontogianni et al. (2012)	2009	Greece	1
Kontogianni et al. (2013)	2010	Greece	2
Kontogianni et al. (2014)	2005	Greece	1
Kotchen & Reiling (2000)	1997	United States	2
Kourtis & Tsihrintzis (2017)	2014	Greece	1
Kwak et al. (2003)	2001	South Korea	1
Kwon et al. (2018)	2016	South Korea	1
Labao et al. (2008)	2005	Philippines	2

Continued on next page

Short reference	Study year	Study country	Provided WTP estimates
Latvala et al. (2021)	2019	Finland	3
Lee (2012)	2009	South Korea	2
Lee (2020)	2017	South Korea	1
Lee & Hwang (2016)	2012	South Korea	2
Lee & Mjelde (2007)	2005	South Korea	1
Lee et al. (2013)	2010	South Korea	1
Lee et al. (2017)	2014	South Korea	2
Lee et al. (2018a)	2016	South Korea	1
Lee et al. (2018b)	2017	South Korea	1
Lehtoranta et al. (2013)	2011	Finland	1
Lehtoranta et al. (2017)	2013	Finland	3
Lewis et al. (2017)	2014	United States	1
Li & Hu (2018)	2012	China	1
Li et al. (2014)	2011	China	1
Liebe et al. (2011)	2004	Germany	1
Lillo et al. (2014)	2014	Chile	1
Lim et al. (2017a)	2014	South Korea	1
Lim et al. (2017b)	2015	South Korea	2
Lin et al. (2017)	2016	Singapore	2
Lin et al. (2020)	2017	Taiwan	1
Lindhjem & Navrud (2009)	2007	Norway	4
Lindhjem & Navrud (2011)	2007	Norway	2
Liu et al. (2019)	2017	Taiwan	1
Liu et al. (2021a)	2020	China	1
Liu et al. (2021b)	2018	Taiwan	1
Longo et al. (2012)	2008	Spain	3
Loomis et al. (2002)	1999	United States	4
Lopes & Kipperberg (2020)	2013	Norway	4
Loureiro et al. (2009)	2006	Spain	1
Loureiro et al. (2013)	2010	Spain	1
Lyssenko & Martínez-Espiñeira (2012a)	2005	Canada	1
Lyssenko & Martínez-Espiñeira (2012b)	2008	Canada	1
Ma et al. (2015)	2010	China	2
Ma et al. (2021)	2018	China	3
Madureira et al. (2011)	2003	Portugal	1
Magnan et al. (2012)	2004	United States	2

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Short reference	Study year	Study country	Provided WTP estimates
Maharana et al. (2000a)	1997	India	1
Maharana et al. (2000b)	1998	India	1
Mahieu et al. (2017)	2015	France	1
Makwinja et al. (2019)	2015	Malawi	1
Malinauskaite et al. (2020)	2018	Iceland	1
Martín-López et al. (2007a)	2004	Spain	1
Martín-López et al. (2007b)	2004	Spain	1
Martínez-Espiñeira (2007)	2003	Canada	1
Martínez-Espiñeira & Lyssenko (2011)	2005	Canada	1
Martínez-Paz et al. (2019)	2016	Spain	1
Martínez-Paz et al. (2021)	2018	Spain	1
Masud et al. (2015)	2012	Malaysia	1
Maynard et al. (2019)	2016	Taiwan	1
Mazzocchi & Sali (2016)	2015	Italy	1
McDougall et al. (2020)	2018	United Kingdom	2
Metcalfe & Baker (2015)	2008, 2009	United Kingdom	2
Meyerhoff & Liebe (2008)	2004	Germany	2
Meyerhoff et al. (2012a)	2009	Germany	8
Meyerhoff et al. (2012b)	2004	Germany	2
Milovantseva (2016)	2010	United States	1
Mjelde et al. (2017)	2015	South Korea	1
Mohamed et al. (2012)	2011	Malaysia	1
Mohammed (2009)	2005	Thailand	1
Monteiro et al. (2012)	2008	Brazil	1
Morais et al. (2014)	2010	Brazil	1
Morawetz & Koemle (2017)	2013	Austria	1
Mostafa & Al-Hamdi (2016)	2012	Kuwait	1
Mourato et al. (2004)	2001	United Kingdom	1
Muchapondwa et al. (2008)	2000	Zimbabwe	2
Muhammad et al. (2021)	2017	Turkey	2
Muñoz-Pizza et al. (2020)	2019	Mexico	1
Musa et al. (2020)	2017	Malaysia	1
Mwebaze et al. (2018)	2014	United Kingdom	1
Nallathiga & Paravasthu (2010)	2006	India	1
Nastis & Mattas (2018)	2014	Greece	1

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Short reference	Study year	Study country	Provided WTP estimates
Ndambiri et al. (2017)	2013	Kenya	2
Ndebele & Forgie (2017)	2008	New Zealand	1
Nielsen-Pincus et al. (2017)	2012	United States	1
Nieminen et al. (2019)	2017	Finland	1
Ning & Lee (2019)	2018	South Korea, China	2
Ning et al. (2019)	2019	China	1
Nishizawa et al. (2006)	2003	Japan	1
Noring et al. (2016)	2012	Norway	1
Novikova et al. (2019)	2017	Lithuania	1
Nurin Fadhlin et al. (2021)	2019	Malaysia	1
O'Connor et al. (2020)	2019	Italy	1
O'Garra & Mourato (2007)	2003	United Kingdom	1
O'Garra et al. (2007)	2003	United Kingdom, Australia	2
Ofori & Rouleau (2020)	2018	Ghana	1
Oh et al. (2019)	2017	South Korea	1
Östberg et al. (2012)	2009	Sweden	4
Pakhtigian & Jeuland (2019)	2017	Nepal	3
Palanca-Tan (2020)	2019	Philippines	1
Park & Chang (2019)	2017	South Korea	1
Park et al. (2013)	2010	South Korea	1
Peixer et al. (2011)	2006	Brazil	8
Pemberton et al. (2010)	2001	Dominica	4
Pérez-Sánchez et al. (2021)	2018	Colombia	1
Perni et al. (2011)	2010	Spain	4
Petrolia & Kim (2009)	2008	United States	2
Petrolia & Kim (2011)	2009	United States	1
Petrolia et al. (2011)	2009	United States	1
Pham et al. (2018)	2016	Vietnam	1
Pinto et al. (2016)	2011	Portugal	2
Piriyapada & Wang (2014)	2013	Thailand	1
Poder & He (2017)	2009	Canada, France	2
Polyzos & Minetos (2007)	1995	United Kingdom	4
Ponce et al. (2011)	2008	Chile	4
Pouta et al. (2002)	1997	Finland	1
Pu et al. (2019)	2017	China	1
Rakthai (2018)	2015	Thailand	1
Ramos et al. (2019)	2013	Portugal	2
Ready et al. (2002)	1996	Latvia	1

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Short reference	Study year	Study country	Provided WTP estimates
Rekola & Pouta (2005)	1996	Finland	2
Rekola et al. (2000)	1997	Finland	1
Resende et al. (2017)	2012	Brazil	1
Ressurreição et al. (2012)	2008	Portugal, Poland	8
Ressurreição et al. (2011)	2007	Portugal	12
Ressurreição et al. (2012)	2007	Italy, Portugal, Poland	30
Rhodes et al. (2018)	2005	United States	1
Rodella et al. (2019)	2015	Italy	3
Roomratanapun (2001)	1996	Thailand	1
Sabyrbekov et al. (2020)	2014	Kyrgyz Republic	1
Saengsupavanich et al. (2008)	2006	Thailand	1
Sale et al. (2009)	2003	South Africa	2
Schiappacasse et al. (2012)	2008	Chile	1
Schiappacasse et al. (2013)	2008	Chile	1
Schläpfer & Getzner (2020)	2015	Austria	12
Schläpfer et al. (2004)	2001	Switzerland	2
Šebo et al. (2019)	2018	Slovak Republic	1
Shaari et al. (2020)	2017	Malaysia	1
Shah et al. (2016)	2012	Pakistan	1
Shang et al. (2012)	2011	China	1
Shu (2018)	2015	China	1
Sinha & Mishra (2015)	2010	India	3
Söderberg & Barton (2014)	2007	Norway	1
Soliño et al. (2009)	2006	Spain	1
Solomon & Johnson (2009)	2007	United States	1
Srisawasdi et al. (2021)	2019	Thailand	1
Stanley (2005)	2001	United States	2
Stevens et al. (2000)	1996	United States	1
Stoll et al. (2006)	1996	United States	2
Subade & Francisco (2014)	2010	Philippines	2
Sun et al. (2016a)	2013	China	1
Sun et al. (2016b)	2014	China	1
Tan & Zhao (2014)	2008	China	2
Tello et al. (2018)	2012	Argentina	1
Thormann & Wicker (2021)	2019	Germany	1
Tilahun et al. (2015)	2009	Ethiopia	1

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Short reference	Study year	Study country	Provided WTP estimates
Toivonen et al. (2004)	1999	Denmark, Sweden, Norway, Finland	27
Tolunay & Başsüllü (2015)	2013	Turkey	1
Tonin (2019)	2016	Italy	4
Tran et al. (2017)	2013	United States	1
Treiman & Gartner (2006)	2004	United States	1
Trung et al. (2020)	2017	Vietnam	1
Tseng et al. (2015)	2011	Taiwan	1
Tuan et al. (2014)	2010	Vietnam	1
Turpie (2003)	2001	South Africa	4
Tziakis et al. (2009)	2006	Greece	1
Uehara et al. (2018)	1998	Japan	2
Ureta et al. (2014)	2006	Philippines	1
Van et al. (2007)	2006	China	1
Van Oijstaeijen et al. (2020)	2017	Ethiopia	1
Vargas & Díaz (2014)	2012	Colombia	1
Vásquez & de Rezende (2019)	2016	Brazil	1
Vásquez-Lavín et al. (2016)	2009	Bolivia	1
Vaughan et al. (2000)	1998	Brazil	1
Veisten et al. (2004)	1992	Norway	4
Verbič & Slabe-Erker (2009)	2005	Slovenia	1
Verbič et al. (2016)	2015	Slovenia	1
Vesely (2007)	2003	New Zealand	1
Vieira et al. (2016)	2015	Brazil	1
Voltaire et al. (2017)	2013	France	1
Wang & He (2018)	2007	China	2
Wang & Zhang (2009)	2006	China	1
Wang et al. (2006)	1999	China	1
Wang et al. (2013a)	2009	China	1
Wang et al. (2013b)	2007	China	1
Wang et al. (2016)	2014	China	1
Wang et al. (2016)	2015	China	2
Wang et al. (2018)	2016	China	1
Wang et al. (2020)	2014	China	2
Whitehead (2005)	1998	United States	1
Wilson et al. (2010)	2006	Canada	1
Wilson et al. (2012)	2006	Canada	3

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Short reference	Study year	Study country	Provided WTP estimates
Wilson et al. (2019)	2015	Australia	1
Winden et al. (2018)	2013	United States, China	4
Wu et al. (2020)	2013	China	1
Xiao et al. (2020)	2017	China	6
Xu & Shan (2018)	2014	China	3
Xu et al. (2020)	2018	China	1
Yaacovi et al. (2021)	2018	Israel	3
Yang et al. (2014)	2011	China	1
Yang et al. (2018a)	2014	China	4
Yang et al. (2018b)	2016	China	1
Yi (2019)	2018	South Korea	1
Yi & Kim (2020)	2018	South Korea	1
Yoo & Kwak (2009)	1999	South Korea	1
Yoo et al. (2001)	1997	South Korea	1
Yoskowitz & Montagna (2009)	2007	United States	1
Yu et al. (2018)	2017	China	2
Zambrano-Monserrate (2020)	2019	Ecuador	1
Zander et al. (2014)	2011	Australia	1
Zeybrandt & Barnes (2001)	1998	Namibia	1
Zhang et al. (2020)	2018	China	3
Zhao et al. (2013)	2008	China	2
Zhongmin et al. (2003)	2001	China	2

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