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Economic valuation of green and blue nature in cities: A meta-analysis

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ABSTRACT

There is an increased interest in applying nature for addressing various urban challenges, such as those related to air pollution, climate change, and health, but the economic value of urban 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 60 primary studies that elicited urban nature values from in total more than 41,000 respondents worldwide. Moreover, 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. For example, using global and European value functions, estimates of the average value of an urban park vary between 12,000USD and 33,100USD, respectively, while estimates of the average value of urban forest vary between 3,000USD and 2,250USD, respectively. We apply these value transfer functions to natural interventions in several cities in Europe, illustrating how these functions can be used for estimating the value of specific natural areas in a variety of urban settings.

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 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 quantifying how nature is contributing to urban well-being, as is shown by assessments of benefits of existing nature in cities, the quantification of benefits of ecosystem services provided by urban nature, and valuation of nature-based solutions[1] that can be employed as ‘green’ alternatives to traditional ‘grey’ solutions to address urban challenges (Raymond et al., 2017). The relevance of a monetary quantification of the benefits provided by urban nature is becoming more broadly acknowledged (Brander and Koetse, 2011). Such a monetary valuation can be used in assessing green interventions within the established approaches of ecosystem service provision, natural capital accounting, green infrastructure development, biodiversity conservation, as well as be applied to more recent concepts, such as nature-based solutions.

Nature in cities can be seen as any manifestation of natural elements, be it blue or green, in an urban planning context. It can range from an urban park or forest, a water body, individual street trees or green building facades. Green interventions 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. Although green interventions of various types 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 in existing markets, which leads to under-provision 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 these benefits outweigh costs of implementing and maintaining such areas, and also prohibits comparing the benefits of various alternative uses of money and space. An improved understanding of the economic benefits of nature in cities can therefore aid

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[1] Nature-based solutions is an emerging concept that can be defined as 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, like vertical green in the form of green walls or green roofs (Nesshöver et al., 2017; European Commission, 2015).

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policy makers in making more informed decisions about the economic desirability of specific types of urban nature, 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.[2] 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 feasible.

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 applies these estimates to an unstudied site at a different place or in a different context. For example, values for a lake used for recreational fishing in a particular city can be estimated by applying (adjusted) 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. More spatially explicit valuation 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 an up-to-date meta-analysis of economic values of nature in cities, in order to estimate value functions that can support decision making about urban planning that involves urban nature. We focus on WTP estimates from stated preference studies that capture a wide variety of values, including use and non-use values, instead of focusing on value estimates from revealed preference studies that only capture direct use values.

Here, we update and extend a meta-analysis 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 make five main contributions to this previous work. 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, and green nature connected to grey infrastructure, such as green walls, facades and living roofs. 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 services. The services we added are climate regulation, noise reduction, flood regulation and cultural services. 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, our extended meta-database allowed us to estimate two value functions: one that describes variations in global valuation of nature, while another describes region-specific variations in values of urban nature for Europe. These two estimated functions thus enable a more precise value transfer that depends on the contextual and locational circumstances of a specific value transfer application. Fifth, the updated meta-analysis database includes 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 includes a discussion and Section 6 concludes.

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 method, 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 (https://www.evri.ca/en), ENVALUE (https://www.environment.nsw.gov.au/envalueapp/), and used the search engines Google Scholar and Scopus. Moreover, primary articles were checked for cross-references. The search terms used included three main components: valuation method, location, and the type of nature or service. Specific terms for each category are:

- Method: value, valuation, economic value, stated preferences, contingent valuation, dichotomous choice, choice experiment, stated choice;
- Location: urban, city / cities, local, community;
- Type of nature / service: 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.

To ensure the quality of primary valuation studies, only peer-reviewed published academic papers were considered. As a result, 40 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 value observations used in the current meta-analysis has doubled to in total 147 value entries. Multiple value observations were recorded if they referred to different natural sites, locations or elicitation formats. The maximum number of value observations drawn from one study is 24 observations from the study of Scarpa et al. (2000). Apart from 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. 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. Moreover, the new database also includes discrete choice experiments as elicitation format, which were not yet represented in

[2] An example is the commonly used hedonic pricing method which estimates the value of nature embedded in housing market prices.

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

N primary studies	Publication	Study site	Type of urban nature	Sample size	Number of observations
1*	Bergstrom et al. (1985)	Greenville county, South Carolina, USA	Agricultural land	250	4
2*	Bishop (1992)	Derwent and Watford, UK	Forest	100	2
3*	Bowker, Didychuk (1994)	Moncton, New Brunswick, Canada	Agricultural land	92	4
4*	Breffle et al. (1998)	Boulder, Colorado, USA	Undeveloped land	72	1
5*	Chen (2005)	Taiwan	Agricultural land	236	2
6*	Fleischer (2000)	Hula and Jezreel valleys, Israel	Agricultural land	161	2
7*	Fleischer, Tsur (2009)	Northern Israel	Agricultural land	350	1
8*	Hanley, Knight (1992)	Chester, UK	Agricultural land	119	1
9*	Jim, Chen (2006)	Guangzhou, China	Urban green space	340	1
10*	Krieger (1999)	Chicago collar counties, USA	Agricultural land	1681	3
11*	Kwak et al. (2003)	Seoul Metropolitan Area, South Korea	Forest	600	1
12*	Lindsey, Knaap (1999)	Marian County, Indiana, USA	Urban green space	354	1
13*	Lockwood, Tracy (1995)	Centennial Park, Sydney, Australia	Urban park	105	1
14*	Maxwell (1994)	Marston Vale, Bedforshire, UK	Forest	100	4
15*	Rosenberger, Walsh (1997)	Routt County, Colorado, USA	Agricultural land	171	4
16*	Ready et al. (1997)	Kentucky, USA	Agricultural land	110	1
17*	Scarpa et al. (2000)	24 forests in N. and Rep. Ireland	Forest	300	24
18*	Tyrväinen, Väänänen (1998)	Joensuu, Finland	Forest	71 up to 205	8
19*	Tyrväinen (2001)	Salo, Finland	Forest	67 up to 235	6
20*	Willis, Whitby (1985)	Tyne county, UK	Agricultural land	103	1
21	Barton (2002)	Jaco and Puntarenas, Costa Rica	Coastal water	281 and 376	2
22	Bueno et al. (2016)	Sampaloc Lake, Philippines	Urban lake	349	1
23	Bertram et al. (2017)	Berlin, Germany	Urban parks	1598	2
24	Bujosa et al.(2018)	Mallorca, Spain	Touristic resort	407	3
25	Chau et al. (2010)	Hong Kong	Green buildings	480	5
26	Chaudhry et al.(2008)	Chandigarh, India	Urban forest	2358	1
27	Shang et al. (2012)	Shanghai, China	River network	531	1
28	Chen, Jim (2012)	Hong Kong	Country parks	613	1
29	Chen et al.(2014)	Big meadow, Belgium	Riparian meadow	259	1
30	Chui, Ngai (2016)	Hong Kong	Sustainable drainage	600	1
31	Collins et al.(2017)	Southmapton, UK	green facade and living wall	217	4
32	Czajkowski et al. (2017)	Coastal Baltic cities in Denmark, Sweden, Finland, Estonia, Latvia, Lithuania	Baltic sea condition	505 up to1645	6
33	Dare et al. (2015)	Abeokata South, Nigeria	Urban tree forest	120	1
34	Dumenu (2013)	Kwame Nkrumah University of Science and Technology (KNUST), Ghana	Forest area	200	1
35	Ezebilo (2016)	Mount Wilhelm, Papua New Guinea	Mountain	130	1
36	Giergiczny, Kronenberg (2014)	Lodz, Poland	Urban street trees	351	2
37	Hampson et al. (2017)	Norwich, UK	River Yare	200	2
38	Jianjun et al.(2013)	Wenling City, China	Cultivated land	206	1
39	Kenney et al.(2012)	Stony Run Watershed, USA	Urban streams	228	2
40	Kim et al. (2016)	Seoul, Buasn, Incheon, Kwangju, Deajeon, Uslan and Deagu, South Korea	Urban forest	448	3
41	Kim et al. (2015)	Yeochun-Cheon, South Korea	Urban branch stream	984	1
42	Koetse et al. (2017)	Dutch cities, the Netherlands	Green and blue urban nature	1360	6
43	Lantz et al. (2013)	Credit River, Canada	Wetland	1407 and 1088	2
44	Latinopoulos et al. (2016)	Thessaloniki, Greece	Urban park	600	2
45	Leng, Lei (2011)	Zhangjiajie, China	Forest	185	1
46	Lo, Jim (2010)	Hong Kong	Urban green space	495	2
47	Machado et al. (2014)	Feijao River, Brazil	Watershed	280	1
48	Majumdar et al. (2011)	Savannah, USA	Urban forest	640	1
49	Mell et al. (2013)	Withworthstreet West, UK	Street trees	512	1
50	Mueller (2014)	Lake Mary and Upper Rio De Flag	Watershed	120	1
51	Rosenberger et al. (2012)	McDonald-Dunn forest, USA	Forest	607	1
52	Sarvilinna et al. (2017)	Helsinki, Finland	Urban streams	265	1
53	Sattout et al. (2007)	Lebanon	Ceder forest	425	1
54	Mohamed et al. (2012)	Hula Langat, Malaysia	Watershed	500	1
55	Tao et al. (2011)	Heshui Watershed, China	Watershed	170	1
56	Tu et al. (2016)	Nancy, France	Peri-urban forest	180	4
57	Wang et al. (2013)	Liyu River and Xinzhuang River	Rivers	444	1
58	Windle, Cramb (1993)	White Hill/Pine Mountain Reserve, Australia	Bushland	85	1
59	Yoo et al. (2008)	Seoul, South Korea	Urban air pollution	600	1
60	Zhao et al. (2013)	Zhangjiabang Creek, China	Urban rivers	646 and 507	2

Studies with an asterisk are included in Brander and Koetse (2011).

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

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**

of papers and number of observations is depicted in Table 2.

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 and differences in coding were discussed. For example, in cases where the information provided in the primary articles regarding the description and attributes of the nature assessed was not always complete, the coding had to rely to some degree on researchers' interpretation and mutual consensus.

We use the same dependent variable as in Brander and Koetse (2011), which is the dollar value of a hectare of urban nature per year, 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 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. Primary studies that did not contain this data were excluded from the sample. Moreover, all regular WTP contributions expressed per time unit (week/month/year) and agent unit (household/individual with a national average household size as a proxy) 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.[3] 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 publicly accessible internet sites of the area. Thus, the dependent variable in our meta-analysis is the monetary value of urban nature measured in 2016 US dollars per hectare per year. This metric has the advantage that value transfer is easier compared to a metric with values per person, since the latter requires the difficult task of determining the number of beneficiaries for nature areas to which the value transfer is applied.

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, 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 used to approximate income levels. The GDP per capita variable was transformed to the 2016 dollar value via a GDP deflator factor obtained from the World Bank[4] . 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. These PPP LCU data were obtained from the OECD database based on IMF classification[5] . The data on population density was in most cases absent in the primary studies, therefore this data was extracted from Eurostat[6], the OECD[7] and Demographia (Demographia, 2018). 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 are used of the nearest city that was assumed to benefit from this nature.

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, Contingent Valuation Method, and within the latter: dichotomous choice, payment card and the open-ended WTP question format. These elicitation formats and the different contingent valuation method types were coded as dummy variables. With respect to controlling for differences in the precision of value estimates, the first-best approach is weighting all observations with their respective standard errors (Koetse et al., 2010). However, these standard errors are not readily available, and almost impossible to derive without access to the original datasets used in the underlying primary studies. Identical to the meta-analysis by Brander and Koetse (2011), we therefore use the square root of the sample size for weighting the results of primary studies in our meta-sample. The sample size varies widely between studies, ranging from 67 to 2,358, and our 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.

The explanatory variables related to the site characteristics are nature area in hectare, type of urban nature, and environmental services. The information on the size of the studied area was not always

[3] For all observations the total urban population of the location valued in the primary study was assumed to be benefitting from any piece of urban nature, following Brander and Koetse (2011). This is a simplifying assumption since the extent of direct beneficiaries can vary per specific piece of urban nature and would normally not cover all urban inhabitants. At the same time, connected pieces of urban nature contribute to the network of urban nature that provides important ecosystem services to the whole urban area and its population, such as improving overall air quality, carbon sequestration, and biodiversity. These services of urban nature can thus be potentially enjoyed at different locations and for different purposes, such as living, working, recreating, shopping, and therefore be valued by all urban residents. Nevertheless, some regulating services, like water capture, decreasing noise and providing cooling in shades are enjoyed locally and can depend on the size of nature.

[4] The corresponding link is: https://data.worldbank.org/indicator/NY.GDP.PCAP.KD.ZG

[5] The corresponding links are: https://data.oecd.org/conversion/exchange-rates.htm and https://data.oecd.org/conversion/purchasing-power-parities-ppp.htm#indicator-chart.

[6] The corresponding link to data on NUTS3 level is: https://ec.europa.eu/eurostat/web/products-datasets/product?code=demo_r_d3dens

[7] The corresponding link is: https://stats.oecd.org/Index.aspx?DataSetCode=REGION_DEMOGR.

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, small urban green, green areas connected to grey infrastructure, peri-urban land[8], and blue nature, such as urban rivers, ponds or canals. See Table 3 for a more detailed description of nature types. Each value observation in our database has a unique dummy-coded nature type variable. In addition, we have added a multiscape dummy variable in order to account for the quality of urban nature. A piece of valued nature was specified to possess a 'multiscape' if it had two or more landscape types, such as parkscape, waterscape, soilscape, etc. Note, however, that while the multiscape dummy is assumed to act as a proxy for the quality of urban nature, it does not take into account the maintenance level of urban nature. An example can be a case of a polluted river running through a park, which would rather be perceived as a dis-amenity.

Ecosystem services 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 sub-categories were extracted from the primary study description or specific study context, and are coded as dummy variables that take value 1 when the nature area provides the ecosystem service, and 0 otherwise. Table 3 includes the ecosystem service variables ultimately included in our analysis. Often, a single type of open space provides multiple ecosystem services, implying that ecosystem service dummy variables are overlapping.[9]

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 heteroskedasticity 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 variables. This way multilevel models can ensure that the standard errors of the parameters of interest are correctly estimated, and that the significance of the coefficients of the explanatory variables is accurately judged. Multilevel models allow 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[10] (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 imply that primary-study estimates are clustered. We thus expect that value estimates obtained from studies with the same first author 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. The latter 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:

$$y_{ij} = \alpha + \beta^{S}\boldsymbol{X}_{ij}^{S} + \beta^{ED}\boldsymbol{X}_{ij}^{ED} + \beta^{ESS}\boldsymbol{X}_{ij}^{ESS} + \mu_j + \varepsilon_{ij} \tag{1}$$

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 socio-economic characteristics, such as area of a nature site, GDP per capita, and population density, and it includes study characteristics, such as 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

[8] The category peri-urban land consists of undeveloped land and agricultural land which directly borders on urban areas and from which urban inhabitants can directly extract utility, like recreation or a scenic view.

[9] There is also an overlap between ecosystem services dummies and type of nature dummies. For example, the relatively high amount of studies with provisioning services (0.497) may be related to a relatively high proportion of periurban areas, which are mainly agricultural land (0.231). Moreover, certain urban nature types, like forests or rivers and ponds, are in some cultures more directly used for provisioning purposes, for example in Asia or Eastern Europe.

[10] Note that we have tested geographical variation in three ways. First, to account for regional variation we estimated several models that included continental dummies for North America and Europe (Asia and other countries as a reference group). These models have not resulted in statistically significant coefficients for respective dummies, reflecting that average values of urban nature do not differ across continents. These dummies were therefore not included in the reported meta-model specification. Second, we estimated a model that included the environmental performance index for 2018 (EPI, Yale, https://epi.envirocenter.yale.edu/epi-topline?country=&order=field_epi_score_new&sort=asc), which provides a per country score. EPI is an average of 2 components: environmental health and ecosystem vitality. This model has not resulted in statistically significant coefficients of EPI, reflecting that values of urban nature are not associated with EPI scores by country. The EPI score was therefore not included in the reported meta-model specification. Third, we have estimated a model that included a cultural index (Hynes et al., 2013), which provides a per country score. This model has not resulted in statistically significant coefficients of the index (p-value = 0.091) at the conventional 1% and 5% significance levels, reflecting that values of urban nature are not associated with the cultural index by country. The cultural index was therefore not included in our final meta-model specification.

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	1678
Spatial and methodological variables:		
Area	Size of the nature area in hectares	1474
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
CE	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 an urban forest, 0 = otherwise	0.408
Park	1 = valued nature type is an urban park, 0 = otherwise	0.048
Small urban green	1 = valued nature type is relatively small green urban areas (such as neighbourhood green spaces, pocket parks, green corridors), 0 = otherwise	0.054
Green connected to grey	1 = valued nature type is green areas connected to grey infrastructure (such as green roofs, green walls or façades, street green, street trees), 0 = otherwise	0.095
Blue	1 = valued nature type is blue nature (such as lake, ponds, rivers, streams, canals, urban sea coasts, wetland), 0 = otherwise	0.163
Peri-urban	1 = valued nature type is peri-urban nature (such as undeveloped land, agricultural land, golf course), 0 = otherwise	0.231
Multiscape	1 = valued nature type resembles multiple landscape types, 0 = otherwise	0.156
Ecosystem services:		
Provisioning	1 = ecosystem service is provisioning of food, medicinal or other natural resources, 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

author level (level 2).

All continuous variables in the model are log-log transformed because this generally better describes relationships between the dependent and independent variables, as it assumes a linear relationship in relative terms (constant elasticity) rather than in absolute terms (see also Brander and Koetse, 2011; Johnston et al., 2017). Further, in order to be able to interpret the intercept α, the 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 LN 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

In this section we present results of estimated meta-regression models. We start with estimating two value transfer functions based on the global value data. Model 1 presents a basic model with spatial and study variables, methodological variables and type of urban nature variables. Model 2 extends model 1 by adding variables for ecosystem services (both model results are given in Table 4). The coefficients of the explanatory variables in both models 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, and the variance portioning coefficients are quite high, at 0.880 and 0.842 for models 1 and 2, respectively. This statistic indicates that a significant part of the variance can be attributed to the authorship of primary studies included in the meta-analysis. Because a multilevel model does not produce a goodness of fit statistic except for the log likelihood, estimating the adjusted-R2 of equivalent models using OLS provides a more intuitive indicator of model fit. These adjusted-R2 values are 0.660 for model 1 and 0.699 for model 2, which indicate a good model fit. AIC is 592.

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 = 1474 ha, GDP = 23,026 in 2016 USD, population density = 396 persons per km2, see Table 4) and at the reference group for dummy-coded variables (e.g. peri-urban areas, elicited with a contingent valuation method, no tax as payment vehicle in model 1). As an illustration, for model 1 this average value is $2249 per ha per year.

The study and spatial 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 -0.952, depending on the model specification. As an illustration of the coefficient in model 1, a nature area that is 10% larger than the average, is valued about 9.64% per ha less. This is 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 natural areas in regions with a 1% higher income have a 1.5% higher value according to model 1 and a 1.4% higher value according to model 2. To illustrate the effect of income in isolation 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 $1327 lower in value per ha per year than the sample average ($2249), ceteris paribus. Nature implemented in Nancy, France, where the GDP per capita is higher than average ($31,827 in 2016), is valued $1438 higher than the sample average, ceteris paribus.

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

	MODEL 1 Coeff.	Std.err.		Average WTP value[a]	MODEL 2 Coeff.	Std.err.	
Constant	7.718	0.502	***		8.093	0.920	***
Spatial and study variables:							
Area (ln)	−0.964	0.101	***		−0.952	0.090	***
GDP (ln)	1.527	0.358	***		1.414	0.338	***
Population density (ln)	0.241	0.070	***		0.240	0.072	***
Methodological variables:							
Choice experiment	1.900	1.063	*		1.741	1.003	*
Tax	−2.723	0.726	***		−2.612	0.751	***
Type of nature:							
Peri-urban areas (baseline category)				$2249			
Park	1.674	0.693	***	$11,992	2.414	0.906	***
Forest	0.059	0.705		$2386	0.437	0.816	
Small urban green	−0.144	1.639		$1948	0.715	1.410	
Green connected to grey	−0.589	1.502		$1248	−0.591	1.248	
Blue	0.221	0.836		$2805	0.586	0.757	
Multiscape	0.231	0.808			0.542	0.749	
Ecosystem services:							
Local climate regulation					−0.301	0.525	
Noise reduction					−1.093	0.793	
Flood regulation					−0.464	0.728	
Biodiversity and habitat					−0.138	0.491	
Recreation					−1.350	0.581	**
Aesthetics					1.174	0.799	
Cultural					1.220	0.598	**
Variance components:							
Level 1 (estimate) variance	0.959	0.213	**		0.992	0.217	**
Level 2 (author) variance	7.033	1.466	**		5.746	1.416	**
Estimation statistics:							
N value observations	147				147		
log likelihood	−282				−277		
AIC	592				595		

***,**, * stands for statistical significance at the 1%, 5% and 10% level, respectively.
[a] average WTP values are based on model 1, and are expressed in 2016 USD per ha per year.

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 0.24% higher. As an illustration of this coefficient in model 1, nature created in Hong Kong would be valued higher by €2246 per ha per year due to its high population density (6987 persons per km2) compared to the sample average.

Of the methodological variables, only the dummies for the choice experiment elicitation format and tax as a payment vehicle were included in the final model estimation. Other methodological variables, such as different elicitation formats of the contingent valuation method and payment vehicle variables for donation and entry fee were insignificant (not reported in Table 4) and hence excluded. The results show 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 $223 per ha per year if it is elicited by means of a tax, while it is $3401 otherwise, ceteris paribus. A negative interpretation of this result is that people strongly dislike paying for nature through tax increases, but the result may also show that payments through binding payment vehicles (suggested to be preferable to non-binding payment vehicle in Johnston et al., 2017) are less prone to hypothetical bias than payments elicited through voluntary payment vehicles. Moreover, if a primary study used a choice experiment as elicitation format for the willingness to pay, then the average value of urban nature was higher compared to contingent valuation studies. This dummy is statistically significant on the 10% level. Choice experiments are a well-established and a widespread method in environmental valuation and provide valuable insights into the value formation by examining how WTP depends on attributes of the valued good. Since more value observations elicited with choice experiments are expected to be available in the future, it can be important methodological control variable in future meta-analytical studies. Based on the current results of model 1, the average value of nature is $6656 per ha per year if it is elicited by means of a choice experiment, and $995 per ha per year if it is elicited by means of a contingent valuation method, ceteris paribus.

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: green sites connected to grey, small urban green, peri-urban areas, forests, blue sites, and parks. The coefficient on parks 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 $12,000 per ha per year, and is clearly higher than the values of the other types of nature, which range between $1250 and $2800. Note that in estimating these average WTP values, all continuous dependent variables are at their sample average and the methodological dummy variables and multiscape variable are set to zero.

Model 2 reports the estimation results of a model which includes both the types of urban nature and ecosystem services as explanatory variables. The baseline in this model represents the value of the peri-urban areas and the ecosystem service variables set to zero, which may capture 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 is similar to that in model 1. Concerning ecosystem services, lower values than the baseline 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. It should be realized that this negative coefficient does not mean that these services are negatively valued; it means that these services are valued lower than the baseline of excluded ecosystem services in our model. 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 specification is that it can be used to estimate values for combinations of nature types and ecosystem services.[11] 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 aims to provide. However we need to note here that at the moment coefficient values obtained from model 2 are sensitive to using different specifications of the model, especially concerning the types of ecosystem services included in the estimation. Therefore, we do not yet advise value transfer applications based on model 2.

Our database has a relatively large number of observations (81) from Europe, which allows us to estimate a regional value function for Europe, using a similar model specification as for model 1. The model for the European sub-sample (Model 3) 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 outside the city centers in urban periphery, which contextually justifies merging these two types of nature. The results for the European model are presented in Table 5. Also this model has a good model fit, as is evident from the adjusted-R2 of 0.815 as estimated with this model's OLS equivalent. AIC is 309. 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 (0.836), which reflects the large amount of variation that also in the European studies is attributed to the authorship of original studies included in the meta-analysis.

The model estimates show that average WTP values per nature type are higher, and they 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 combined with small urban green are substantially higher in Europe compared to the global average (with factor 5 up to 6, respectively). For blue nature, forests and peri-urban sites the European model-based average values are also above the global average values, but the differences are in the range of a factor 2 up to 2.5. The higher average values of nature within the European sub-sample can be expected because the average income level is higher in Europe compared to the global average. The differences in relative valuation of different types of urban nature are most probably attributed to the specific preferences of the European population for urban parks and urban green connected to grey infrastructure. For instance, these types of nature may be relatively scarce in European contexts. It is important to realize, however, that the model based on the European sub-sample (Table 5) has a lower statistical power compared to the global models (Table 4) as far as the types of nature are concerned due to the smaller sample size.[12] 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 traditional contingent valuation method.

Table 5
Meta-regressions results of the value of nature in cities dependent on spatial, methodological and study variables as well as type of nature for Europe only.

	MODEL 3 Coeff.	Std.err.		Average WTP value of nature types (2016 USD per ha per year)
Constant	8.005	1.118	***	
<u>Spatial and study variables:</u>				
Area (ln)	−0.937	0.125	***	
GDP (ln)	1.496	0.581	***	
Population density (ln)	0.201	0.090	***	
<u>Methodological variables:</u>				
Choice experiment	4.041	1.472	***	
Tax	−3.424	0.409	***	
<u>Type of nature:</u>				
Forest and peri-urban (baseline category)				$ 2995
Park	2.402	1.691		$33,093
Small urban green &Green connected to grey	0.837	1.671		$ 6914
Blue	0.107	0.837		$ 3334
Multiscape	−0.807	2.615		
<u>Variance components:</u>				
Level 1 (estimate) variance	0.992	0.240	**	
Level 2 (author) variance	6.681	2.812	**	
<u>Estimation statistics:</u>				
N value observations	81			
log likelihood	−142			
AIC	309			

***,**, * stands for statistical significance on the 1%, 5% and 10% level, respectively.

4. Value transfer: functions and applications

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 5: namely, a function for nature types derived from the global and European data (models 1 and 3, respectively). These functions can directly be applied to specific nature types, accounting for local circumstances. The global value function (equation 2) and European value function (equation 3) are given by:

$$\text{Value of nature per hectare per year} = \exp(7.718 - 0.964 \times (\ln(\text{Area}) - \ln(1474)) + 1.527 \times (\ln(\text{GDP}) - \ln(23{,}026)) + 0.241 \times (\ln(\text{Density}) - \ln(396)) + 1{,}900 \times \text{Choice experiment} - 2.723 \times \text{Tax} + 1{,}674 \times \text{Park} + 0.059 \times \text{Forest} - 0.144 \times \text{Small urban green} - 0.589 \times \text{Green connected to grey} + 0.221 \times \text{Blue} + 0.231 \times \text{Multiscape}) \quad (2)$$

and

$$\text{Value of nature per hectare per year} = \exp(8.005 - 0.937 \times (\ln(\text{Area}) - \ln(472)) + 1.496 \times (\ln(\text{GDP}) - \ln(28{,}007)) + 0.201 \times (\ln(\text{Density}) - \ln(211)) + 4.041 \times \text{Choice experiment} - 3.424 \times \text{Tax} + 2.402 \times \text{Park} - 0.837 \times \text{Small urban green \& Green connected to grey} + 0.107 \times \text{Blue} - 0.807 \times \text{Multiscape}) \quad (3)$$

Note that in equations 2 and 3 the respective average ln values are subtracted from the ln variables area, GDP and population density because these variables are centered. Because the dependent variable is measured in natural logarithms we take the exponent (exp) of the value on the right hand side of the equation.

Here, we illustrate the application of equations 2 and 3 to a few nature intervention sites in cities in Europe that are part of a European Urban Nature Atlas database *(*www.naturvation.eu/atlas*)*. The green projects were chosen so that these would include a major intervention and redesign of urban grey or neglected space into green space (see Table 6 for brief project descriptions). While most projects provide

[11] 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.

[12] In this respect it is important to note that the multiscape nature type only appears six times in the European database. Hence, this negative insignificant coefficient is not reliably estimated. Future research can reexamine the value of multiscape urban nature in Europe once more primary valuation study observations become available.

Table 6
Application results of value transfer meta-functions based on models 1 and 3 on actual nature-based solutions from the European Urban Nature Atlas (https://naturvation.eu/atlas).

Project name	Zaragoza (ES) Green Corridor- North	Timişoara (RO) Greening of the Bega channel	Essen (DE) Krupp Park	Toulouse (FR) Grand Park Garonne
Brief project description[a]	The Green Ring North is presented as a series of connections extending the ring and network of green spaces in Zaragoza. The two main axes of the ring are the Ebro and Gallego rivers.	The greening project which aims at cleaning and revitalizing the Bega channel (not revitalized since 1945) on a distance of 44 km, in order to improve water quality, increase economic activities, recreation and avoid floods.	The former site of the Krupp cast steel factory was transformed into a green belt stretching from the city center to the district of Altendorf, with the adjacent industrial wasteland turned into a park.	The Grand Park Garonne urban project aims to rehabilitate and develop the banks of the river Garonne that runs 32 kilometers through the city.
Total project costs (2016 USD)[a]	$11,259,551	$19,101,124	$6,853,933	$32,247,191
City characteristics:				
Area (ha)	29	175	241	3000
GDP per capita (2016 USD)[b]	$29,020	$12,737	$47,291	$43,597
Population density [c]	56	81	2816	215
Social value estimates based on model 1 (global data VTF)				
Value per ha per year (2016 USD)	$472,923	$25,817	$330,764	$13,829
Total value, per year (2016 USD)	$13,620,184	$4,517,970	$79,714,065	$41,485,759
Social value estimates based on model 3 (European data VTF)				
Value per ha per year (2016 USD)	$367,658	$21,272	$229,030	$11,365
Total value, per year (2016 USD)	$10,588,550	$3,722,578	$55,196,313	$34,094,586

[a] Source: European Urban Nature Atlas (https://naturvation.eu/atlas). Used prevailing exchange rate: 1 EUR = 089 USD.
[b] Source: Eurostat (https://ec.europa.eu/eurostat/web/products-datasets/product?code=demo_r_d3dens).

various types of urban green and blue spaces, for the ease of comparison, we assumed that resulting interventions can be classified as parks. Availability of information on the total project costs was another criterion considered in order to facilitate comparison of costs to estimated social benefits. Moreover, the cities were chosen in a way that it enables exploring the application of value transfer functions to value a park in different urban contexts, such as with varying levels of income, population density and the size of the urban park. We stress that these examples were selected purely to illustrate the application of the value function and to provide an impression of the variation in estimated values across the various contexts. We have added data on income (regional GDP) and population density per city, which can be found in Table 6.

Zaragoza (Spain) has the lowest park area size, income level and urban density of the selected cities. Essen (Germany) has the highest income level, almost four times that of Timişoara (Romania). Population density is highest in Essen with 2816 persons per km2, which is ten times that of Toulouse (France) with 215 persons per km2. An important feature for economic valuation of urban parks is its size. The sizes in our selected cases vary between 29 ha (Green Corridor North in Zaragoza) and 175 ha (Greening of the Bega channel in Timişoara) to 241 ha (Krupp Park in Essen) and 3000 ha (Grand Park Garonne in Toulouse). Table 6 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 as described above.

The highest value of almost $473,000 per ha is obtained for Zaragoza, which has a total value of the site of $13.6mln per year based on the global data. Value transfer based on the European function predicts $367,700 per ha with a total value of $10.6mln per year.

The second highest value is obtained for Essen, namely $330,800 per ha based on the global data, which has the highest total value almost $473,000 per ha per year due to the large size of the site. Value transfer based on the European function predicts $229,000 per ha with a total value of $55.2mln per year.

The greening of the Bega channel in Timişoara is valued at $25,800 per ha based on the global value function, and at a total of $4.5mln per year. The value based on the European meta-function is just below $21,300 per ha per year, resulting in total value of $3.7mln per year.

The grand park Garonne in Toulouse is valued at $13,800 per ha per year with the global meta-function, which is the lowest per unit value, and at a yearly total value of $41.5mln for the entire site. Here, the estimate based on the European meta-function reaches $11,400 per ha with a total of $34.1mln for the site, per year.

The application of the value transfer functions as above results in a number of observations. First, substantial differences exist in the estimated values per ha for the four selected cases. Some of the estimated values are relatively high, however not unrealistic. Comparing the estimated total social benefits of urban parks (yearly amounts) to the project costs (see Table 6), we may notice that in cases of Zaragoza, Essen and Toulouse the total project costs were about or even below the total yearly social value created by these interventions. In case of Timişoara, project costs would pay off in 5 or 6 years (for the global or European-based estimates, respectively, and assuming a 3% discount rate).

Second, differences in estimated social values are due to a combination of contextual factors affecting the value of urban nature. For example, while Zaragoza had about an average GDP level and below average density, the high value of its green corridor is mainly due to the much below average area size which drives the value upwards. The high value of the Krupp park in Essen is due to the combination of three factors: i.e. relatively to the sample average, a low area size, high GDP per capita and high population density, all of which have a positive effect on the obtained monetary value. For the Bega channel case of Timişoara, the positive effect of a relatively low area size was countered by a relatively low population density and income level, resulting in a per ha value that is somewhat below the European average for a park site. In case of the Grand Park Garonne in Toulouse, with average population density and above average GDP level, the area size has a major downward effect on the park's monetary value, which is markedly below the European average of $33,000.

Third, in all illustrative cases as above the estimated values are higher when the global function was applied, compared to the estimates based on the European meta-function. The differences range between 121% and 129% for Zaragoza, Timişoara and Toulouse, and 144% for Essen. Theoretically, the European meta-function should be preferred for applications to European cases, because it closer approximates the similarity of contexts (see Bergstrom and Taylor, 2006). However, analysis of predicted values for studies from our sample applying the global and European-only value functions has shown a twice as high root mean square error for the European function compared to the global function. This provides evidence in favor of using the global value transfer function from current meta-analysis also for European applications.

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 that is quantified based on context-specific characteristics.

5. Discussion

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 infrastructure 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.

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 from 60 primary studies conducted worldwide.

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 (see Table 7). With regards to ecosystem services Brander and Koetse (2011) 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.

Comparing the results of our meta-analysis to other meta-analyses, we find a similar positive effects of population density in Brander et al. (2006) and Zandersen and Tol (2009). Besides, most meta-analyses also find a decreasing marginal returns to scale effect for area size (Brander et al., 2006; Zanderson and Tol, 2009), with the exception of Barrio and Loureiro (2010) who find evidence of constant marginal returns. The evidence on income effects in turn prove to be mixed. Generally, meta-analyses using stated preference valuation studies find positive income effects on the willingness to pay (Johnston et al., 2017; Brander et al., 2006; Barrio and Loureiro, 2010), which supports a hypothesis that nature is a normal good. However, evidence from meta-analyses that use insight from revealed preference studies do not find a significant association between income and WTP such as Brander and Koetse (2011) in a meta-analysis on values of urban open space obtained from hedonic pricing studies, or even find a negative income effect such as Zanderson and Tol (2009) in a meta-analysis on forest recreation values obtained from travel cost studies. The latter would in fact support a hypothesis that nature is an inferior good, meaning that as income rises, better-off households tend to be willing to pay less, and therefore consume less, of public nature, allegedly substituting it by paying more for private natural outdoor and recreational arrangements. Respondents to state preference surveys may oversee this effect and therefore overstate their WTP for public nature or its services, which would lead to more pronounced income effects in meta-analyses on stated preference values (Bouma and Koetse, 2019).

Even though our study is an improvement of earlier work, it has a number of limitations that are worth mentioning here. The attribution of ecosystem services to a specific site is to some degree uncertain, because not all studies explicitly value specific ecosystem services. This has directly to do with the aim of valuation, which in some cases reflect valuation of ecosystem services, but may also relate to valuation of a specific site per se, or urban challenges to which nature can provide an answer. Ecosystem services can alternatively be extracted from the description of the study, like we do here but this approach is an approximation which may result in biases. A more robust value transfer function can alternatively be obtained from models based on the type of urban nature which can be defined in a more direct way. This is why for value transfer purposes we advise to use such models, like models 1 and 3 in this paper, out of which model 1 is a preferred model due to its lower error in extrapolation. Moreover, it should be realized that our value transfer functions are estimated using primary valuation studies of urban nature that mainly have a large area size. For instance, our sample includes only 3.4% of observations with an area size of less than 10 ha. This implies that value estimates for nature with area sizes below 10 ha may be unreliable, since in those cases extrapolations are made that are beyond most of our sample observations.

Another limitation is the determination of the number of potential users of urban nature. Not all primary studies record this information, in which case we assumed it equals the total urban population of the location valued in the primary study, while this is important for the valuation outcome. For example, a small park would assumedly have a more local effect from which mainly a local population benefits, while a major urban park would probably be of benefit for many inhabitants as well as visitors of a city. Although our analysis accounts for population density and the size of nature, it is advisable to authors of primary studies to provide a best estimate of affected population which will allow for a better inclusion of this variable in future meta-analyses.

Table 7
Comparison of average values of urban nature between our estimates (models 1 and 2) and Brander and Koetse (2011).[a].

	Average WTP value (global model 1) (2016 USD per ha per year)	Average WTP value (global model 2) (2016 USD per ha per year)[b]	Average WTP value Brander en Koetse (2011) (2006 USD per ha per year)
Type of nature:			
Peri-urban nature[c]	$2249	$1728	$8955
Park	$11,992	$19,317	$14,765
Forest	$2386	$2674	$1556
Small urban green	$1948	$3533	
Green connected to grey	$1248	$956	
Blue	$2805	$3103	
Estimation statistics:			
N value observations	147	147	125

[a] in estimating all average WTP values, all continuous dependent variables are at their sample average and all dummy variables are set to zero.

[b] average WTP values obtained from model 2 were computed with ecosystem service dummies that were not included in Brander and Koetse (2011) set to 1. This was done to approximate the value function specification in model 2 which includes a broader range of ecosystem services to the specification of Brander and Koetse (2011), which only accounts for the effects of preservation, recreation and aesthetics.

[c] In Brander and Koetse (2011), specified as Agricultural and undeveloped land. In our sample, extended by golf courses and thus renamed into peri-urban nature as it is usually located on the urban fringe.

6. Conclusion

In this study we present an up-to-date meta-analysis of the value of urban nature in order to estimate value transfer functions. By assessing the primary studies that valued urban nature worldwide we obtain insights into the main determinants of variation in 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. A hierarchical multilevel estimation methodology is applied, which accounts for the variance component that arises from author level characteristics of WTP values obtained from primary valuation studies.

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, of which more is desired to be consumed in monetary terms as income increases. Population density can be considered as a proxy for nature scarcity in an urban context, and is significantly positively related to values of urban nature. This reflects 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 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 examples of value transfer have found non-trivial values of urban nature for four parks in different European cities.

Finally, 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 value transfer functions. Our sample contains sufficient observations for estimating a European value transfer function, but at the moment insufficient primary valuations studies are available from other regions to estimate reliable value transfer functions for those regions. Future research can update these functions, and extend them with more estimates of local functions when more primary valuation studies become available. This can allow 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 various regions in the world.

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