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Benefit-Cost Analysis of Green Infrastructure Investments: Application to Small Urban Projects in Hinesville, GA

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1. INTRODUCTION

While built infrastructure has played a central role in modern societies for millennia, nature-based, or green, infrastructure has only gained modern prominence in the past several decades. The emergence of green infrastructure as a tangible management option is due to the recognition of a number of tacit and explicit values, including the limits of conventional built infrastructure, the economic and social costs of lost ecosystem services associated with land conversion and development, and the risks of climate change. The emerging significance of green infrastructure stems from an evolving understanding of the diminution in ecological services due to loss of natural assets and reduced adaptative capacity of natural systems to respond to environmental change (Benedict and McMahon 2002). Lost ecological services have resulted from the conversion of natural systems, interruption of ecological process and function, fragmentation of the connectivity of green spaces, and degradation of soil, air, and water (Steffen, Crutzen, and McNeill 2007).

Green infrastructure investments include large scale public works, like maintenance or restoration of wetlands, dam removal and waterway rehabilitation, offline water storage, and sediment management measures (like prevention of soil erosion or beach and dune enhancement). These types of projects often entail sizable financial investments and involve multiple jurisdictional authorities. Other aspects of green infrastructure can be implemented on smaller scales by municipalities, households, or businesses; these include construction of bioretention ponds; urban agriculture, trees, and parks; green roofs, green walls, rain gardens, and rainfall harvesting; and use of permeable pavement or other investments to improve water infiltration, runoff flow reduction, and natural hydrologic function (Wise, et al. 2010). Augmenting and protecting green infrastructure can provide an array of socio-economic benefits, some of which are conventional (e.g., protecting roadways from intermittent or chronic flooding) and others that are less conventional (e.g. improvements in biodiversity, recreation, and aesthetics; enhancements in micro-climate and urban temperature regulation).

In this paper, we use existing meta-analysis results for an international sample of green infrastructure projects to value ecological benefits of green infrastructure investments in coastal Georgia. While our application is a local US study, our methods have broader implications for benefit-cost analysis of green infrastructure investments, more generally. Focusing on our study site, the short coastline of Georgia exhibits a wide array of development patterns and environmental conditions; four of the fourteen barrier islands are densely developed tourist destinations, and the rest are largely preserved through public ownership or perpetual legal protection. Savannah and Brunswick are regional urban hubs, many small towns dot the landscape, while most other areas are still relatively undeveloped and bucolic. Due to lack of widespread development pressure and significant management efforts, the Georgia coast is home to almost 40% of the extant salt marshes along the US east coast. Despite the preservation of extensive green infrastructure features, however, many developed areas and urban centers are located in low-lying and low-relief areas that are threatened by rising sea levels and intensifying precipitation patterns. Similar risks are found across the globe. To better understand how green infrastructure practices can be effectively integrated into human development to enhance the resilience of these developments and to protect the larger-scale green infrastructure benefits of local ecological systems, we investigate the economic efficiency of proposed site-scale green infrastructure elements in the City of Hinesville, Georgia.[1]

Community-driven planning efforts were conducted by the City of Hinesville and the local development authority, in collaboration with Georgia Department of Natural Resources and University of Georgia’s Carl Vinson Institute of Government. Results of public input highlighted interest in redeveloping the city’s central downtown green space, Bradwell Park, as well as a desire to leverage available resources to make use of that redevelopment to increase the community’s resilience to stormwater flooding and protect the downstream environment. The design team incorporated a series of small-scale green

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[1] This analysis is part of a regional effort to enhance community resilience in Coastal Georgia, in part through the use of green infrastructure practices, which is being funded by National Oceanic and Atmospheric Administration (NOAA) Office of Coastal Management and led by the Georgia Coastal Management Program at the Georgia Department of Natural Resources, Coastal Resources Division.

infrastructure elements into a conceptual redevelopment plan, which was then built into a preliminary design plan by the city engineer.

This paper conducts benefit-cost analysis to explore the net economic benefits of small-scale urban green infrastructure designs, in which development or redevelopment opportunities are utilized to enhance the use of natural systems in the built environment. As is typical with these types of projects, detailed cost estimates are derived in scoping and assessment of planned project elements. Benefit estimates, which are typically more difficult to derive, are recovered from a meta-analysis of urban green infrastructure projects (Brockarjova, Botzen, and Koetse 2020), which we tailor to our study site. We conduct sensitivity analysis with regard to a number of factors (discount rate, benefits measures) and find that green infrastructure investments in Hinesville, GA are welfare-enhancing, producing positive net benefit between $738,312 to over $5.5 million (under a range of plausible benefit scenarios). Benefit-to-cost ratios range from 4.8 to 30 and are robust to substantial cost increases. Our paper demonstrates how to make similar calculations for projects in other locations.

The rest of paper is organized as follows. Section Two presents a background discussion on the use of green infrastructure and review relevant literature. Section Three provides details on projects planned at the study site. Section Four introduces the methods utilized to estimate benefits and costs, while Section Five provides an overview of our results. Section Six offers discussion and conclusions.

2. BACKGROUND AND PREVIOUS LITERATURE

Green infrastructure investments typically center around improvements in hydrological flow and function, but can also provide enhancements in vegetation, soil quality and quantity, habitat, recreation opportunities, and aesthetics. For example, preservation and restoration of green spaces and use of permeable paving materials are very helpful in decreasing the risk of flash floods since these physical alterations intercept rainfall and improve water penetration into soil and substrate. Controlling for precipitation level, urban areas with impervious ground cover (50-90%) can absorb 13-60 percent of rainfall, whereas forested area can absorb 87 percent of rainfall (Kaye, et al. 2006; Pataki, et al. 2011). Aside from flood control, restoration of urban wetlands can improve water quality, increase recreation opportunities, enhance aesthetics, and conserve biodiversity (Zhou, et al. 2013). Green spaces, roofs, and walls reduce the urban heat island effect, decrease ambient temperatures, can decrease energy needs, and cut carbon emissions (Akbari 2002; Nicholson-Lord 2003; Gill, et al. 2007).

Improvements in ecological services may also enhance human health status and decrease mortality (Maas, et al. 2006; Mitchell and Popham 2008), while providing habitat for animals and improving biodiversity (Fuller, et al. 2007). A deep literature review on property values reveals that real estate prices increase with proximity to green areas (Brander and Koetse 2011), with green space being particularly valuable in urban areas, but less so in rural areas (where such natural amenities are already plentiful) (Kriesel, Mullen, and Dorfman 2010). In addition, property values decrease due to flood risk (Bin, Kruse, and Landry 2008; Samarasinghe and Sharp 2010; Rambaldi, et al. 2012), though the effect of flood risk depends upon frequency of flooding and other market dynamics (Hallstrom and Smith 2005; Carbone, Hallstrom, and Smith 2006; Bin and Landry 2013; Atreya and Ferreira 2015).

In assessing potential investments in public projects to promote green infrastructure, the economic practice of benefit-cost analysis (BCA) can provide helpful guidance to inform decision makers whether the economic value of investments justify the economic costs. From an analytical perspective, important characteristics of green infrastructure investments and adaptation to climate change include ubiquity of impacts, intangibility of some effects, the prevalence of non-marginal changes (i.e. discrete, potentially large changes in levels of amenities or risk), potentially long timeframes, and uncertainty (Sussman, et al. 2015). These difficulties interact with conventional challenges, such as valuing non-market effects, assessing low-probability/high-impact outcomes, and choice of an appropriate discount rate (Sussman, et al. 2015). Moreover, since most adaptation measures cannot eliminate climate and weather risks, analysts must often contend with residual risk in assessment of green infrastructure measures (Neumann, et al. 2011).

Li, Mullan, and Helgeson (2014) review recent developments and applications of BCA with implications for climate risk management and adaptation decision making. They find that BCA has been used mostly to conduct project-based appraisals, with much less focus on evaluating adaptation decisions. Challenges related to BCA for climate change adaptation include long-time frames of analysis, the importance of intangible effects, and the need to grapple with Knightian uncertainty (i.e. situations in which probabilities are unknown, and perhaps unknowable, at least within the time frame relevant to decision making) (Sussman, et al. 2015). Uncertainty may be particularly great at the regional and local levels, precisely where many adaptation actions take place. Use of BCA for assessment of green infrastructure investments must recognize the approaches formulation on individual/household welfare as a basis for decision making and appreciate the distinction between efficiency and equity (Sussman, et al. 2015). Given these complexities, Li, Mullan, and Helgeson (2014) recommend BCAs of climate adaptation-relevant decisions that employ multiple analytical methods, due to the complexity of adaptation decisions and the diversity of adaptation measures and decision-making contexts.[2]

Elmqvist, et al. (2015) assess monetary and non-monetary benefits of investments in green infrastructure in terms of improvements in urban landscapes, social welfare, biodiversity augmentation, and urban resiliency. Green infrastructure provides urban ecosystem services in habitats such as parks, urban forests, cemeteries, vacant lots, gardens and yards, campus areas, and stormwater retention ponds. They highlight the ecological, social, and economic advantages of investing in urban green infrastructure. Using benefit transfer (described in detail below), one can assess the economic impacts of urban woodlands and green spaces on stormwater flows and pluvial flooding (Xiao, et al. 1998; McPherson 2003) and the recreation and amenity benefits they create (Pataki, et al. 2011).

Kousky and Walls (2014) investigate the benefits and costs of preserving floodplains as a flood mitigation strategy along the Meramec River in St. Louis County, Missouri. They estimate the opportunity costs (loss of development or other land-use that would have occurred absent preservation), avoided flood damages, and the capitalization of proximity to protected lands into nearby home prices. To estimate avoided flood damages, they undertake a parcel-level analysis using the Hazus-MH flood model, a GIS-based model developed for FEMA that

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[2] Sussman, et al. (2015) suggest the use of Robust Decision Making (RDM), which uses Monte Carlo simulations to stress-test competing policies against scenarios that are most relevant for success. This approach is particularly relevant for analyses that involve stochastic outcomes (prevalent in study of climate change) and applications in risk management.

couples hydrology and hydraulics models with a damage model relating flood depths to property values. Kousky and Walls examine the distribution of damages across parcels, demonstrating that careful spatial targeting can increase the net benefits of floodplain conservation. In addition, they estimate a hedonic property price model, and findings indicate that increased property values for homes near protected lands are more than three times larger than the avoided flood damages, stressing the continued importance of traditional conservation values. The proximity benefits alone exceed the opportunity costs; avoided flood damages further strengthen the economic case for floodplain conservation.

Cooper, et al. (2016) conduct BCA for construction of an earthen berm in the Meadowlands Region in Bergen County, New Jersey. The project is designed to mitigate flood risks associated with coastal storms. Th authors consider life cycle costs of the project, including land acquisition, upfront construction, restoration of wetlands, creation of recreation zones surrounding the berm, and ongoing maintenance. Project benefits include preserving life, preventing residential and commercial damages, protecting conventional infrastructure systems (transportation, power, water), and mitigating debris removal expenses. Incidental benefits include recreational and health impacts and ecosystem services from wetlands, which are assessed using benefit transfer methods. Aggregating and discounting benefits and costs over a 50-year time horizon, Cooper et al. (2016) incorporate climate change by increasing the risks of 100- and 500-year flood events; they find that the green infrastructure investment is welfare enhancing, with BC ratios exceeding 2 (4) for a 7% (3%) discount rate.

Vojinovic, et al. (2017) conduct BCA for green and grey (i.e., conventional) infrastructure options for areas with existing cultural heritage assets. They demonstrate how the intersections of flood protection, education, art/culture, recreation, and tourism can be incorporated in economic analysis for selection of multifunctional measures for flood resilience. They stress the importance of stakeholder involvement and conceptual landscape design in achieving ecologically sustainability and social acceptability in managing flood risk in areas with cultural heritage. Likewise, Alves, et al. (2018) propose a framework for the selection of green infrastructures based on a co-benefits analysis. The aim is to include the achievement of co-benefits and human well-being into decision-making for flood management and incorporate stakeholders’ perceptions to define the most important benefits to be enhanced.

De Groot, et al. (2013) make ten recommendations to encourage the utilization of existing knowledge and to improve the incorporation of ecosystems into policy, planning, and funding for coastal hazard risk reduction. Zhou, et al. (2013) address climate change adaptation and extreme rainfall in urban areas by evaluating benefit and costs of four adaptation projects; they conclude that integration of open drainage basins in an urban setting is the best adaptation strategy compared to stormwater pipe enlargement and investments in small scale infiltration improvements.

While monetary aspects of infrastructure enhancement projects are often apparent, nonmarket effects (e.g. protecting human health, promoting recreation on public lands, providing ecosystem services) are typically much more nebulous. Physical models and simulations can be used to assess changes in service provision, but valuation usually requires additional data collection. A cost-effective alternative is to use extant studies and results to conduct benefit transfer: "the adaptation of existing value information to a new context" (Rosenberger and Loomis 2017).

Critical to our empirical approach is a recent meta-analysis conducted by Brockarjova, Botzen, and Koetse (2020). They utilize value transfer functions from 60 empirical studies (encompassing over 40,000 observations) focused on economic value of urban green infrastructure projects across all six inhabited continents (with a majority in Europe, North American, and Asia). Their regression approach utilizes a standardized measure of WTP as the dependent variable and controls for determinants of urban green infrastructure values, including characteristics of the study and methods, types of investments, location and size of projects, and ecosystem services as independent variables (Brockarjova, Botzen, and Koetse 2020). They find, for example, that urban parks produce annual economic values between $12,000 and $33,100 per hectare (US), and urban forested areas produced annual economic values between $2,250 and $3,000 per hectare (US). We describe their methods & results in detail below, but first discuss our study site.

3. STUDY SITE AND PROJECTS

Hinesville is the county seat and largest city in Liberty County, Georgia. Liberty County is located on the Atlantic Coast, though the city of Hinesville is approximately 25 miles inland. It is located on an ancient dune ridge that elevates it above much of surrounding terrain, and its downtown urban center encompass the headwaters for the coastal creeks that drain the area. This location provides some protection from coastal flooding and storm damage compared with other coastal communities, but it also means that stormwater runoff and other development impacts can affect larger parts of the coastal ecosystem. See Figure 1.

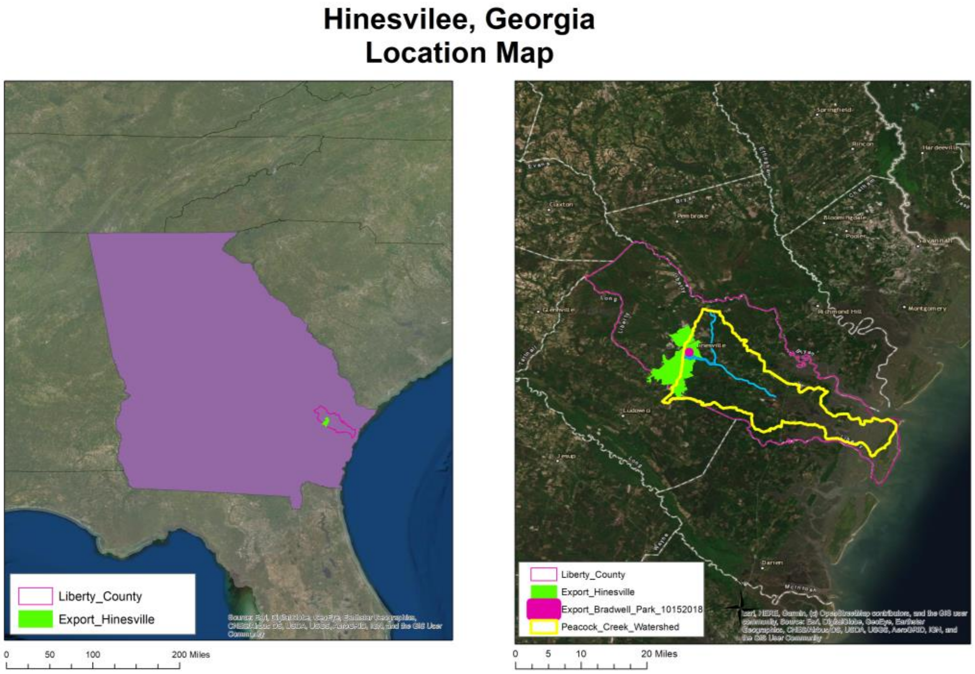

Figure 1: Location of Liberty County; Hinesville, GA; and lower watershed

The population of Hinesville was 33,437 at the 2010 census and is estimated to have declined slightly since then. It covers 18.24 square miles (47.24 square km), and thus has a population density of 1,809.4/sq mi (698.6/km^2). The median household income was $35,013 in 2010, with a median income of $27,135

($20,813) for single males (females). The per capita income for the city was $14,300. About 13.8% of families and 14.8% of the population were below the poverty line, including 20.9% of those under age 18 and 12.3% of those age 65 or over. Thus, Hinesville is less dense and less wealthy than many larger coastal cities in the US.

The specific site for the green infrastructure interventions is Bradwell Park in downtown Hinesville. The park is an approximately one-half acre public space located amidst municipal and commercial developments. It is immediately adjacent to the Hinesville City Hall, the Liberty County administrative offices, a regional bank, as well as restaurants, shops, and office buildings. It is one of the primary public spaces in the city, and it hosts the weekly farmers market, festivals, concerts, and other public events. The green infrastructure redevelopment plan calls for a complete renovation of the entire park and the streets that surround it, entailing installation of 7,956 square feet of green space, mostly composed of bioswales and tree planting, but also including pervious pavers, drainage improvements, and rain gardens. Figure 2 provides an artist rendition of improvements in the project area.

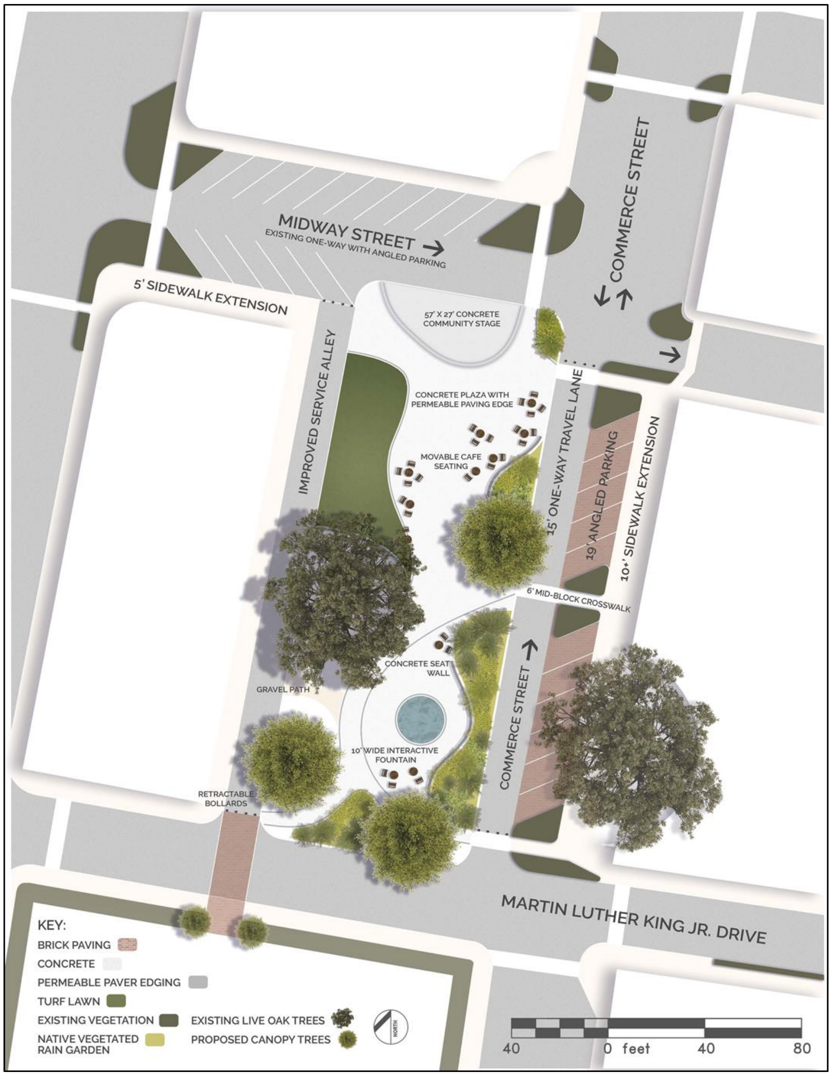

Figure 2: Green Infrastructure Projects in downtown Hinesville, GA

4. METHODS

Economic assessment of green infrastructure investments in Hinesville/ Liberty County is built upon the economic concept of the “Hicks-Kaldor” compensation criterion, which stipulates that a policy or project presents a potential “Pareto Improvement” if the gains from the policy could be redistributed amongst all parties (those that gain and those that lose) so that no party is worse off (Bateman and Kling 2020). In practice, this principle is typically applied as benefit-cost analysis (BCA). BCA is conducted by: 1) Clearly describing the project under consideration and any necessary assumptions that are needed to analyze the project; 2) Identifying relevant beneficiaries and others that will be affected by aspects of the project; 3) Carefully identifying all the negative (costs, inputs, and undesirable outcomes) and positive (benefits, outputs, and desirable use of residuals [e.g. recycling waste or utilizing something that would otherwise be discarded, inducing cost]) aspects of a particular project; 4) Empirically estimating [or in some other way simulating or approximating] social values of inputs/costs and outputs/benefits; 5) Identifying and documenting limitations of value estimates and intangibles or things that cannot be valued; 6) Keeping track of particular groups of "winners" and "losers" from project (to permit assessment of equity); and, finally 7) Comparing benefits to costs [net difference or ratio] and conducting sensitivity analysis to assess how robust results are to assumptions and uncertainties (while keeping account of intangible effects and equity issues). This approach to policy analysis is widely applied in the public sector and has been endorsed by numerous Presidential Executive Orders: 12044 (Carter), 12291 (Reagan), 12866 (Clinton), and 13563 (Obama).[3]

The project under consideration is fine-scaled and place specific, so our analysis is focused on estimated project performance and cost metrics. Beneficiaries of these investments are residents of Liberty County; we recognize that, in addition, the project may have spillover benefits for visitors and may enhance tourism (which we currently note as an unquantified benefit). In evaluating benefits and costs, we use engineering estimates of the quantities and value of inputs (materials, land, labor), and identify project outputs (stormwater flows, overflow reductions, and aesthetics) associated with stormwater management, aesthetics, and provision of green spaces in downtown Hinesville. The benefits of such investments can include: 1) reduction in nutrient pollution in waterways; 2) improvements in groundwater recharge; 3) stormwater storage and conveyance; and 4) provision of greenspace. These benefits are the basis of our willingness-to-pay (WTP) assessments; WTP is a theoretical monetary measure of the change in household or individual utility (or satisfaction) associated with

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[3] President Trump's "one-in-two-out" executive order did not embrace the use of BCA and even went so far as to tout cost reductions in regulatory removal without accounting for loss in benefits that such a policy might also create (Bateman and Kling 2020).

provision of some private or public good (Johnston, et al. 2020). We assess WTP using benefit transfer measures based on the results of a meta-analysis performed by Brockarjova, Botzen, and Koetse (2020).

The greatest limitation of benefit transfer is that value estimates are not specific to the population (residents of Liberty County) or projects (small-scale urban infrastructure) under study. The advantage of applying meta-analysis, however, is that descriptive variables can be used to tailor the results to the population and project under study. (More on this below.) For our application to Liberty County, a review of stakeholders' positions and inputs did not identify any specific groups that stood to lose from the projects under study. Thus, we forego any analysis of equity issues.

4.1 Assessing Benefits using Meta-Analysis

Synthesizing an extensive set of project evaluation data, Brockarjova, Botzen, and Koetse (2020) are able to standardize measures of economic value for urban infrastructure investments, and they use meta-regression analysis to explore the variation due to observable factors (like project type, size, location), while employing statistical methods to control the influence of unobserved factors that vary across studies. Their data set includes value functions from 60 economic studies that utilize responses from over 41,000 subjects. The primary equation of interest is given by:

$$WTP_{ij} = \alpha + \beta^{S} X_{ij}^{s} + \beta^{ED} X_{ij}^{ED} + \beta^{ESS} X_{ij}^{ESS} + \mu_j + \varepsilon_{ij} \qquad (1)$$

where WTP_{ij} is the annual value of urban green infrastructure, per hectare (in 2016 USD); the subscript i indexes the value observation (first level), and subscript j indexes the study (second level). Thus, the regression model is multi-level and controls for unobserved study level influences by imposing a hierarchical structure on the error terms (μ_j associated with study j and ε_{ij}, which is observation specific).

The multi-level modelling approach does not require independent and identically distributed residuals; study level fixed effects permit deviations in the mean, while clustered standard errors permit study-specific heteroskedasticity. The vectors X account for socio-economic, site, and study characteristics (S); type of urban infrastructure investments (ED) [*mutually exclusive characterization*]; and the character of ecosystem services engendered by the project (ESS) [*not mutually exclusive*]. The α term is the regression intercept, and the β are coefficients that are statistically estimated based on information from 58 studies (thus, $j = 1$ to 58) and 147 observations ($i = 1$ to 147). In estimation, Brockarjova, Botzen, and Koetse (2020) transform their covariates into centered logarithms[4] and natural log-transform the dependent variable (*WTP/hectare*). Thus, WTP_{ij} in equation (1) is actually $\ln[WTP_{ij}/hectare]$, and the continuous, strictly positive X variables are expressed as $\ln\left[X_{ij}\right] - \ln\,[\bar{X}]$, where $\bar{X}$ is the mean of variable X across all i, j observations.

Model diagnostics indicate statistical significance of the hierarchical variance structure, which supports the model specification (Brockarjova, Botzen, and Koetse 2020). Quasi R-squared for the two primary models are 0.660 and 0.699, suggesting high explanatory power. Overall, Brockarjova, Botzen, and Koetse (2020) find a highly significant and positive constant term (α), which, given their specification, reflects the average value of urban green infrastructure across all projects in their dataset. This amounts to $2,246 per hectare, per year (model 1 – controlling for population size). They find that economic values for green infrastructure are increasing in per-capita GDP and population density, while the value per hectare is decreasing in project size (indicating an increasing, but concave relationship between economic value and land area). They find larger values for urban parks, smaller values associated with recreation services, but larger values stemming from cultural assets. They also find effects related to economic valuation methods—larger values for use of choice experiments and negative effects associated with using tax as the payment vehicle.

Following Brockarjova, Botzen, and Koetse (2020), we use their meta-regression results to estimate economic benefits of urban green infrastructure in

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[4] Centered logarithms are derived by natural-log transformation of continuous variables and taking differences from ln-transformed means of the entire meta-dataset.

Hinesville, GA (noting that this approach can be used in many empirical contexts, in which costs are estimated but benefits are difficult to value). We utilize their parameterized model, fitting the estimates to characteristics of Liberty County and attributes of the proposed investments in downtown Hinesville. The results are presented in Tables 1 and 2. Multi-level meta-regression model coefficient and standard error estimates are presented in the first two columns (with * indicating statistical significance). Except for the intercept term and dummy variables, the regression models are based on natural-log deviation in means, so to transfer values to a project site (in our case, Hinesville), the analyst must multiply the model coefficient ("Parm" in column 1) by the difference in natural-log covariates values (e.g., ln[*area of Liberty County*] – ln[*average area in BBK meta-analysis study*]). This procedure applies only to positive, continuous variables (area, GDP, population density); the intercept term and dummy variables in the regression models contribute in levels (as oppose to natural logs).

The benefit transfer estimates are derived as:

$$\widehat{WTP}_{Hinesville} = e^{\beta' X} \tag{2}$$

where

$$\beta' X = 7.718 - 0.964 \times [\ln(1) - \ln(1474)] + 1.527 \times [\ln(14300) - \ln(23{,}026)] + 0.241 \times [\ln(698.62) - \ln(396)] - 0.144$$

Equation (2) shows how the base value of green infrastructure is adjusted from the mean value from the meta-analysis (represented by the constant term 7.718), based on natural-log differences in project size,[5] GDP per capita, and population density, in addition to an adjustment for project type (in our case,

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[5] In predicting WTP for small urban green infrastructure, we utilize a single acre in equation (2) and scale the measure by project size. Justification and details are provided in the next section.

coefficient on small urban: -0.144).[6] The third column in Table 1 presents means from the meta-analysis dataset, while the fourth columns indicates the contribution to the estimate for WTP for the Hinesville project. The contribution to estimated WTP is calculated as regression coefficient multiplied by difference in natural logs, plus intercept and parameter (in our case) for small urban,[7] as depicted above. The exponential of the sum of terms in column four produces an empirical estimate of $1,222,605 per hectare of green infrastructure. Note, this value estimate controls for Liberty County population, county income, and project type ("small urban green"), but does not account for project size (addressed below).

Table 1: Meta-regression Model 1 for Green Infrastructure: Hinesville, GA

	MODEL 1				**Hinesville**
	Parm	**SE**		**Mean**	**DEVIATION**
Constant	7.718	0.502	***	1	7.718
					0
Ln (area)	-0.964	0.101	***	1474	7.03308861
Ln (GDP)	1.527	0.358	***	23026	-0.7274086
Ln (pop density)	0.241	0.07	***	396	0.13681395
CE	1.9	1.063	*	0.218	
Tax	-2.723	0.726	***	0.299	

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[6] Assessing different project types would utilize other coefficients in Tables 1 and 2.

[7] While "park" is a category of ED project, the categories are mutually exclusive, and "small urban" better fits the subject of our analysis.

Park	1.674	0.693	***	0.048	
Forest	0.059	0.705		0.408	
Small Urban	-0.144	1.639		0.054	-0.144
Green-grey	-0.589	1.502		0.095	
Blue	0.221	0.836		0.163	
Multi	0.231	0.808		0.156	
Var(L1)	0.959	0.213	**	**E[WTP]**	$1,222,605
Var(L2)	7.033	1.466	**		

Note: stars indicate statistical significance level in meta-regression:

* = 10%; ** = 5%; *** = 1%

Table 2 presents results from Bockarjova, et al. (2020) Model 2, which includes covariate effects for ecosystem services (*ESS* – not mutually exclusive). As indicated in Table 2, this meta-regression model controls for classes of ecosystem serviced identified by the empirical analysts, namely: climate regulation, noise reduction, flood regulation, biodiversity/ habitat, recreation, aesthetics, and cultural value. In doing so, Model 2 permits adjustments in the average value of urban green infrastructure for the presence or absence of the services identified in the valuation exercises that comprise the meta-analysis dataset. Results suggest negative adjustments for climate regulation, noise reduction, flood regulation, biodiversity/habitat, and recreation, and positive adjustments for aesthetics and cultural value. Following best practices in sensitivity analysis, we first estimate benefit transfer values using only the coefficients in Model 1, then add the additional effects introduced by Model 2.

Table 2: Meta-regression Model 2 for Green Infrastructure: Hinesville, GA

	MODEL 2				**Hinesville**
	Parm	**SE**		**Mean**	**DEVIATION**
Constant	8.093	0.92	***	1	8.093
Ln (area)	-0.952	0.09	***	1474	6.94553979
Ln (GDP)	1.414	0.338	***	23026	-0.6735794
Ln (pop density)	0.24	0.072	***	396	0.13624626
CE	1.741	1.003	*	0.218	
Tax	-2.612	0.751	***	0.299	
Park	2.414	0.906	***	0.048	
Forest	0.437	0.816		0.408	
Small Urban Green	0.715	1.41		0.054	0.715
Green-grey	-0.591	1.248		0.095	
Blue	0.586	0.757		0.163	
Multi	0.542	0.749		0.156	
Climate reg	-0.301	0.525		**E[WTP]**	$4,058,024
Noise reduction	-1.093	0.793			
Flood reg	-0.464	0.728			

Biodiversity/habitat	-0.138	0.491			
Recreation	-1.35	0.581	**		
Aesthetics	1.174	0.799			
Cultural	1.22	0.598	**		
Var (L1)	0.992	0.217	**		
Var (L2)	5.746	1.416	**		

Note: stars indicate statistical significance level in meta-regression:

* = 10%; ** = 5%; *** = 1%

We first ignore the estimated ecosystem service effects, but utilize the coefficient estimates of Model 2 that parallel Model 1; this benefit calculation is the the same calculation presented in equation (2), but from a different regression model that controls for ecosystem services (though we don't take those differences into account, initially). For our application to Hinesville, Georgia, the new value estimate is $4,058,024 per hectare. Again, this estimate adjusts for project size, per capita GDP, and population density, while accounting for the small urban nature of the investment, but not ecological services produced. Turning to Table 3, we introduce the additional coefficient estimated by Model 2 to account for ecosystem services engendered by the project. Based on consultation with project personnel, we include climate regulation, noise reduction, flood regulation, biodiversity/habitat provision, and aesthetics in our estimation procedures. The estimated per-hectare value is $1,783,711. Thus, the range of estimates from the models of Bockarjova, Botzen, and Koetse (2020) indicate that a hectare of small-urban green infrastructure in Liberty County, Georgia will generate economic benefits ranging between $1.223 million and $4.058 million per year (2016 US dollars). This procedure can be applied to many locations across the globe to assess standardized benefit estimates based on best available economic data.

Table 3: Meta-regression Model 2 for Green Infrastructure: Hinesville, GA

	MODEL 2				**Hinesville**
	Parm	**SE**		**Mean**	**DEVIATION**
Constant	8.093	0.92	***	1	8.093
Ln (area)	-0.952	0.09	***	1474	6.94553979
Ln (GDP)	1.414	0.338	***	23026	-0.6735794
Ln (pop density)	0.24	0.072	***	396	0.13624626
CE	1.741	1.003	*	0.218	
Tax	-2.612	0.751	***	0.299	
Park	2.414	0.906	***	0.048	
Forest	0.437	0.816		0.408	
Small Urban Green	0.715	1.41		0.054	0.715
Green-grey	-0.591	1.248		0.095	
Blue	0.586	0.757		0.163	
Multi	0.542	0.749		0.156	
Climate reg	-0.301	0.525			-0.301
Noise reduction	-1.093	0.793			-1.093
Flood reg	-0.464	0.728			-0.464

Biodiversity/habitat	-0.138	0.491			-0.138
Recreation	-1.35	0.581	**		
Aesthetics	1.174	0.799			1.174
Cultural	1.22	0.598	**		
				E[WTP]	$1,783,711
Var (L1)	0.992	0.217	**		
Var (L2)	5.746	1.416	**		

Note: stars indicate statistical significance level in meta-regression:

* = 10%; ** = 5%; *** = 1%

4.2 Censoring for Small Size Projects

The meta-regression model estimated by Bockarjova, Botzen, and Koetse (2020) uses a natural log transformation to capture decreasing average returns to project size. This is a common functional form and makes intuitive sense in this application if additional area provides additional benefits, but at a declining rate (which makes sense in many, but perhaps not all, applications).[8] One potential problem in using their results for benefit transfer, however, is out-of-sample predictions (i.e., smaller projects) that are not in the range of the data they use to estimate the meta-regression (Johnston et al. 2020). Unfortunately, the authors do not report the range of project sizes in the data that are utilized to estimate their model. In their original working paper, however, they conduct demonstrative benefit transfer for project sites in Europe; part of this analysis includes forecasting benefit measures for a project that ranges from 1 to 27 hectares. This

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[8] The authors do not report exploration of other functional forms, and the models they present exhibit high external validity.

gives us confidence that small-scale projects can be addressed with their data, but one additional potential problem remains.

For projects that are significantly less than a hectare (as is the case for our study site), the natural log transformation on project size suggests that per-hectare values are extremely large, approaching infinity as project size approaches zero! This is clearly an undesirable feature of the functional form. To remedy this problem, we employ censoring at project size of one hectare. To accomplish this, we create a piecewise transfer function that follows the estimates of Bockarjova, Botzen, and Koetse (2020) for project sizes between one hectare and infinity. But for project sizes below one hectare, we employ a linear function that maps from the origin to the meta-analysis estimate for one hectare (which varies between \$1.223 million and \$4.058 million in our transfer models). See Figure 3, which depicts the slope of the benefit transfer function for project size. Our assumption produces benefit transfer estimates that are defined as = [fraction of hectare]× [value of singe hectare GI].

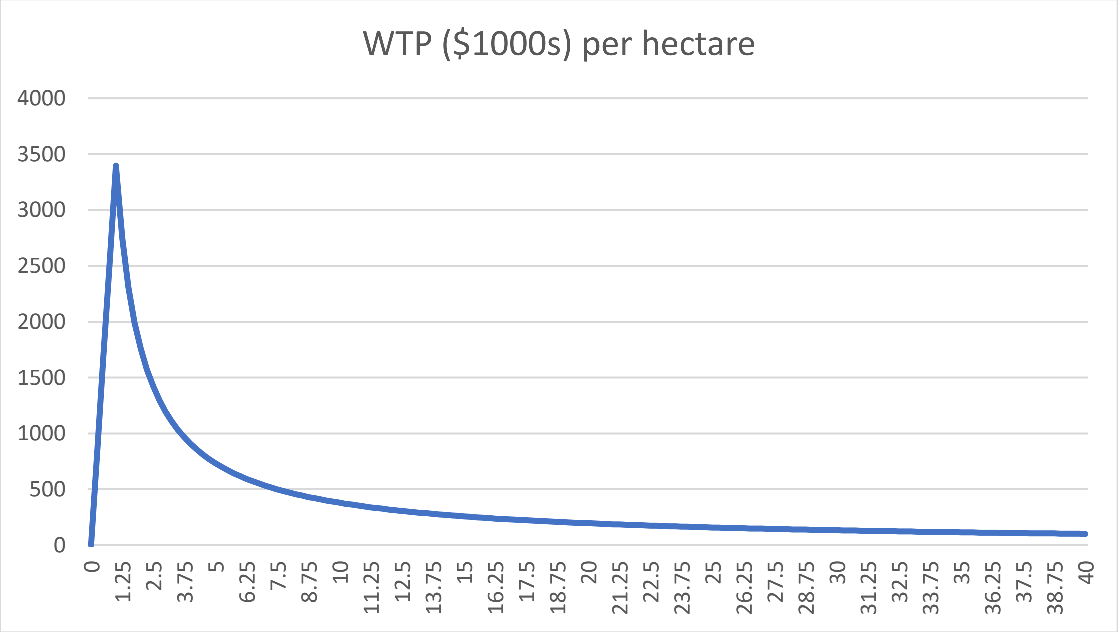

Figure 3: Meta-Analysis Value Transfer Function – WTP for Green Infrastructure (in \$1000s)

Thus, our project-size specific estimate for Model 1 is derived by multiplying the per-hectare value of Model 1 ($1.223 million) by the fraction of a hectare associated with the downtown Hinesville projects (0.0551) for a project estimate of $67,366 per year. Similarly, for the predicted benefits from Model 2, we estimate an annual value of $223,597 for downtown Hinesville ([0.0551]× [$4,058,024]) when ignoring ESS categories and an annual value of $98,282 for downtown Hinesville ([0.0551]× [$1,783,711]) when accounting for ESS categories: climate regulation, noise reduction, flood regulation, biodiversity/habitat provision, and aesthetics.

4.3 Assessing Costs of Green Infrastructure Investments

Project costs are typically derived during the process of planning and are somewhat easier to assess than economic benefits. The projected costs of the Hinesville urban green infrastructure projects are presented in Table 4. Major physical inputs include pervious pavers, rain gardens, bioswales, and improvements in drainage. The inputs also include educational components (signage and a kiosk). The subtotal for physical inputs is almost $146,000. Accounting for mobilization of capital inputs (1% of subtotal), engineering costs (10% of subtotal), educational programs, program monitoring, and contingencies (10% of subtotal), produces a total project cost of $211,655. In comparing benefits to costs, we assume a 50-year project life and apply discount rates of 3% and 7% (OMB Circular A-4, 2003).

Table 4: Projected Projects Costs for Green Infrastructure: Hinesville, GA

Item	Dimensions	Units	Unit cost	Cost
Pervious pavers	**2000**	**SF**	$24.00	$48,000.00
4" Underdrain indl stone bedding	**400**	**LF**	$55.00	$22,000.00
Rain Garden	**2516**	**SF**	$18.50	$46,546.00
Bio Swales	**720**	**SF**	$15.00	$10,800.00

Education Signage & Kiosk				$12,500.00
Conc containment Wall	**300**	**LF**	$20.50	$6,150.00
SUBTOTAL				$145,996.00
Mobilization		0.01		$1,459.96
Contingency		0.1		$14,599.60
Engineering		0.1		$14,599.60
Education Program				$20,000.00
Monitoring				$15,000.00
			TOTAL	$211,655.16

Note: SF = square feet; LF = linear feet;

5. RESULTS

We consider the results in Table 3 to be our best estimates of economic value, as they are the most comprehensive in terms of estimated effects, but we conduct sensitivity analysis utilizing other results (to test robustness of our findings). Project construction, contingency, and engineering costs are allocated to the current time period (t=0), while education and monitoring are amortized over a presumed project lifetime of 50 years (t=1 to 50). The benefit transfer estimate for green infrastructure investments apply to the first year after project completion and extend for entire 50 years (t=1 to 50). Benefit-cost estimates could be modified to account for more time necessary for project completion, but this is unlikely to affect the qualitative findings.

Table 5 presents an example of the benefit and cost calculations accruing over 50 years using our preferred benefit estimate ($98,282) and the present value of net benefits under a 3% discount rate. These results indicate net benefits over the project life of just over $2.329 million, a benefit-to-cost ratio of 12.69, and an internal rate of return (IRR) of 50%.[9] Applying a 7% discount rate to the same measures of net benefits, net returns are lower at $1.165 million, with a benefit-to-cost ratio of 7.09, and an internal rate of return of 45%.

Table 5: Benefit-Cost Analysis of Green Infrastructure Projects in Hinesville, GA

	Benefits	**Costs**	**Net Benefit**		**Benefits**	**Costs**	**Net Benefit**
0	$0	$176,655	-$176,655				
1	$95,419.42	$1,262	$94,157	26	$45,572.85	$139	$45,434
2	$92,640.21	$1,225	$91,415	27	$44,245.48	$135	$44,110
3	$89,941.95	$1,190	$88,752	28	$42,956.78	$131	$42,826
4	$87,322.28	$1,155	$86,167	29	$41,705.61	$127	$41,578
5	$84,778.92	$1,121	$83,658	30	$40,490.88	$124	$40,367
6	$82,309.63	$1,089	$81,221	31	$39,311.54	$120	$39,192
7	$79,912.26	$1,057	$78,855	32	$38,166.54	$117	$38,050
8	$77,584.72	$1,026	$76,558	33	$37,054.89	$113	$36,942
9	$75,324.97	$996	$74,329	34	$35,975.62	$110	$35,866
10	$73,131.04	$967	$72,164	35	$34,927.79	$107	$34,821
11	$71,001.01	$939	$70,062	36	$33,910.48	$104	$33,807
12	$68,933.02	$912	$68,021	37	$32,922.79	$100	$32,822
13	$66,925.26	$885	$66,040	38	$31,963.88	$98	$31,866
14	$64,975.98	$859	$64,117	39	$31,032.89	$95	$30,938

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[9] Internal rate of return is an financial metric that assesses profitability of investments; it can be conceptualized as the discount rate that renders a null net present value of investment net cash flows.

15	$63,083.48	$834	$62,249	40	$30,129.02	$92	$30,037
16	$61,246.09	$810	$60,436	41	$29,251.48	$89	$29,162
17	$59,462.23	$787	$58,676	42	$28,399.49	$87	$28,313
18	$57,730.32	$764	$56,967	43	$27,572.32	$84	$27,488
19	$56,048.85	$741	$55,307	44	$26,769.24	$82	$26,688
20	$54,416.36	$720	$53,697	45	$25,989.56	$79	$25,910
21	$52,831.42	$161	$52,670	46	$25,232.58	$77	$25,156
22	$51,292.64	$157	$51,136	47	$24,497.65	$75	$24,423
23	$49,798.68	$152	$49,647	48	$23,784.13	$73	$23,712
24	$48,348.23	$148	$48,201	49	$23,091.38	$70	$23,021
25	$46,940.03	$143	$46,797	50	$22,418.82	$68	$22,350
					$2,528,772.67	$199,252	$2,329,521

Note: this table uses the benefit estimates from Model 2

with ESS ($98,282) and a 3% discount rate

Table 6 presents the BCA results for the other benefit estimates applying the two discount rates recommended by OMB (2003) [3% and 7%]. Using the smallest benefit estimate from Bockarjova, Botzen, and Koetse (2020): Model 1 ($67,366), we find net benefits of $1.534 million under a 3% discount rate (BCR = 9.05 and IRR = 33%) and over $738,000 under a 7% discount rate (BCR = 4.86 and IRR = 28%). Alternatively, using the largest benefit estimate from Bockarjova, Botzen, and Koetse (2020): Model 2 ($223,597), we find net benefits of $5.554 million under a 3% discount rate (BCR = 30.06 and IRR = 119%) and $2.894 million under a 7% discount rate (BCR = 16.12 and IRR = 111%).

Table 6: Net Benefits of Green Infrastructure Projects in Hinesville, GA

Model	3% Rate	7% Rate
M1	$1,534,060	$738,312
M2	$5,553,846	$2,894,416
M2 w/ ESS	$2,329,521	$1,164,976

To further assess sensitivity of our findings, we explore doubling and tripling of cost estimates. If project costs were to double to $353,310 in construction and $30,000 in education and monitoring (amortized over 50 years), net benefits of small urban green infrastructure in Hinesville, Georgia amount to $2.134 million under a 3% discount rate (BCR =6.40 and IRR=23%). Under a 7% discount rates, net benefits of this scenario are just over $974,000 (BCR=3.55 and IRR=19%). Even if project costs were to quadruple ($706,620 in construction and $60,000 in education and monitoring (amortized over 50 years)), small urban green infrastructure yield positive net returns of $1,741,534 (BCR=3.21 and IRR=10%) under 3% discount rate and $593,694 (BCR=1.78 and IRR=6%) under 7% discount rate.[10]

6. DISCUSSION AND CONCLUSIONS

Small scale urban green infrastructure (nature-based solutions) provides for local ecological services that should be accounted for in project assessment. During the scoping and planning process, necessary inputs and project expenditures are routinely estimated to assess resource needs and project costs. Project benefits are often defined and explored, but extensive quantification and valuation of benefits

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[10] All of the cost sensitivity results use the preferred (middle) benefit estimate of $98,282 from Model 2 with ESS.

is sometimes beyond the expertise of project planners and often out of scope of the project budget. Original research to assess benefits usually requires primary data collection and analysis, which can be very expensive and time consuming and requires specialized expertise.

The process of benefit transfer provides a cost-effective alternative to primary analysis, but the quality of benefit transfer estimates is highly dependent upon available data, researcher expertise, project timing, and applied statistical techniques used to assess a given project (Johnston, et al. 2020). Benefit transfer approaches are generally classified as *unit-value* or *benefit function* methods;[11] the latter are generally seen as more flexible and robust and can make use of synthesis techniques like meta-analysis (or preference calibration)[12] (Johnston, et al. 2020). There is growing consensus of advantages associated with meta-regression that is estimated with a wealth of data and utilizes best practices in controlling for differences in empirical analysis that reflet project characteristics, study site attributes, and methodological aspects of individual studies (Boyle, et al. 2009; Kaul, et al. 2013; Johnston, et al. 2020).

For assessing economic benefits, applied researchers can utilize results of a meta-analysis for urban green infrastructure projects was recently published in the peer-reviewed journal *Ecological Economics* (Bockarjova, Botzen, and Koetse 2020). The analysis therein applies state-of-the-art methods to synthesize an extensive set of carefully culled existing value estimates and to specify an array of statistical models to predict economic benefits of ecological services. The authors comb the peer-reviewed, published literature for applied economic papers that use stated preference analysis (e.g., contingent valuation and choice experiments) to assess value of urban, local, or community investments in green infrastructure.

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[11] The *unit-value* method is a simple approach that takes a small number of existing value estimates (one or more) and applies them in a new context, sometimes with a limited amount of *ad hoc* adjusting (such as inflating for differences in income or cost-of-living among study and policy sites).

[12] The *preference calibration* approach specifies a theoretical structure for a decision model (e.g. utility, demand, or function) and makes use of existing studies to approximate the parameters of that function.

The resulting dataset includes 147 observations from 60 empirical studies utilizing information from over 40,000 survey respondents.

The meta-regression is well suited for benefit transfer; the authors account for size of the urban wetlands project, GDP of the population under study, and population density of the area. Each of these variables are included as differences in natural-log transformed means (see equation (2)). The meta-regression also includes a mutually exclusive accounting of project type: park; forest; small-urban project; green-grey; blue; or multiple; as well as non-mutually exclusive accounting of ecological services that the project is expected to produce: climate regulation; noise reduction; flood regulation; biological benefits/ habitat; recreation; aesthetics; and cultural. As such, the exponential transformation of the intercept term produces the average WTP per hectare in the dataset, and deviations from the mean can be predicted by plugging in study site descriptors (e.g., project size, GDP, and population density) and turning relevant dummy variables "on" (e.g., account for the "small-urban project" shift coefficient and any relevant ecological services expected in the project area).

We demonstrate how to apply these meta-regression results to assess green infrastructure projects by focusing on a proposed investment plan in coastal Georgia. Our study site, the city of Hinesville (located in Liberty County) is a small, somewhat bucolic town with a population of just over 33,000 (and metro area population of almost 78,000). Most of the population is in near vicinity of Hinesville, which sits on an ancient dune ridge that provides some flood protection for the city (and nearby US Army base Fort Stewart). The particular project under consideration entails a number of green infrastructure investments to improve a primary public site in downtown Hinesville. Situated amongst the City Hall, Liberty County municipal offices, and other commercial and retail buildings, Bradwell Park is an approximately one-half acre public space that hosts numerous events (farmers markets, festivals, concerts, etc.) and provides green space and natural amenities for the downtown area. The downtown and park are located in the headwaters of the coastal creeks that drain this part of the coastal plain; the low-lying area is vulnerable to pluvial, fluvial, and storm surge flooding, and runoff from Hinesville can affect large swathes of the surrounding coastline.

Planned green infrastructure investments for Bradwell Park entail installation of almost 8,000 square feet of green space, composed of bioswales, rain gardens, and tree plantings in new beds, in addition to use of pervious pavers and other drainage improvements. The project also entails redesign of traffic flow, pedestrian walkways, and parking facilities – all of which may create additional benefit. Our benefit-cost analysis is focused exclusively on the monetary costs and ecological service benefits derived from green infrastructure components. Using the meta-regression results of Bockarjova, Botzen, and Koetse (2020) permits prediction of economic benefits for urban green infrastructure investments; the commodity and context match our application well (Johnston, et al. 2020), and the approach we use could be applied in other, similar contexts across the globe. The small-scale of projects in Hinesville, nonetheless, require further adjustments. The scale of the planned projects is outside of the scope of the data utilized by Bockarjova, Botzen, and Koetse (2020), though the earlier working paper they produced (Bockarjova, Botzen, and Koetse 2018) indicates that their results can be used to predict value of ecological services for a single hectare, exhibiting confidence in forecasts on this scale.

The functional form of the meta-regression, however, as an exponential of difference in natural logs of project area, posits the marginal value of small-scale projects (less than one hectare) going to infinity as area goes to zero. This is clearly undesirable from a theoretical perspective and requires modification of benefit transfer function (Johnston, et al. 2020). We utilize a censoring protocol to address this problem, capping the marginal value at a single hectare and utilizing a linear translation from the origin for projects less than a hectare. (See Figure 3.) Nonetheless, the predicted benefits of small-scale projects we evaluate for Hinesville, GA (about 0.05 hectares) compare favorably to project costs (even when we inflate costs well above their predicated value).

Utilizing the middle estimate of project benefits (which we consider the most appropriate), we find net benefits ranging between $1.165 and $2.329 million (benefit-to-cost ratio (BCR) between 7.09 and 12.69), depending upon the discount rate. These estimates correspond with internal rates of return (IRR - a typical heuristic to evaluate the value of a variable stream of returns) of 45% to 50% percent – substantial rates of return that would entice commercial investors in droves. Even if project costs were to quadruple, small urban green infrastructure investments in Hinesville would produce expected net benefits of over half-a-million dollars or almost $2 million (depending upon the discount rate), with BCRs of 1.78 or 3.21 and IRsR of 6% and 10%, respectively.

Exploring robustness of benefit estimates derived from the meta-regression results, we consider other predicted values from Bockarjova, Botzen, and Koetse (2020) models. Utilizing their first set of regression results (Model 1: which ignores classification of ecological service provision), we find net project benefits ranging between $738,000 and $1.534 million (depending on the discount rate), with corresponding BCRs of 4.86 and 9.05 and IRsR of 28% and 33%, respectively. Alternatively, if we employ Bockarjova, Botzen, and Koetse (2020) Model 2 without invoking ecological service provision parameters, we find net benefits ranging between $2.894 and $5.554 million (depending upon the discount rate), with corresponding BCRs of 16.12 and 30.06 and IRsR of 111% and 119%, respectively.

Johnston, et al. (2020) review criteria for assessing accuracy and reliability of benefit transfer estimates, including (relevant to our application) content and construct validity. Content validity “focuses on whether the valuation method chosen, and all procedures used to implement it are conducive to measuring the *true* value.” (Boyle and Bishop 2019, pg. 564) [emphasis added]. Assessing content validity requires an understanding of the underlying economic and econometric theory, accumulated knowledge and experience of experts in the field, and previous findings in the literature (Boyle and Bishop 2019; Johnston, et al. 2020). Construct validity focuses on prior expectations of how economic values are related to other contextual variables and is typically assessed using statistical tests (Boyle and Bishop 2019; Johnston, et al. 2020).

The meta-regression results of Bockarjova, Botzen, and Koetse (2020) offer sound content validity for our application (and likely for many others). The meta-database includes peer-reviewed, stated preference (SP) valuation studies that are trained on urban green infrastructure investments in diverse locations across the globe. The peer-review process enhances the likelihood that underlying studies employed appropriate theoretical foundations and statistical techniques. In addition, SP studies offer the only known way to assess non-use value, which can be an important component of ecological services stemming from green infrastructure. For example, biodiversity and habitat benefits can have a substantial non-use component, implying there may be no observable behaviors that can be assessed to infer economic value. Also, some ecological services, like aesthetics, recreation, and culture, can provide vicarious use benefits (another type of non-use value), which is associated with values for other peoples' use. Thus, the meta-analysis of Bockarjova, Botzen, and Koetse (2020) exhibits favorable content validity in the context of globally diverse urban green infrastructure assessment.

While assessing construct validity of individual studies is beyond the scope of the Bockarjova, Botzen, and Koetse (2020) analysis, the authors' findings support overall construct validity in positive and statistically significant relationships among WTP (per hectare, per year) and population density and GDP and a negative and statistically significant relationship between WTP and area of green infrastructure investments. Economic theory suggests that urban ecological amenities should exhibit greater economic value when they are scarcer, which would be associated with greater population density. Similarly, theory predicts a positive association among wealth/income (proxied by GDP) and WTP. Lastly, many ecological services may exhibit diminishing marginal returns to size, which is implied by the negative coefficient on ln(area). Thus, the meta-analysis of Bockarjova, Botzen, and Koetse (2020) also exhibits favorable construct validity. Future applications to other locations should verify content and construct validity in their particular context (Boyle and Bishop 2019; Johnston, et al. 2020)

For our particular application, we find substantial evidence in support of small scale, urban green infrastructure investments in coastal Georgia. We not that our analysis does not account for potential tourism or other commercial benefits that investments in Bradwell Park could induce, thus our benefit measures likely do not capture the full array of positive economic aspects. Moreover, we do not foresee unanticipated costs or downsides from the proposed projects. Thus, benefit-cost analysis indicates that small urban green infrastructure investments in Hinesville, Georgia are economically efficient and worthy of further consideration.

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