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A Meta-Analysis

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Abstract

There is an increased interest in applying nature-based solutions for addressing various urban challenges, such as those related to air pollution, climate change, and (mental) health. It is clear that nature can bring various benefits to city inhabitants, but the economic value of nature is not always well recognized. In this study we present a meta-analysis of a rapidly expanding literature that applied stated preference valuation methods to value green and blue urban nature in a variety of contexts. We estimate value transfer functions based on primary studies that elicited nature values from in total more than 41,000 respondents worldwide. We obtain insights into the main determinants of values of urban nature, in terms of study and methodological characteristics, types of nature, and ecosystem services. Main findings are that the per hectare value of nature is negatively related to the size of the nature area, and positively related to income and population density. Parks are the most highly valued types of urban nature, and aesthetics and cultural heritage services are the most highly valued ecosystem services it provides. Moreover, certain methodological choices in eliciting nature values appear to affect the final valuation results, such as the payment vehicle in stated preference surveys, and to some degree the valuation method. We present and illustrate the use of benefit transfer functions, which can be used for estimating the value of specific nature types and ecosystem services in a variety of urban settings.

Keywords: benefit tranfser, stated preferences, ecosystem services, meta-analysis, nature-based solution, urban nature.

JEL classification: C21, D12, H41, Q50, Q51

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1. Introduction

Many cities face environmental problems due to urbanization, air pollution, and climate change, which have negative effects on societal well-being. More than a half of the world population and around three quarters of the EU population lives in cities, and urbanization is expected to continue in the future (Eurostat, 2016). This highlights the importance of creating clean, healthy, and attractive urban living environments. There is an increased interest in how nature-based solutions can be employed to address urban challenges (Raymond et al., 2017). Nature-based solutions are actions inspired by, supported by, or copied from nature, which can include the use or enhancement of existing nature solutions to pressing challenges, as well as more novel solutions (Nesshöver et al., 2017; European Commission, 2015), like vertical green in the form of green walls or green roofs. Essentially, nature-based solutions is an overarching concept that builds on and supports other closely related concepts, such as the ecosystem approach, ecosystem services, ecosystem-based adaptation and mitigation, green engineering and green and blue infrastructure (Nesshöver et al., 2017).

Nature-based solutions can have the potential to simultaneously meet environmental, social and economic objectives. For instance, city parks offer habitats for species, are used for recreation, act as local climate regulation by cooling the city, and can attract tourism. Even though nature-based solutions appear to be a promising means to address current urban environmental challenges, their applicability into practice is often hampered. While nature can provide a number of benefits to their users, these benefits generally have public good characteristics and are not priced on existing markets, leading to under-provisioning in the absence of policy intervention (e.g. Kotchen and Powers, 2006). Benefits provided by nature are difficult to assess and are often underappreciated (Naumann et al., 2011), while nature in cities where space is scarce competes with other land uses. A lack of understanding of the benefits of nature impairs the ability to assess whether they outweigh their implementation, maintenance and opportunity costs, and benefits of alternative solutions. An improved understanding of the economic benefits of nature in cities can aid policy makers in making more informed decisions about the economic desirability of specific nature-based solutions, which can foster their implementation.

A rapidly expanding number of studies estimate economic values of different types of nature in cities using environmental valuation methods. This literature traditionally distinguishes between stated and revealed preference valuation methods (Champ et al., 2017; Dlamini, 2012). Stated preference methods estimate the value of non-traded goods and services in terms of willingness-to-pay (WTP) using survey instruments (Champ et al., 2017). Revealed preference methods rely on prices of goods related to nature observed in real markets and aim at deriving the monetary values of nature that are reflected in these market prices. An example is the commonly used hedonic pricing method which estimates the value of nature embedded in housing market prices. However, these primary valuation methods are not always pursued for a detailed valuation of nature at a particular site, because they are costly, time-consuming or because market data is lacking. Moreover, when aiming at valuation of nature and its benefits at large(r) geographical scales, performing individual studies for each nature-site is not viable.

Another strategy is to apply the value transfer method in cases when conducting a detailed primary valuation study of nature at a particular site or for a particular region is infeasible (Johnston et al., 2015). Value transfer makes use of existing primary valuation estimates and entails the application of these estimates to an unstudied site at a different place and in or a different context. For example, values for a city lake used for recreational fishing in a particular city may be estimated by applying (adjusted) measures of recreational fishing values from a primary valuation study conducted in another city. The state-of-the art of value transfer is to base it upon meta-analysis, which is a statistical method that explains variation in values from primary valuation studies using differences in characteristics of these studies, such as differences in methodologies, welfare levels, and the valued natural good (Bergstrom and Taylor, 2006). Advantages of a meta-analysis are that it aggregates available information from a variety of primary studies, and controls for methodological and context-specific differences of the studies in a relatively straightforward way. From the meta-analysis data a value transfer function can be estimated from which values of a good or service of interest can be derived, which can be tailored to the need of a site and nature specific assessment. Specifically interesting is that more and more spatially explicit information is becoming available, implying that spatially-specific value transfer is possible, thereby increasing the accuracy of this method (e.g., Johnston et al., 2017).

The objective of this study is to conduct a meta-analysis of economic values of nature in cities, in order to derive value functions which can be used for value transfer for valuing different types of urban nature. We focus on WTP estimates from stated preference studies that provide a wide variety of values, including use and non-use values, opposed to just focusing on value estimates from revealed preference studies that only capture direct use values.

A starting point for our study is the meta-analysis of stated preference values of urban open space by Brander and Koetse (2011), who estimated how WTP values of green open space in cities relate to site characteristics (type of open space, open space service, and area of site), study characteristics (e.g. payment vehicle), and socio-economic characteristics (i.e. GDP per capita and population density). We extend the original meta-analysis by Brander and Koetse (2011) in the following five main ways. First, the types of urban nature (forest, park, green space, undeveloped land, and agricultural land) are extended in our study to also include blue nature, such as lakes, rivers and canals. Second, while Brander and Koetse (2011) relate WTP to three main categories of services provided by green open space (recreation, preservation, and aesthetic), we examine how WTP values relate to a broader range of ecosystem service classifications. Because specific nature types are implemented to serve a certain policy objective or ecosystem service provision, it is useful if the nature values can be connected to these ecosystem services as much as possible in order to arrive at more accurate values for specific nature types to guide urban planning. Third, in addition to values derived from the contingent valuation method included in the previous meta-analysis, we also include WTP values derived from the increasingly popular choice experiment method. Fourth, we estimate a region-specific value function for Europe, which is relevant because the more similar the contextual and locational circumstances of the transfer sites are to the original primary valuation sites, the smaller the errors will be when applying the value transfer functions. Fifth, we updated the meta-analysis database by including more (recent) studies, which increases statistical power of the statistical analyses and allows for the inclusion of more explanatory variables.

The remainder of this paper is structured as follows. Section 2 describes the construction of the database and statistical methods. Section 3 presents the results of the value functions and discusses how these results compare with previous studies. Section 4 illustrates the applications of the derived value transfer functions and WTP estimates. Section 5 concludes.

Table 1. Overview of the primary valuation studies included in the database

Included in Brander and Koetse (2011)	Publication	Study site	Type of urban nature	Sample size	Number of observations
No	Barton (2002)	Jaco and Puntarenas, Costa Rica	Coastal water	281 and 376	2
No	Bueno et al., (2016)	Sampaloc Lake, Philippines	Urban lake	349	1
No	Bertram et al. (2017)	Berlin, Germany	Urban parks	1598	2
No	Bujosa et al.(2018)	Mallorca, Spain	Touristic resort	407	3
No	Chau et al. (2010)	Hong Kong	Green buildings	480	5
No	Chaudhry et al.(2008)	Chandigarh, India	Urban forest	2358	1
No	Shang et al. (2012)	Shanghai, China	River network	531	1
No	Chen, Jim (2012)	Hong Kong	Country parks	613	1
No	Chen et al.(2014)	Big meadow, Belgium	Riparian meadow	259	1
No	Chui, Ngai (2016)	Hong Kong	Sustainable drainage	600	1
No	Collins et al.(2017)	Southmapton, UK	green facade and living wall	217	4
No	Czajkowski et al. (2017)	Coastal Baltic cities in Denmark, Sweden, Finland, Estonia, Latvia, Lithuania	Baltic sea condition	505 up to1645	6
No	Dare et al. (2015)	Abeokata South, Nigeria	Urban tree forest	120	1
No	Dumenu (2013)	Kwame Nkrumah University of Science and Technology (KNUST), Ghana	Forest area	200	1
No	Ezebilo (2016)	Mount Wilhelm, Papua New Guinea	Mountain	130	1
No	Giergiczny, Kronenberg (2014)	Lodz, Poland	Urban street trees	351	2
No	Hampson et al. (2017)	Norwich, UK	River Yare	200	2
No	Jianjun et al.(2013)	Wenling City, China	Cultivated land	206	1
No	Kenney et al.(2012)	Stony Run Watershed, USA	Urban streams	228	2
No	Kim et al. (2016)	Seoul, Buasn, Incheon, Kwangju, Deajeon, Uslan and Deagu, South Korea	Urban forest	448	3
No	Kim et al. (2015)	Yeochun-Cheon, South Korea	Urban branch stream	984	1
No	Koetse et al. (2017)	Dutch cities, the Netherlands	Green and blue urban nature	1360	6
No	Lantz et al. (2013)	Credit River, Canada	Wetland	1407 and 1088	2
No	Latinopoulos et al. (2016)	Thessaloniki, Greece	Urban park	600	2
No	Leng, Lei (2011)	Zhangjiajie, China	Forest	185	1
No	Lo, Jim (2010)	Hong Kong	Urban green space	495	2
No	Machado et al. (2014)	Feijao River, Brazil	Watershed	280	1
No	Majumdar et al. (2011)	Savannah, USA	Urban forest	640	1
No	Mell et al. (2013)	Withworthstreet West, UK	Street trees	512	1
No	Mueller (2014)	Lake Mary and Upper Rio De Flag	Watershed	120	1
No	Rosenberger et al. (2012)	McDonald-Dunn forest, USA	Forest	607	1
No	Sarvilinna et al. (2017)	Helsinki, Finland	Urban streams	265	1
No	Sattout et al. (2007)	Lebanon	Ceder forest	425	1
No	Mohamed et al. (2012)	Hula Langat, Malaysia	Watershed	500	1
No	Tao et al. (2012)	Heshui Watershed, China	Watershed	170	1
No	Tu et al. (2016)	Nancy, France	Peri-urban forest	180	4
No	Wang et al.	Liyu River and Xinzhuang River	Rivers	444	1
No	Windle, Cramb (1993)	White Hill/Pine Mountain Reserve, Australia	Bushland	85	1
No	Yoo et al. (2008)	Seoul, South Korea	Urban air pollution	600	1
No	Zhao et al. (2013)	Zhangjiabang Creek, China	Urban rivers	646 and 507	2
Yes	Bergstrom et al. (1985)	Greenville county, South Carolina, USA	Agricultural land	250	4

Yes	Bishop (1992)	Derwent and Watford, UK	Forest	100	2
Yes	Bowker, Didychuk (1994)	Moncton, New Brunswick, Canada	Agricultural land	92	4
Yes	Breffle et al. (1998)	Boulder, Colorado, USA	Undeveloped land	72	1
Yes	Chen (2005)	Taiwan	Agricultural land	236	2
Yes	Fleischer (2000)	Hula and Jezreel valleys, Israel	Agricultural land	161	2
Yes	Fleischer, Tsur (2009)	Northern Israel	Agricultural land	350	1
Yes	Hanley, Knight (1992)	Chester, UK	Agricultural land	119	1
Yes	Jim, Chen (2006)	Guangzhou, China	Urban green space	340	1
Yes	Krieger (1999)	Chicago collar counties, USA	Agricultural land	1681	3
Yes	Kwak et al.	Seoul Metropolitan Area, South Korea	Forest	600	1
Yes	Lindsey, Knaap (1999)	Marian County, Indiana, USA	Urban green space	354	1
Yes	Lockwood, Tracy (1995)	Centennial Park, Sydney, Australia	Urban park	105	1
Yes	Maxwell (1994)	Marston Vale, Bedforshire, UK	Forest	100	4
Yes	Rosenberger, Walsh (1997)	Routt County, Colorado, USA	Agricultural land	171	4
Yes	Ready et al. (1997)	Kentucky, USA	Agricultural land	110	1
Yes	Scarpa et al. (2000)	24 forests in N. and Rep. Ireland	Forest	300	24
Yes	Tyrväinen, Väänänen (1998)	Joensuu, Finland	Forest	71 up to 205	8
Yes	Tyrväinen (2001)	Salo, Finland	Forest	67 up to 235	6
Yes	Willis, Whitby (1985)	Tyne county, UK	Agricultural land	103	1

2. Database and statistical methods

2.1. Literature search and database

The database collected for the meta-analysis consists of monetary value assessments obtained by means of the stated preference methods, including the contingent valuation and discrete choice experiment methods. For reasons of consistency and comparability we have followed the same procedure for literature search as Brander and Koetse (2011), and thus have searched publicly accessible databases, such as EVRI, ENVALUE, and used the search engines Google Scholar and Scopus.[1] Moreover, primary articles were checked for cross-references. To ensure the quality of primary valuation studies, only peer-reviewed published academic papers were considered. As a result, 46 new studies were added to the original database of Brander and Koetse (2011). Table 1 gives an overview of the studies included in our database. The total number of observations used in the current meta-analysis has doubled to in total 147 value entries, which were derived from in total more than 41,000 respondents. The maximum number of observations drawn from one study is 24 observations from the study of Scarpa et al. (2000). Besides the higher number of observations, the final database differs from the database of Brander and Koetse (2011) in other ways as well. The final database includes more types of urban nature (in particular, blue urban nature is added, such as urban rivers, ponds and canals) and more types of ecosystem services. Moreover, the new database also includes discrete choice experiments as elicitation format, which were not yet represented in Brander and Koetse (2011). Furthermore, the geographical coverage of the studied nature sites is expanded compared to the original meta-analysis of urban open space (ibid). The new database contains more studies from Asia (China, South-Korea, Malaysia, Papua New Guinea and Philippines), two studies from African countries (Ghana and Nigeria) and Brazil as an emerging economy of South America, in addition to a greater number of studies from Europe and North America. The geographical distribution of papers and number of observations is depicted in Table 2.

[1] The search terms used included three main components: valuation method, location, and the type of nature or service. Specific terms for method are: value, valuation, economic value, stated preferences, contingent valuation, dichotomous choice, choice experiment, stated choice. Specific terms for location are: urban, city, cities, local, community. Specific terms for type of nature or service are: natural infrastructure, green infrastructure, blue infrastructure, blue amenities, terrestrial water, watershed, wetlands, open space, water assets, water bodies, canals, lakes, green, greenbelt, green roof, garden, park, forest, natural, nature, water, water quality, ecosystem, ecosystem services.

Table 2. Geographical range of studies and observations in the database

		Brander and Koetse (2011) database		Current database	
		Studies	Observations	Studies	Observations
Location	Europe	6	44	20	81
	North America	8	20	12	26
	South America	0	0	2	3
	Asia	5	8	22	33
	Africa	0	0	2	2
	Australia	1	1	2	2
Total		**24**	**73**	**60**	**147**

2.2. Coding of the variables used in meta-analysis

For variables that are similar to the meta-analysis of Brander and Koetse (2011) we followed a similar coding method. The process of variable coding was attempted to be as accurate as possible and followed a four-eye principle, which means the coding was done by two researchers independently of each other. However, the information provided in the primary articles regarding the description and attributes of the nature assessed is not always complete. Therefore, the coding had to rely to some degree on researchers' interpretation, which is to some degree an unavoidable limitation of the method.

We use the same dependent variable as in Brander and Koetse (2011), which allows us to directly compare our results to that particular meta-analysis. Because the primary studies report their results in various monetary and spatial units, the extracted values had to be transformed to a common monetary metric. First, we have transformed all monetary WTP estimates to 2016 US dollars. Second, temporal and spatial units had to be aligned. Typically, the primary studies provide their WTP estimates either as a regular contribution or a WTP per visit. To be consistent with Brander and Koetse (2011), all values that were originally recorded as a per visit WTP were transformed into a US dollar WTP on an annual basis. This has been done by multiplying the WTP per visit by the annual number of visitors, where the data on the number of visitors was obtained from the primary studies. Moreover, all regular WTP contributions expressed per time unit (week/month/year) and agent unit (household/individual) were set to a US dollar value per year per household. As a next step, multiplying the value per year per household by the number of households generates the aggregate WTP value. The information on number of households, household size and population size was extracted from Demographia (www.demographia.com), for the OECD and the rest of the World. Finally, the calculated aggregated values were subsequently divided by the area size of the valued nature site in question, expressed in hectares. This information was either extracted from the primary studies, or found on the internet. Thus, the dependent variable in our meta-analysis is the monetary value of urban nature measured in 2016 US dollars per hectare per year. As explained by Brander and Koetse (2011) the dependent variable expressed in values per hectare per year has the advantage that it is more easily used for value transfer, compared to values per person per year. Determining the area size of a nature size is more clear-cut than determining the number of beneficiaries from the specific nature area.

The socio-economic variables included as explanatory variables are GDP per capita and population density. Most of the primary studies included income levels of the beneficiaries to control for the effect of income levels, however average data of these income levels was not readily accessible. Instead, GDP per capita for the relevant city (and where not available, region or country) and year of the primary studies was therefore used to approximate income levels. The GDP per capita variable was transformed to 2016 dollar via a GDP deflator factor obtained from the World Bank. To correct for purchasing power differences, the data was then divided by the purchasing power parity (PPP) local currency units (LCU) conversion factor with 2016 as a base year; PPP LCU data were obtained from the IMF database. The data on population density was in most cases absent in the primary studies. The data therefore was extracted from the World Bank, the OECD and Demographia. Population density is measured as number of people per square kilometre and corresponds with the spatial scale of the nature area (national level, province level or city level). Furthermore, in the case of peri-urban areas, the population density numbers of the nearest city are chosen.

Other study characteristics which may be relevant to include as explanatory variables in the value function estimation are the payment vehicle and the value elicitation format. The primary studies mostly used entry charge, taxation, water bills and donation to a fund as a payment vehicle in the stated preference survey, which are binary coded as entry charge, tax, donation to a fund and a category containing other payment vehicles. The elicitation formats used in the primary studies were Choice Experiment (CE), Contingent Valuation Method (CVM) and within CVM dichotomous choice, payment card and the open-ended WTP question format. These elicitation formats and the different CVM types were coded as dummy variables. Sample size can be an indication of quality of the primary studies, and it is therefore relevant for the estimation of a value transfer meta-function (Brander and Koetse, 2011). The sample size varies widely between studies, ranging from 67 to 2,358. Similarly to the original meta-analysis (ibid), the square root of the sample size was used for weighting the results of primary studies in our meta-sample. This approach implies that data from primary valuation studies with larger sample sizes have a more substantial impact on estimation results than studies with lower sample sizes.

Table 3. Coding of the dependent variable and final set of explanatory variables

Variable	Description	Mean
Dependent variable		
Value of nature	The value of nature in 2016 US dollars per hectare per year	1,678
Spatial and methodological variables:		
Area	Size of the nature area in hectares	1,474
GDP	GDP per capita in 2016 US dollars	23,026
Population density	Population density in number of people per square kilometre	396
Tax	1= tax was used as payment vehicle, 0=otherwise	0.299
Donation	1= donation to a fund was used as payment vehicle, 0=otherwise	0.184
Entry fee	1= entry fee was used as payment vehicle, 0=otherwise	0.272
Other payment vehicle	1=payment vehicle is not an entry fee, donation or a tax, 0=otherwise	0.265
Choice experiment	1=valuation method is a choice experiment, 0=otherwise	0.218
CVM dichotomous choice	1= valuation method is the contingent valuation method with a dichotomous choice format, 0=otherwise	0.333
CVM payment card	1= valuation method is the contingent valuation method with a payment card format, 0=otherwise	0.279
CVM open ended	1= valuation method is the contingent valuation method with an open ended format, 0=otherwise	0.136
Type of nature:		
Forest	1=valued nature type is a forest, 0=otherwise	0.408
Park	1=valued nature type is a park, 0=otherwise	0.048
Green connected to grey	1=valued nature type is green areas connected to grey infrastructure, 0=otherwise	0.150
Blue	1=valued nature type is blue nature, 0=otherwise	0.163
Peri-urban	1=valued nature type is peri-urban nature, 0=otherwise	0.231
Ecosystem services:		
Provisioning	1=ecosystem service is provisioning of food, resources or medicinal, 0=otherwise	0.497
Local climate regulation	1=ecosystem service is local climate regulation, 0=otherwise	0.442
Noise reduction	1=ecosystem service is noise reduction, 0=otherwise	0.517
Flood regulation	1=ecosystem service is flood regulation, 0=otherwise	0.673
Biodiversity and habitat	1=ecosystem service is biodiversity preservation and habitat, 0=otherwise	0.782
Recreation	1=ecosystem service is recreation, 0=otherwise	0.837
Aesthetics	1=ecosystem service is aesthetics, 0=otherwise	0.830
Cultural	1=ecosystem service is preservation of cultural heritage, 0=otherwise	0.510

The explanatory variables related to the nature site characteristics of the observations are nature area in hectare, type of urban nature and environmental services. The information on the size of the studied nature area was not always present and/or expressed in hectares. In case it was absent, the information was obtained from the internet or the size was calculated based on information from Google Maps. In case the information was given in a different unit, the unit was transformed to hectares. Regarding the type of nature or type of open space, the original classification of urban space (Brander and Koetse, 2011) was extended and now includes forests, parks, green areas connected to grey infrastructure, peri-urban land (consisting of undeveloped land and agricultural land), and blue nature (such as urban rivers, ponds or canals). Each value entry in our database has a unique dummy-coded nature type variable. Ecosystem services (ESS) are divided into four main categories, namely, "provisioning services", "regulating services", "cultural services", and "habitat and supporting, or preservation services" (TEEB, 2010). We could also distinguish sub-categories of ecosystem services in our sample, such as local climate regulation, flood regulation and noise reduction regulating ecosystem services, recreation, aesthetic and cultural services. All these categories and subcategories are coded as dummy variables that take value 1 when the open space provides the ecosystem service, and 0 otherwise. Table 3 includes the ecosystem service variables ultimately included in our analysis. Oftentimes, a single type of open space provides multiple ecosystem services, implying that ecosystem service dummy variables are largely overlapping.

2.3 Model specification of the meta-regression

Meta-data often include a hierarchical structure, which means that observations are not independent, but rather can be clustered or nested at some level. Such a clustering implies that the standard OLS regression model assumption of independent and identically distributed (i.i.d.) error terms is violated. Two different methodological approaches are commonly used to estimate meta-regression models: namely, standard OLS or WLS regressions, and multilevel models with the possibility of controlling for the supposed level of hierarchy in the meta-data (Bateman and Jones, 2003; Brander and Koetse, 2011; Schmidt and Hunter, 2004). Multilevel models (MLM) can take account of latent variation and potential heteroscedasticity by imposing a hierarchical (or nested) structure in the error terms, which relaxes the strong i.i.d. assumption (Bateman and Jones, 2003). In other words, the researcher does not have to assume homoscedasticity, because the model can identify a part of the variance of the error term that depends on certain explanatory variables. This way MLM can ensure that the standard errors of the parameters of interest are correctly estimated and that the significance of the coefficients on the independent variables is accurately judged. MLM allows for modelling the structure of the error term, by identifying the variance that is due to a pre-specified variable. For this purpose, the regression residual is split into two components: one that corresponds to the variance at the level of observations, and one that corresponds to the variance at the level of the variable specified by the researcher. The dependence between observations that explains the differences in variance might come from diverse sources. The most frequently used clustering variables in the literature are the study level, the author level, or the geographical division (Brander and Koetse, 2011; Schmidt and Hunter, 2004).

The meta-analysis presented here uses a two-level model, in which the value observations from the primary studies make up the first level and the authorship of a study is the second level. If multiple studies have the same first author, then these studies are categorized as having same authorship. The idea behind using authorship as the second-level variable is that there are personal characteristics in terms of context, research performance or in the methodological approach at the author level that make that primary-study estimates are clustered. We thus expect that value estimates obtained from studies with (a subset of) the same authors might be closer to each other than to value estimates from other studies, due to some intrinsic determinants that cannot be captured by other explanatory variables. We note that because only two first authors have multiple studies in our database with 60 different studies and 58 different first authors, hierarchy based on authorship is closely related to study level hierarchy which assumes clustering of values at the primary study level. However, we have chosen to use authorship as a second-level variable because it provided the best model fit compared to the models in which regional or study variables are used as second-level variables. Models with authorship produced the highest values of the variance partition coefficient (VPC), which reflects a higher explanatory power of the residual variance that is attributed to a particular variable (authorship in our case).

The estimated model is structured in the following way:

$$y_{ij} = \alpha + \beta^{S}\boldsymbol{X}_{ij}^{S} + \beta^{ED}\boldsymbol{X}_{ij}^{ED} + \beta^{ESS}\boldsymbol{X}_{ij}^{ESS} + \mu_j + \varepsilon_{ij} \qquad \text{[equation 1]}$$

The dependent variable $\boldsymbol{y_{ij}}$ is the annual per hectare value of urban nature in 2016 USD, the subscript $\boldsymbol{i}$ is for the observation level, which is level one, and ranges from 1 to 147, as we have N=147 value observations. The subscript $\boldsymbol{j}$ is for the second level, which is author level, and ranges from 1 to 58, which is the total number of different authors. The variables and dummies used in the model are grouped into matrices, based on socio-economic, study and site characteristics. The vector $\boldsymbol{X}_{ij}^{S}$ includes study and socio-economic characteristics, such as area of a nature site, GDP per capita, population density payment vehicle and method of value elicitation. The vector $\boldsymbol{X}_{ij}^{ED}$ contains variables that identify the type of urban nature. The vector $\boldsymbol{X}_{ij}^{ESS}$ contains ecosystem services. The residual of the observation level (level 1) is $\boldsymbol{\mu_j}$ and $\boldsymbol{\varepsilon_{ij}}$ is the residual of the author level (level 2).

All continuous variables in the model are log-transformed to ensure normality required by the multi-level model. Besides, log transformations are often used because they describe relationships between the dependent and independent variables better, as they assume a linear relationship in relative terms (constant elasticity) rather than a linear relationship in absolute terms. Further, in order to be able to interpret the intercept α, independent continuous variables were centred. Centring the variables means that the overall mean value of the variable is subtracted from the individual values per observation (Hox, 2010). With centred variables, the intercept can be interpreted as the nature value for the reference category when all continuous explanatory variables have average characteristics (GDP per capita, area size and population density) and dummy variables are set to zero (type of nature, type of ecosystem service, payment vehicle and if applicable method of value elicitation).

3. Results

3.1. Regression model results and WTP values

We have estimated three different value transfer functions, each separately including indicators of urban nature types, and ecosystem services (models 1 and 2 in Table 4). The coefficients of the explanatory variables that are expressed as centred logarithms can be interpreted as elasticities, i.e., the percentage change in the dependent variable (yearly $ value of nature per ha) given a percentage point change in the explanatory variable. Level 1 and level 2 variances are statistically significant, which shows a significant part of the variance can be attributed to the authorship of original studies included in the meta-analysis.

The constant in the regressions is highly significant and positive. It measures the value of one ha of nature per year when explanatory variables are at their ln average values (which are: site area=ln(1,474) ha, GDP=ln(23,026) in 2016 USD, population density =ln(396) persons per km2, see Table 3) and at the reference group for dummy-coded variables (e.g. peri-urban areas and no tax as payment vehicle in model 1). As an illustration, for model 1 this average value is $2,574 per ha per year.

The study and methodological variables included in the meta-models 1 and 2 (Table 4) can be interpreted in a similar way. The coefficient of area is negative and statistically significant, which means that natural sites of bigger size have a lower value per hectare than natural sites of smaller size, showing decreasing marginal returns to size of a nature area. The coefficient ranges between -0.964 and -1.017, depending on the model specification. As an illustration of this coefficient in model 1, a nature area that is 10% larger than the average, is valued about 10% less per ha, while this is 9.6% less per ha in model 2. This latter coefficient is consistent with a diminishing marginal value of the size of nature. It is also in line with sensitivity to scope since the total value for the complete area of nature still increases when the nature area is bigger.

Income, measured as GDP per capita, is positively and statistically significantly associated with the per ha value of nature. The interpretation is that urban inhabitants with a 1% higher income value nature with about 1.6% higher according to model 1 and 1.5% higher according to model 2. To illustrate the income effect alone based on model 1, nature implemented in Lodz, Poland where per capita GDP is about a half of the sample average ($12,845 in 2016) would be $1,570 lower in value per ha per year than the sample average ($2,574), ceteris paribus. Nature implemented in Nancy, France, where the GDP per capita is higher than average ($31,827 in 2016), is valued $1,766 higher than the sample average due to income effect.

Population density is positively and statistically significantly associated with the per ha value of nature. This means that in urban areas with higher population density the per ha nature value is higher than in areas with lower population density. A 1% higher population density results in a value for nature which is about 0.25% higher. As an illustration of this coefficient in model 1, nature created in Hong Kong would be valued higher with €2,740 per ha per year due to its high population density (6,987 persons per km2) compared to the sample average.

It turns out that none of the valuation method variables (choice experiment or the different CVM elicitation formats) are statistically significant (not reported in Table 4), which is why we excluded these variables from our models. Of the payment vehicle variables only tax has a negative and significant coefficient throughout the two estimated models, while the variables donation and entry fee are insignificant (not reported in Table 4) and hence excluded. This means that nature values elicited by means of a tax as a payment vehicle were systematically valued lower compared to values elicited by means of other payment mechanisms, such as an entry fee or a donation to a fund. For example according to model 1, the average value of nature is only $189 per ha per year if it is elicited by means of a tax, while it is $2,574 otherwise, ceteris paribus. This suggests that people strongly dislike paying for nature through tax increases.

Table 4. Meta-regressions results and the average values of nature for various types of urban nature.

	Model 1		**Average WTP value (model 1, in 2016 USD)**	**Model 2**	
Constant	7.853	***		8.908	***
Spatial and methodological variables:					
Area (ln)	-1.017	***		-0.964	***
GDP (ln)	1.614	***		1.496	***
Population density (ln)	0.253	***		0.242	***
Tax	-2.611	***		-2.620	***
Type of nature:					
Park	2.235	***	$11,007	2.772	***
Forest	0.257		$1,523	0.684	
Green connected to grey	0.507		$1,955	0.440	
Blue	0.476		$1,895	0.738	
Peri-urban areas (baseline category)			$1,187		
Ecosystem services:					
Local climate regulation				-0.376	
Noise reduction				-0.921	
Flood regulation				-1.105	
Biodiversity and habitat				-0.319	
Recreation				-1.228	**
Aesthetics				0.934	
Cultural				1.193	
Variance components					
Level 1 (estimate) variance	0.956	**		0.991	**
Level 2 (author) variance	7.477	**		5.726	**
Estimation statistics					
N observations / values	147			147	
log likelihood	-284			-278	
AIC	589			593	

In addition to the study and methodological variables, model 1 includes explanatory variables which represent different types of nature. Model estimation results show that compared to the excluded baseline of peri-urban sites, the other types of nature have higher values in the following ascending order: forests, green sites connected to grey, blue sites, and parks. The coefficient of park is large and statistically significant, which is not the case for the other types of urban nature. Table 4 also presents the sample average values of the urban nature types according to model 1. The value of parks is $11,007 per ha per year, and is clearly higher than the values of the other types of nature, which range between $1,187 and $1,955. Note that in estimating these average WTP values, also the tax dummy is set to its sample average (0.3).

Model 2 reports the results of estimation which includes both the types of urban nature and ecosystem services as explanatory variables. The baseline in this model includes the peri-urban areas, absence of ecosystem service variables that are included in the model, as well as possibly other ecosystem services that are not included as explanatory variables in the model, such as provisioning services of food and resources. The association between the WTP and the type of nature are similar to that in model 1. Concerning ecosystem services, lower values are observed for urban nature featuring regulating services that pertain to local climate regulation, noise reduction and flood risk management, habitat and biodiversity services, and cultural ecosystem services which are recreational. The coefficient of the latter service is statistically significant. Ecosystem services that are valued higher than the baseline are those related to aesthetics and preservation of cultural heritage services. An advantage of this model is that it can be used to estimate values for combinations of nature types and ecosystem services.[2] For example, this model can be used for deriving value estimates for an *ex ante* nature intervention, if it is known *a priori* which types of ecosystem services the particular nature type will be aiming to provide. Illustrative values for specific nature types and bundles of ecosystem services estimated with model 2 are given in Table 5. For example, it shows that peri-urban sites which offer regulating services like local climate regulation and flood regulation, as well as, habitat and biodiversity services are valued on average at $670 per ha per year, while this value increases to $1,706 if in addition the site also provides aesthetic enjoyment. A forest that provides local climate regulation services, serves as habitat and hosts biodiversity as well as can be used for recreation has an average value of $977, while if it also acts as preservation of cultural heritage services then its average

[2] We note here that we did not report results of interactions between the nature type and ecosystem services. Models including interactions between the types of nature and ecosystem services were estimated, but the number of observations in the subcategories were too small, making estimation results unreliable.

value increases to $3,220. Blue nature that in addition to flood regulation also provides biodiversity and preservation services and aesthetic enjoyment, is valued higher than blue infrastructure that only serves flood regulation ($5,197 versus $2,809 per ha per year). Green areas connected to grey infrastructure, such as green roofs, are valued less if they only serve flood regulation ($2,086 per ha per year) compared to an intervention that is also important for biodiversity and preservation provision and aesthetics ($3,859 per ha per year). It is clear from Table 5 that parks are valued the highest, especially if they also provide cultural services and biodiversity and habitat for species, in addition to providing noise reduction, local climate regulation and recreation and aesthetic services ($21,914 versus $9,145 per ha per year). However we need to note here that values obtained based on model 2 are relatively sensitive to model specification and e.g. the types of ecosystem services included in the estimation. Therefore, we use this model and values derived for illustrative purposes, while we do not yet advise value transfer applications based on model 2.

Table 5. Average value of type of nature according to ecosystem services per hectare per year according to model 2 (2016 USD)

Type of nature	**Provided ecosystems services**	**Average value**
Peri-urban sites	Local climate regulation Flood regulation Habitat & biodiversity	$ 670
Peri-urban sites	Local climate regulation Flood regulation Habitat & biodiversity Aesthetics	$ 1,706
Forest	Local climate regulation Habitat & biodiversity Recreation	$977
Forest	–Local climate regulation Habitat & biodiversity Recreation Cultural	$3,220
Blue	Flood reduction	$2,809
Blue	Flood reduction Habitat & biodiversity Aesthetics	$5,197
Green connected to grey	Flood reduction	$2,086
Green connected to grey	Flood reduction Habitat & biodiversity Aesthetics	$3,859
Park	Local climate regulation Noise reduction Recreation Aesthetics	$9,145
Park	Local climate regulation Noise reduction Habitat & biodiversity Recreation Aesthetics Cultural	$21,914

Our database has a relatively large number of observations from Europe (namely 81 values), allowing us to estimate a regional value function for Europe, using a similar model specification as for model 1. Model 3 for the European sub-sample was estimated using forest and peri-urban nature as the baseline category due to a low number of observations for peri-urban nature in this sub-sample. Urban forests are often located off the city centres in urban periphery, which contextually justifies merging these two types of nature. The results for the European model are presented in Table 6. These estimates show that average WTP values per nature type convey a different pattern in Europe compared to those derived for the global sample. For example, average monetary values of park and green urban nature connected to grey are higher in Europe compared to the global average, while average values of blue urban nature as well as urban forest and peri-urban areas lie below the global average. However, it is important to realize that the model based on the European sub-sample (Table 6) has a lower statistical power compared to the global models (Table 4) as far as the types of nature are concerned. All spatial and methodological variables are statistically significant at 1% level and have expected signs. In the European sub-sample we find that nature values elicited by means of the choice experiment method are significantly higher than those elicited with the traditions CVM method. Similar to the global model 1 (Table 4), the European model resembles level 1 and level 2 variances that are statistically significant. The variance partition coefficient is quite high (0.874), which reflects the large amount of variation also in the European studies that is attributed to the authorship of original studies included in the meta-analysis.

Table 6. Meta-regressions results of the value of nature in cities dependent on city and study variables as well as type of nature for Europe only

	Model 3		Average WTP value of nature types (2016 USD)
Constant	7.899	***	
Spatial and methodological variables:			
Area (ln)	-0.941	***	
GDP (ln)	1.479	***	
Population density (ln)	0.205	***	
Tax	-3.414	***	
Choice experiment	3.941	***	
Type of nature:			
Forest and peri-urban (excluded baseline)			$ 980
Park	2.533		$ 12,338
Green connected to grey	0.976		$ 2,601
Blue	0.077		$ 1,058
Variance components:			
Level 1 (estimate) variance	0.988	**	
Level 2 (author) variance	6.826	**	
Estimation statistics:			
N observations / values	81		
log likelihood	-143		
AIC	307		

3.2. Comparison with the previous meta-analysis

Since our meta-analysis extends the previous meta-analysis of Brander and Koetse (2011) about the value of green urban open space, it is of interest to compare our findings with that study. With regards to the study site variables, we observe similar effects for area and population density which are positively and significantly related to the value of urban nature in our study as well as to the value of urban green open space in Brander and Koetse (2011). The coefficient size for area is very similar in both meta-analyses, while our coefficient of population density is about half of the size of this coefficient estimated in the original meta-analysis. An interesting new finding in our study is that the value of nature significantly relates to GDP per capita. Although Brander and Koetse (2011) also found a positive coefficient of GDP, it was insignificant. That we are able to detect a significant positive coefficient of GDP per capita can be due to the larger sample size which increases statistical power as well as due to the inclusion of a wider diversity of cities with different GDP levels. It is generally expected that income is positively related to the valuation of nature (Jacobson and Hanley, 2009), which is confirmed by our findings for urban nature.

For the methodological variables, our finding that using a tax as a payment vehicle significantly lowers WTP values for urban nature is consistent with the negative significant coefficient of tax in the meta-analysis by Brander and Koetse (2011). The latter also observe a negative effect of using donations to a fund as a payment vehicle, which we do not observe. The finding that using a tax as payment vehicle lowers environmental valuation estimates has also been observed in a meta-analysis of values of ecosystem conservation by Hjerpe et al. (2015). We did not observe the finding in Brander and Koetse (2011) that dichotomous choice and payment card contingent valuation method approaches lower WTP, compared to an open-ended WTP question. However, it should be noted that our study also included observations elicited by choice experiments that were not part of the original meta-analysis, which implies that the included valuation methods are not directly comparable. A novel finding in our study is that, at least for European observations, the choice experiment method results in higher value estimates than the contingent valuation method.

Findings with regards to the values of types of nature are not directly comparable between our meta-analysis and the one by Brander and Koetse (2011) because we include a wider range of nature types and ecosystem services. A consistent finding between the two studies is that parks are valued the highest. With regards to ecosystem services Brander and Koetse find that recreation services are valued more than agricultural and environmental services. This finding is not directly comparable to ours since we were able to use a more detailed ecosystem services classification due to our inclusion of more primary valuation studies, which changes the baseline for estimation of the effect of ecosystem services.

4. Value transfer functions and illustrative examples

Two types of value transfer functions that can be used for the value transfer method can be derived from our results in Tables 4 and 6: namely, a function for nature types derived from the global and European data (models 1 and 3, respectively). These functions can directly be applicable to specific nature types, accounting for specific local circumstances. The function that can be applied to determine the value of a type of nature for the value transfer site based on the global data takes the form:

Value of nature per hectare per year = exp(7.853 -1.017 ×(ln(Area)-ln(1474)) + 1.614×(ln(GDP)-ln(23026))+ 0.253×(ln(population density)-ln(396)) - 2.611×Tax + 2.235×Park + 0.257×Forest + 0.507×Green connected to grey + 0.476× Blue) [equation 3]

The function that can be applied to determine the value of a type of nature for the value transfer site based on the European data takes the form:

Value of nature per hectare per year = exp(7.899 -0.941 ×(ln(Area)-ln(472)) + 1.479×(ln(GDP)-ln(28007))+ 0.205×(ln(population density)-ln(211)) – 3.414×Tax + 3.941×Choice experiment + 2.533×Park + 0.976×Green connected to grey + 0.077× Blue) [equation 4]

Note that in equations 3 and 4 the respective average ln values at valuation are subtracted from the variables area, GDP and population density because these variables are centered. In order to arrive at an absolute value of nature the exponent (exp) is taken of the right hand side of the equation because the dependent variable is measured in natural logarithms.

Here, we illustrate the application of equations 3 and 4 to a few actual nature intervention sites in cities in Europe that are part of a European Urban Nature Atlas database *(https://naturvation.eu/atlas)*. From this database we selected nature-based interventions of urban parks in four different European cities, with varying level of income, population density and size of the urban park. We have added data on income (regional GDP, OECD) and population density per city, which can be found in Table 6. Cordoba (Spain) has the lowest income level and urban density of the four selected cities. Strasbourg (France) and Athens (Greece) have about the same income level, which is almost twice as high in Stockholm (Sweden). At the same time, Stockholm and Strasbourg have about the same population density, which is highest in Athens with 7500 persons per km2. An important feature for economic valuation of urban parks is its size. The sizes in our selected cases vary between 1ha and 27ha (Danube Eco-District in Strasbourg and Asomadilla Park in Cordoba) to 200ha and 2700ha (Hellenikon Metropolitan Park in Athens and The Royal National City Park in Stockholm, respectively).

Table 7 lists all features of the cities as well as values estimated when applying the meta value-functions based on the global and European data. We recall that all values are in 2016 USD, representing yearly per ha values of nature, and take into account specific features of each natural intervention and locality.

The highest per ha value is found in Strasbourg and amounts to 68.9mnl USD per ha based on the global meta-function, and to 33.5mln USD per ha based on the European meta-function. These values are also the total value of the park which has a size of 1ha.

The second highest value is obtained for Cordoba at 802,114 USD per ha, which has a total value of the site of 21.7mln USD on a yearly basis based on the global data. However, value estimation based on the European function predicts 509,194 USD per ha with the total value of 13.7mln USD per year.

The Royal National City Park in Stockholm is valued at 203,000 USD per ha based on the global function, adding to the highest project total of 548mln USD per year. The value based on the European meta-function is considerably below this global estimate: namely, 46,336 USD per ha and a total of 125.1mln USD for this intervention on a yearly basis.

Athens' Hellenikon Metropolitan Park is valued at 357,164 USD per ha with the global meta-function, resulting in a yearly total of 71.4mln USD for the entire site. Here, the estimate based on European meta-function is lower and reaches 251,865 USD per ha with a total of 50.4mln USD for the site, per year.

The application of the value transfer functions as above results in two main observations. First, substantial differences exist in the estimated values per ha for all four selected cases. In all four cases the estimated values are higher when the global function was applied, compared to the estimates based on the European meta-function. The difference goes from 122% and 135% for Stockholm and Cordoba, respectively to 142% and 206% for Athens and Strasbourg, respectively. Theoretically, the European meta-function should be preferred for applications of European cases, because it closer approximates the similarity of context condition (see Bergstrom and Taylor, 2006). Second, the estimated values are relatively high, however not unrealistic. The cases selected for this illustrative calculation resemble substantially higher income levels and population density levels compared to the respective global average levels included in the estimation of both models 1 and 3. Moreover, our cases resemble substantial variation in the area size of parks from the mean. All these factors contribute to the obtained values.

In summary, our illustrative applications of the value transfer functions to four European cities with urban parks show that these urban nature sites deliver much worth to the urban inhabitants and city visitors.

Table 7. Application results of meta-functions based on models 1 and 3 on actual nature-based solutions from European Urban Nature Atlas (https://naturvation.eu/atlas)

	Cordoba	**Stockholm**	**Strasbourg**	**Athens**
	Asomadilla Park	The Royal National City Park	Danube Eco-District	Hellenikon Metropolitan Park
Area (ha)	27	2700	1	200
GDP per capita (2016 USD)	25587	65853	37160	35653
Population density	260	3597	3500	7500
Meta-functions based on model 1 (global data)				
Value per ha per year (2016 USD)	$685,518	$56,614	$68,906,738	$357,164
Total value, per year (2016 USD)	$18,508,997	$152,856,567	$68,906,738	$71,432,827
Meta-functions based on model 3 (European data)				
Value per ha per year (2016 USD)	$509,194	$46,336	$33,527,530	$251,865
Total value, per year (2016 USD)	$13,748,234	$125,107,874	$33,527,530	$50,372,975

5. Conclusion

It has been argued that nature-based solutions are promising for addressing various urban challenges, such as those related to air pollution, climate change, and (mental) health. Urban nature, such as parks, green roofs, and blue areas, can bring various benefits to citizens, but the value of nature is not always well recognized or reflected in decision making since it is not directly expressed in monetary terms. Hence, a rapidly expanding literature has applied economic valuation methods to value different types of urban nature in a variety of contexts. Such estimates of economic values of nature can be useful for guiding urban planning, for example, as input in cost-benefit analyses of the implementation of nature-based projects in cities. However, conducting primary valuation studies for particular sites is data intensive, time consuming, and requires a high level of expertise, which is why conducting such studies is not always feasible. An alternative is to estimate values of nature using a value transfer method, which applies value estimates obtained from primary valuation studies of other sites that are adjusted to match the local context of the type of nature and site of interest. Such a value transfer is best done using value transfer functions which are estimated on the basis of a meta-analysis.

In this study we conduct a meta-analysis of the value of urban nature in order to estimate value transfer functions. By assessing the primary studies that valued urban nature we obtain insights into the main determinants of these values, in terms of study and methodological characteristics, spatially specific variables (income, population density and size of the studies area), types of nature, and ecosystem services. An MLM estimation methodology is applied, which accounts for variance component that arises from author level characteristics of WTP values obtained from primary valuation studies. We built upon an existing meta-analysis of stated preference valuation studies of urban green open space (see Brander and Koetse, 2011), which we extended in various ways: in particular, by adding blue nature as a nature type, considering a broader range of ecosystem services as explanatory variables, including value estimates derived from the increasingly popular choice experiment method, and by estimating a regional (European) value transfer function. The total number of value observations used in our current meta-analysis has approximately doubled, and is based on stated preference surveys in which more than 41,000 respondents participated.

Our main findings can be summarized as follows. The per hectare value of nature is significantly negatively related to the size of the nature area, which reflects a diminishing marginal value of nature. The value of nature is positively and statistically significantly related to income, which shows nature is a normal good according to economic terminology. Population density as a proxy for nature scarcity is significantly positively related to values of urban nature, reflecting an increase in a per hectare value with the number of potential users. If a stated preference survey used a tax as a payment vehicle to elicit values of nature, then significantly lower values were obtained, reflecting that people strongly dislike paying for nature through higher taxes compared with other payment methods, like donations to a fund or an entry fee. With regards to the different nature types, we consistently observe that parks are the most highly valued types of urban nature. Moreover, the values of nature depend on the ecosystem services it provides; in particular, (significantly) lower values are observed for nature which provides recreation, regulating services (such as local climate regulation, noise reduction and flood regulation) and biodiversity and habitat services, while cultural services and aesthetics are most highly valued. A regional value transfer function for Europe showed that the different nature types are on average valued slightly differently in Europe compared to the rest of the world, and that values elicited with the choice experiment method significantly exceed those elicited with the traditional contingent valuation method. Our illustrative example of value transfer has resembled non-trivial values of urban nature for four parks in different European cities.

Our study presented and illustrated value transfer functions which can be used for estimating the value of nature in a particular city. Our illustrative applications of the obtained value transfer functions showed the importance of using regional (in our case European) value transfer functions. Future research can update these functions when more primary valuation studies become available, which can allow for obtaining more precise and more detailed insights into how values of urban nature relate to a broader range of ecosystem services and how these values differ between a variety of regions in the world.

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