Citizens' preferences on green infrastructure practices and their enhancement in Portland, Oregon

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Abstract

Green infrastructure (GI) has been gaining increasing attention due to its efficiency in controlling and purifying urban stormwater runoff, creating environmental amenities, and biodiversity conservation. Nevertheless, the existing knowledge of people's preferences for GI is not yet sufficient for evidence-based policymaking for enhancing GI. This study analyzes citizens' perceptions of the relative importance of six GI practices and estimates their willingness to pay (WTP) to enhance them. To this end, the study applies two types of stated preference methods (best-worst scaling and contingent valuation) to citizen survey data collected in Portland, Oregon. We found that GI practices that are more likely to lead to private benefits (e.g., rain barrels, urban trees) received relatively higher ratings, whereas the ratings of practices that do not offer such benefits (e.g., bioswales, rain gardens) were relatively lower. However, the diversity of preferences was large, as the relative importance varied widely among respondents. Heterogeneous preferences were also found in terms of citizens' WTP for hypothetical GI enhancement. Our comparison of uniform and variable payment schemes revealed that variable payment outperformed uniform payment because of the significant variation in citizens' WTP. The difference was large when the annual household payment was small.

Keywords: best-worst scaling; contingent valuation; green infrastructure; Portland; stated preference; willingness to pay

1. Introduction

Urban stormwater runoff is an ongoing major environmental concern. Runoff transports roadside pollutants such as bacteria, chemicals, and heavy metals with rainwater, causing various water pollution problems (Hu et al., 2010; LeFevre et al., 2015; Müller et al., 2020). Urban stormwater runoff also causes flooding, as heavy rains over short periods of time have become more localized in recent years. This frequency and the intensity of urban flooding have continued to increase with each passing year (Depietri et al., 2012; Miller and Hutchins, 2017).

In this context, green infrastructure (GI) has been receiving increasing attention worldwide. This trend has become even stronger in the US since the enactment of the Federal Water Infrastructure Improvement Act in 2019, which defines GI as "the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or surface waters" (Water infrastructure improvement act, H.R., 2018).

GI also outperforms existing gray infrastructure in economically controlling stormwater runoff. For example, the City of Indianapolis, Illinois, has saved more than $300 million by reducing the diameter of its planned new sewer pipes from 33 feet to 26 feet by using wetlands, trees, and downspout disconnections to reduce stormwater inflow to the combined sewer system (American Rivers n.b.; City Of Indianapolis, 2016). Similar examples can be found not only in the US, but also in numerous cities in the EU, Oceania, and Asia.[1]

[1] See, for example, Hansen et al. (2015), Neumann et al. (2011), and USEPA (2010) for case studies in differenet countries and regions.

Most GI projects rely on public funding. McGeehan (2014) reviewed 431 successful GI projects in 44 states across the US and found that 74% of them were implemented using public funds. Although this study was based on old data, the importance of public funds has remained the same, if not increased. It is essential to examine publicly funded GI projects from an economic perspective that explores not only their cost-effectiveness relative to conventional “gray” infrastructure but also their additional social and environmental benefits.

There is already a significant body of research on GI (see Haaland and van Den Bosch, 2015; Jayasooriya and Ng, 2014; Mell, 2017; Monteiro et al., 2020). Although studies that analyze GI from an economic perspective are relatively limited, they have been gaining increasing attention. The following section outlines some of the most relevant ones. For instance, Jayasooriya et al. (2018, 2019) proposed the elicitation of stakeholder preference through a rounded Delphi survey to identify the performance measures and obtain their weights for decision making. They applied this approach to GI in industrial areas in Melbourne. Vandermeulen et al. (2011) used the benefit transfer approach[2] to calculate the economic value of various GI benefits (recreation, health improvement, environmental improvement, and traffic risk reduction). Based on the estimates from the results of various studies, they calculated the total economic value provided by GI. They also conducted a cost–benefit analysis to determine whether the investment in GI matched its perceived economic value (Vandermeulen et al., 2011). Jaffe (2010) also illustrated the cost-effectiveness of GI and argued that it is economically better than conventional gray infrastructure even when

[2] Benefit transfer is a procedure for taking the estimates of economic benefits (or values in general) gathered from one site and applying them to another (Plummer, 2009). It is rarely the best choice for analyzing the economic value of a policy, but the costs of gathering primary, site-specific data have made it a common practice for studies of the recreational uses of natural sites (Rosenberger and Loomis, 2001).

only its direct costs and savings are taken into account (i.e., its social and environmental benefits are not considered).

While Jaffe's argument is interesting and could facilitate the popularization of GI, failing to consider the social and environmental benefits of GI may lead to its undervaluation, which would result in a failure to provide GI at economically desirable levels. To avoid this, it is critical to quantify the economic value of GI, both academically and practically. In this regard, Derkzen et al. (2017) estimated the economic value of GI by calculating citizens' willingness to pay (WTP) for GI measures using data from face-to-face surveys in the city of Rotterdam. They presented respondents with annual household tax amounts, which ranged from €0 to €40 per year, and asked them what level of tax they were willing to pay for new GI measures. They found that about two-thirds of the respondents were willing to pay for GI measures, and most respondents agreed that an annual tax of €15 per household would be acceptable. Baptiste et al. (2015) used face-to-face surveys in Syracuse, New York, to quantify respondents' willingness to implement GI projects under different hypothetical scenarios. They found that the key factors that affected citizens' willingness to implement GI were efficacy, aesthetics, and cost.

More recently, several researchers have applied discrete choice experiments (DCEs), a multi-attribute stated preference technique, to the valuation of GI. In typical DCEs, respondents are presented with a set of hypothetical GI scenarios consisting of related attributes, and then asked to choose the most preferred scenario among competing ones. By repeating the same questions under different attribute levels, researchers can derive the marginal WTP (MWTP) for each of the attributes that make up the GI. This technique has been applied to stormwater ponds (Ureta et al., 2021) and rain gardens (Meng and Hsu, 2019; Shr et al., 2019). DCEs are informative and respondents have multiple chances to express their preferences on valued goods or services.

If there is too much information, however, this advantage can become a disadvantage (OECD, 2018). Whether or not this is due to avoidance of such potential problem, all three of the above studies focused on the specific type of GIs and did not quantify preferences for different GI practices.[3] Understanding not only whether people prefer a particular GI but also what kind of GI they prefer is a necessary question for developing the GI on larger scales. In this sense, this study is expected to contribute to the literature by addressing this gap in previous studies. More specifically, our findings would help better understand the relative importance of citizens' WTP for GI practices and facilitate the popularization and implementation of such practices on a larger scale, which would resultantly benefit the environment and the citizens themselves.

Thus, the objectives of this study were to estimate (1) the relative importance of major GI practices and (2) citizens' WTP for GI enhancement. To accomplish these objectives, we administered an in-depth questionnaire survey to the general public in Portland and its surrounding three counties in Oregon in early 2020 (Figure 1). In total, 666 responses were collected and analyzed in this study.

[Insert Figure 1 here]

The city of Portland was a relatively early adopter of GI and has been using it since the 1990s as a means of managing stormwater and reducing combined sewer overflows (CSOs). Over a 20-year period from 1991 to 2011, the city invested a total of $1.4 billion into a CSO control program, in which the use of GI reduced the size requirements and cost of construction (City of Portland, 2015). Portland uses green streets, ecoroofs, trees, downspout disconnection,

[3] We also initially tried to evaluate different GI practices with DCE. However, a number of participants in the focus group discussions commented that the questions were too complex and difficult to answer with confidence. We therefore decided to use two stated preference approaches and combine them as proposed in this study.

bioswales, and other GI to slow stormwater runoff, reduce runoff volumes, protect water quality, and improve overall watershed health (City of Portland, 2021).

Because of its early adoption and external recognition, there are a number of previous GI studies in Portland (Chan and Hopkins, 2017; Church, 2015; Everett et al., 2018; Makido et al., 2019; Netusil et al., 2014; Shandas, 2015; Thorne et al., 2018). Among them, Netusil et al. (2014) used the hedonic price method to show that characteristics of green street facilities, such as facility size, coverage of tree canopy, and design complexity, influence residential property prices. Chan and Hopkins (2017) find significant correlations between sociodemographic factors and the placement of green streets and green roofs. They suggest that installing green infrastructure may contribute to additional social and economic benefits given its placement.

We believe that the contribution of this study to literacy is that it brings a new perspective in GI valuation. As noted above, while most previous studies have focused their analysis on specific GI practices, this study assesses the relative importance of various GI practices, and then estimates the value of enhancing them. Without imposing a significant burden on respondents, the study elucidates the value of GI practices from multiple perspectives and uses this information to conduct policy simulations. We also believe that our methodology and findings provide useful information for GI practitioners and make a certain contribution to the evidence-based GI promotions.

2. Methods

As mentioned in the previous section, our empirical model is a combination of two types of stated preference methods. The first model quantifies citizens' preferences (relative importance) with regard to six different types of GI practices using best–worst scaling (BWS). The second model estimates citizens' WTP for GI enhancement using the contingent valuation method (CVM). Technical information on these methods is provided in sections 2.2

and 2.3. A combination of the results of these models facilitated our discussion regarding public preferences for GI and its economic value. This section begins with a description of the questionnaire used in the survey conducted in three counties in Oregon, including the city of Portland. Then, we discuss the estimation methods used in the two models. Finally, we present a brief summary of the survey results and compare our sample with the population in the study area.

2.1 Questionnaire Design

To gain a detailed understanding of citizens' GI-related preferences, we developed a three-part questionnaire. It queried (1) the relative importance of GI practices, (2) the respondents' receptivity to hypothetical GI enhancement, and (3) the demographic characteristics of the respondents. We used the web-based Qualtrics survey tool to conduct our online survey.[4] We attempted to make it easy for respondents to respond to the survey on any device. A downloadable PDF version of the entire questionnaire was also made available.[5]

The first section consisted of a set of questions about the relative importance of GI practices. Although there are many different types of practices that fall under the GI category,[6] evaluating all of them would be inefficient and cumbersome. Therefore, through preliminary interviews with local residents and discussions with experts, we selected the following six GI practices that are particularly representative and effective for reducing urban stormwater runoff: (1) bioswales, (2) ecoroofs, (3) rain barrels, (4) rain gardens, (5) tree

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[4] https://www.qualtrics.com/

[5] The entire questionnaire is available for download at: https://is.gd/OR_GI_2020.

[6] USEPA (2021) identified the following 11 practices as GI: downspout disconnection, rainwater harvesting, rain gardens, planter boxes, bioswales, permeable pavements, green streets and alleys, green parking, green roofs, urban tree canopy, and land conservation.

boxes, and (6) urban trees.[7] These are indeed GI practices that are commonly found in the city of Portland and surrounding urban areas. Descriptions and illustrations of each practice were taken from the Delaware Department of Natural Resources and Environmental Control (2016). We comprehensively discuss how these practices were presented to respondents and how their relative importance was assessed in section 2.2.

The second section of the questionnaire concerned the public's receptivity to GI enhancement. We presented respondents with a hypothetical GI enhancement program and inquired whether they would accept the program and pay the proposed amount or reject it and not pay. We explained that, if realized, GI would be established primarily using the practices a respondent rated highly. The content of the GI enhancement program scenario and the estimation of respondents' WTP are described in detail in section 2.3.

The third section of the questionnaire identified the demographic characteristics of the respondents. In addition to general personal attributes such as race, age, gender, education, income level, and trust in others, we also asked questions about GI and natural disasters, which included querying the respondents' knowledge of GI, experience of natural disasters, and level of disaster preparedness. By comparing the collected information with census data, we verified whether our sample adequately represented the population of the study region. These processes are comprehensively outlined in section 2.4.

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[7] There are numerous studies on the effects of GI on stormwater runoff reduction; those include for bioswales (Anderson et al., 2016; Jiang et al., 2017), ecoroofs (Buccola and Spolek, 2011; Mentens et al., 2006), rain barreles (Jennings et al., 2013; Litofsky and Jennings, 2014), rain gardens (Dietz and Clausen, 2005; Yang et al., 2013), urban trees (Berland et al., 2017; Carlyle-Moses et al., 2020), and tree boxes (Ahmed and Borst, 2020; Geronimo et al., 2014). Please refer to these studies for more information on the effects of the six GI practices discussed in this study.

2.2 Relative Importance of Green Infrastructure Practices

As mentioned in the previous section, we quantified the relative importance of six major GI practices. The expected problem was that it would not be easy for the respondents to rank all of these practices. To avoid this difficulty, we used the BWS method to evaluate them in a statistically rigorous manner while being cognizant of the burden on the respondents.

BWS is an extension of the method of paired comparison to multiple choices that asks participants to choose both the most and the least attractive options or features from a set of choices. It is an increasingly popular way for academics and practitioners in social science, business, and other disciplines to study and model choice (Louviere et al., 2015). In case 1 BWS, which this study will use, respondents are asked to choose the best and worst items from a set of alternatives. By repeating this task multiple times with different alternatives, the relative importance of the items can be quantified. Louviere et al.'s (2015) work can be referred to for more technical details regarding BWS.

Figure 2 shows an example of the choice card used in our questionnaire. As this figure shows, each respondent was presented with four of the six GI practices and was asked to choose the most desirable (best) and least desirable (worst) practices. We repeated this question three times with different combinations, which was determined by the balanced incomplete block design (BIBD), with each of the six practices appearing the same number of times. The order of the items in each question was randomized to avoid any order effects.

[Insert Figure 2 here]

We resultantly identified the three best and four worst combinations from each respondent. These data were then applied to a discrete choice model to estimate the relative importance of each practice. Suppose that *N* surveyed individuals were asked to choose the most desirable (best) and the least desirable (worst) GI practices from *T* choice cards (Figure 2). An individual's decision to choose a certain practice from amongst various practices can be modeled using utility maximization by choosing one contract among various alternatives (McFadden, 1973). Following the random utility theory, we assume that the utility of individual n (n =1,…, N), when choosing an alternative j as best and k as the worst from J number of alternatives ($j = 1, \dots, J$) in the t^{th} choice ($t = 1, \dots, T$), U_{njkt}, is defined as follows:

$$U_{njkt} = \mu_j - \mu_k + \varepsilon_{njkt}, \tag{1}$$

where μ_j and μ_k are parameters that indicate the importance of practices j and k relative to certain practice that are normalized to zero for identification. We assume that the random disturbances (ε) are identically distributed among the alternatives and across the population. Assuming that the disturbances follow a Gumbel distribution, the probability that respondent n chooses an alternative j as best and k as the worst in the t^{th} choice takes the conditional logit (CL) form:

$$P_{nt}(jk) = \frac{\exp(\mu_j - \mu_k)}{\sum_{j=1}^{J} \sum_{k=1}^{J} \exp(\mu_j - \mu_k)}. \tag{2}$$

The CL model assumes that random errors are independent and identically distributed, and failure to meet this assumption violates the independence of irrelevant alternatives (IIA). IIA is a strong assumption and is often violated in reality. If the IIA assumption does not hold, the estimates from the CL model are biased and invalid. An alternative approach—the mixed logit (ML) model—relaxes the major limitations of the CL model, including the IIA assumption, by allowing for random taste variation, unrestricted substitution patterns, and correlation in unobserved factors over time (Train, 2009). In the ML model, the parameters are specific to each respondent and randomly distributed across the population with a density function $f(\mu|\theta)$, where θ is a parameter of the distribution of μ over the population.

Conditional on vector μ_n, the probability that respondent n chooses an alternative j as best and k as worst in the t^{th} choice is defined as follows:

$$P_{nt}(jk|\mu_n) = \frac{\exp(\mu_{nj} - \mu_{nk})}{\sum_{j=1}^{J}\sum_{k=1}^{J}\exp(\mu_{nj} - \mu_{nk})}. \quad (3)$$

Then, the unconditional probability of the observed sequence of choices is given by the conditional probability integrated over the distribution of μ:

$$P_n(\theta) = \int \prod_{t=1}^{T} \frac{\exp(\mu_{nj} - \mu_{nk})}{\sum_{j=1}^{J}\sum_{k=1}^{J}\exp(\mu_{nj} - \mu_{nk})} f(\mu|\theta)d\mu, \quad (4)$$

This unconditional probability is a weighted average of a product of logit formulas evaluated at different values of μ, with the weights given by the density function $f(\mu|\theta)$ (Hole 2007). This density function, which indicates respondents' preferences, is typically specified as a normal or lognormal distribution, $\mu \sim N(b, \sigma)$ or $\ln\mu \sim N(b, \sigma)$, where parameters b and σ are the mean and covariance of these distributions, respectively. Because equation 4 is not numerically solvable, the maximum simulated likelihood is commonly used to find the solution (Train, 2009). We used the Stata module *mixlogit* developed by Hole (2007) for the estimation.

2.3 Willingness to Pay for GI Enhancement

The following section explores respondents' preferences on voluntary payment program for GI enhancement. Specifically, we presented a GI enhancement program and a proposed payment and asked respondents whether they would accept or reject it. Figure 3 presents an example of a hypothetical question.

[Insert Figure 3 here]

In this hypothetical program (bond measure "Good Community Growth with Green Infrastructure"), the respondents' community is expected to experience improved GI, resulting in benefits such as reduction of flood risks, water quality improvement, air quality improvement, and biodiversity enhancement. We explained that the GI enhancement would be primarily based on the practices a respondent rated highly. The program was voluntary and required respondents to contribute a proposed amount per household per year if they were willing to pay for GI improvement in their community.

The proposed payment amount was randomly assigned, and respondents were offered either \$5, \$10, \$25, \$50, or \$100. This range of payment amounts was determined by feedback from participants in the focus groups. We collected binary responses from all respondents with respect to the GI improvement program. The resultant binary data were then analyzed to estimate the respondents' WTP using CVM.

CVM is a survey-based approach to nonmarket valuation. A contingent-valuation question carefully describes a stylized market to elicit information on the maximum a person would pay (or accept) for a good or service when market data are not available (Boyle, 2017). Although conventional CVM only derives the mean and median WTP over the entire sample, we propose a more sophisticated method to obtain the expected value of WTP for each respondent. This method has many advantages: it is relatively simple, is consistent with economic theory, and does not lose the simplicity of a CVM. We describe the technical details of our proposed methodology in the remainder of this section.

When viewed from an economic perspective, citizens' decision-making process with respect to whether or not they accept the bond measure to pay for GI enhancement can be viewed as one that is based on utility maximization. We present a model to predict the result of their decision-making process. Let u_i^c and u_i^a be citizen i's utility with and without a bond measure, respectively. If the utility with the bond measure is greater or at least equal to the other (i.e., $u_i^c \geq u_i^a$), then respondent i will accept the bond measure and pay the proposed annual household payment (R). Thus, the probability that respondent i accepts the bond measure ($\Pr(\text{Yes})$) can be modeled as follows:

$$\Pr(u_i^a - u_i^c \geq 0) = \Pr(R \leq \text{WTP}_i), \tag{5}$$

where WTP_i is the maximum amount citizen i is willing to pay for the proposed GI enhancement. Assuming citizens' decisions are binary (accept or reject) and the probability in equation (5) takes the logistic distribution, the cumulative density function of the WTP is defined as follows (Maddala, 1983):

$$F_i(R) = \Pr(\text{WTP}_i \leq R) \\ = \frac{\exp(X'\beta + R\gamma)}{1 + \exp(X'\beta + R\gamma)}, \tag{6}$$

where X is the vector of variables affecting citizen i's decision, and β and γ are the parameters to be estimated. Differentiating equation (6) with respect to R, we obtain the probability density function of the acceptance:

$$f_i(R) = \frac{\exp(X'\beta + R\gamma)}{[1 + \exp(X'\beta + R\gamma)]^2}. \tag{7}$$

By integrating equation (7) over R, we obtain the expected value of citizen i's WTP for the proposed GI enhancement.

$$E(\text{WTP}) = \int_0^\infty R \frac{\exp(X'\beta + R\gamma)}{[1 + \exp(X'\beta + R\gamma)]^2} \cdot \gamma dR \\ = \frac{\exp(X'\beta + R\gamma)}{1 + \exp(X'\beta + R\gamma)}\bigg|_0^\infty + \int_0^\infty R \frac{\exp(X'\beta + R\gamma)}{[1 + \exp(X'\beta + R\gamma)]^2} \cdot \gamma dR \\ = -\frac{1}{\gamma} \log\left(1 + \frac{1}{\exp(X'\beta)}\right). \tag{8}$$

Equation (8) is a simple but useful formula to calculate the WTP for any respondent-specific binary decision.[8] It can be easily estimated using the respondents' demographic characteristics and their estimated coefficients. To do so, we need to collect information relevant to the respondents' decisions, such as their individual characteristics, perception of GI, and payment decisions in the GI enhancement scenario. Because our payment scenario is

[8] By formatting the question as a receipt (e.g., grant or subsidy) rather than a payment, this equation can also be used to estimate the minimum level of acceptable payment. This is referred to as a willingness to accept (WTA) in economics.

hypothetical, we conducted a survey to obtain citizens' responses to hypothetical payments for GI enhancement in the study region.

2.4 Survey Overview and Sample Demographics

The survey was conducted in February of 2020. We outsourced the data collection process, which involved requesting individuals to participate in the survey, collecting their responses, to symmetric sampling.[9] Invitations were sent to 2,583 of the company's sample monitors, adult males and females residing in the state of Oregon. Among them, we received a total of 1,657 responses (response rate: 64 %). We excluded respondents who resided outside the study area and those who provided incomplete responses. As a result, we used a total of 666 responses for our analyses (valid response rate: 25.8 %).

Table 1 compares the sample to the population in the study area. The key attributes included racial composition; percentage of females, the elderly, and college graduates; average household size; and household income. Only the percentage of women was high—exceeding 60 % for all counties in the sample. It should be noted that the sample in this study tended to be slightly skewed toward women, as the ratio of men to women in the region is approximately 50/50. However, in terms of other attributes, the sample in this study reflected the characteristics of the three counties at a reasonable level.

3. Results

3.1 Relative Importance of Green Infrastructure Practices

Table 3 summarizes the estimation results for the conditional and mixed logit models. The value of the mean parameter represents the relative importance of the attributes. The

[9] https://www.symmetricsampling.com/

bioswales served as the baseline attribute for comparison. If the value of an attribute is positive (negative) and significant, it indicates that the attribute is more (less) important than bioswales. As Table 3 shows, all of the mean parameters were positive and significant, indicating that the respondents perceived all five GI practices to be relatively more important than bioswales.

[Table 3 about here]

Rain barrels (1.968) has the largest coefficient value among the GI practices, which suggests that it is the most preferred of the six practices evaluated in this study. This is followed by urban trees (1.835), tree boxes (1.416), ecoroofs (1.216), and rain gardens (0.689) in decreasing order of preference.

Next, we examined the standard deviation parameter (SD) and found that it was statistically significant for all practices. Table 3 indicates that there is significant heterogeneity in the respondents' preferences with regard to GI practices and significant differences in the relative importance that they ascribed to these practices.

By looking at the ratio of the mean parameter to the SD parameter for each attribute, we could compare the diversity in respondents' preferences. The most diverse preference is for rain gardens. Even though its mean parameter is the smallest among the five attributes, the value of its SD parameter is the largest. This indicates that rain gardens have the lowest relative importance collectively, but some respondents consider them very important. Tree boxes also have a large SD parameter in comparison to its mean parameter. However, the SD parameter values for rain barrels, urban trees, and ecoroofs are moderate despite their relatively high mean parameter values, which indicates that there is no notable diversity in respondents' preferences with regard to these practices. The implications of these results are discussed in detail in section 4.1.

3.2 Willingness to Pay for GI Enhancement

The left half of Table 4 summarizes the estimated coefficients and their standard errors of the logit model for whether respondents would support a proposed GI enhancement program. These coefficients are used to estimate the respondent's WTP (equation 8); however, because the logit is a nonlinear model, the coefficients cannot be directly interpreted (Scott Long, 1997). Instead of coefficients, odds ratios are often used to interpret the effects of variables. The odds ratio is a ratio of probabilities [in this context, the probability of accepting GI enhancement divided by that of not accepting GI, i.e., $\Pr(\text{Yes})/\Pr(\text{No})$], and it indicates how many times the odds change by a unit increase of the explanatory variable.

[Insert Table 4 here]

For example, the variable that is statistically significant and has the highest odds ratio is TRUST_NEIGHBOR (2.118). This indicates that respondents who trust their neighbors have about 2.1 times higher odds of accepting GI enhancement than those who do not. Similarly, the variables with relatively high odds ratios are UNPREP × DONTKNOW (2.009), KNOW_GI (1.990), and FLOODEXP (1.945). The model predicts that being unprepared for flooding and not knowing what to do, GI perception, and flood experience significantly increase the odds.

In contrast, the variable with the smallest odds ratio is UNPREP × GOVRESP (0.196). This indicates that the odds of respondents who are unprepared for a disaster and believe it is the government's responsibility are about 0.2 times lower than the odds of those who are not.

The other variable that decreases the odds are LOWINC (0.614) and PAY (0.990). Table 5 summarizes respondents' WTP for GI enhancement, calculated by applying the explanatory variables in the logit model (each respondent's real values) and their estimated parameters to equation 8. The average WTP for the 666 respondents in this study is $48.80, representing the maximum amount (per household) that they would be willing to pay annually for the GI enhancement program.

[Insert Table 5 about here]

As this table shows, the respondents' WTP varies significantly, with the respondents being willing to pay a minimum of US$5.30 while the maximum is $192.70. This indicates the diversity of their preferences, as some respondents are not willing to undertake even a small financial burden for GI enhancement, whereas others are willing to pay approximately $200 per household per year. Respondents from Multnomah County have the highest mean WTP value ($51.50), whereas those from Clackamas and Washington Counties have mean WTP values of $46.30 and $46.50, respectively.

Figure 4 shows a histogram of the distribution of calculated WTP. As indicated by the standard deviation of $31.50 in Table 5, the WTP of most respondents falls between about $17 and $90 per household per year. However, there are respondents with WTPs below or above that range, and the range of respondents with a particularly large WTP is significant, resulting in an asymmetrical and right-skewed distribution.

[Insert Figure 4 here]

Overall, the lower the WTP, the greater the range of preferences (variance of parameters), and the higher the WTP, the smaller the range of preferences.

4. Discussion

4.1 BWS and WTP

The BWS analysis revealed the respondents' preferences (relative importance) with regard to the selected GI practices. Overall, practices that provided direct benefits, specifically rain barrels and urban trees, were considered relatively important. For example, rain barrels provide a flood control function by storing rainwater, and households can use the stored rainwater to water their gardens, wash their cars, and so forth. In addition to the inherent benefits provided by rain barrels, these secondary benefits that the owners of the rain barrels receive could explain the relatively high preference for this practice.

The same is valid for urban trees. In addition to their technical hydrologic function as GI, urban trees provide various social and environmental benefits to nearby residents and passersby, including landscape improvement, air purification, noise suppression, and temperature control. These diverse secondary effects could explain why the relative importance of this practice was high. However, these benefits are not as direct as the use of harvested water. Therefore, the relative importance of rain barrels was higher.

Our results are consistent with those of Baptiste et al. (2015), which were presented in the introduction. Through a face-to-face survey in New York, they found that the key factors affecting citizens' willingness to implement GI are efficacy, aesthetics, and cost. Conceptually, it is quite easy to understand how rain barrels work, and its costs are significantly lower than those of other in-ground GI practices. Additionally, it goes without saying that urban trees are highly aesthetic.

Practices of lesser relative importance can be explained in the same way. Bioswales were found to be the least important practice. In Portland, bioswales have been constructed in an attempt to enhance the landscape and provide recreational areas for neighborhood residents. However, this practice is not visually appealing and primarily focuses on flood control and water purification. We believe that this focus on substantive functions has resulted in bioswales being viewed as less important than other GI practices.

Rain gardens were considered the second least important practice. Rain gardens also provide substantive benefits, but are more visually appealing than bioswales. The aesthetics of private rain gardens are generally focused on, but they do not provide many social benefits because they are on private property. We thus assumed that the relative importance of this practice would be lower, but still higher than that of bioswales.

These results indicate that, to deepen the public's understanding of GI, it is necessary to appeal to not only its technical functions, but also its secondary and tertiary social and environmental benefits and more direct cost-saving benefits. All practices offer varying degrees of direct benefits to citizens. However, the direct benefits of certain practices might not be fully recognized. Our knowledge of GI practices, including their public and private functions, is limited.

The BWS also indicated that the standard deviation parameter in the ML model was significant for all practices. As mentioned in section 3.1, the significance of this parameter implies that the relative importance ascribed by the respondents was heterogeneous (significant variation). In particular, when comparing the ratio to the mean parameter, the heterogeneity was highly pronounced for rain gardens and tree boxes. According to the mean parameters, these practices were of relatively low importance; however, some respondents rated them highly, indicating the existence of a wide range of relative importance.

The respondents' WTP is also found to be heterogeneous. As seen in Table 5 and Figure 4, the average WTP for GI expansion is $48.80. However, the minimum and maximum values vary widely from $5.30 to $192.70, indicating an asymmetric bell-shaped distribution.

This significant variation in WTP indicates that, if all citizens are asked to pay the same amount, the amount would be either too high or too low for most of them. If respondents are asked to pay more than their WTP, they will not participate voluntarily. Meanwhile, respondents who are asked to pay an amount lower than their WTP would accept it and participate, but they would have willingly paid more. Thus, determining the payment level is a highly sensitive issue, and it is an area where quantitative analysis and evidence-based decisions are particularly needed.

Lastly, Figures 5a to 5e plot the estimated WTP and relative importance of each respondent by practice. The bold horizontal lines indicate the estimated mean parameters. Owing to the heterogeneity of the relative importance of rain gardens and tree boxes, they have a wider range on the vertical axis. Although these practices are estimated to be relatively less important, there is a mix of respondents who rated them very low and high, resulting in a great deal of overall variability. While these are valid GI practices, tree boxes are an invisible, underground feature, and rain gardens in Portland are generally functionally oriented and lack aesthetic appeal.

[Insert Figure 5 here]

In contrast, practices that were estimated to be relatively important, such as rain barrels and urban trees, showed less variation in their ratings. As already mentioned, these practices provide direct benefits to citizens that are also easy to understand visually. These characteristics are thought to lead respondents to rate its value as a GI highly, and as a result, the variation in ratings was small.

Overall, the variability across all practices tends to be smaller for respondents with a relatively higher WTP. This is especially true in the case of rain barrels, urban trees, and ecoroofs, which are practices with relatively low variability. The variability of these practices appears to decrease beyond the mean WTP value ($48.80).

4.2 Policy Simulation

Finally, using citizens' WTP from the results of our second analysis, we conducted a policy simulation that examined the cost-effectiveness of two different payment schemes for GI enhancement. Each citizen's decision to accept and pay for GI enhancement was based on a comparison between their WTP and the amount proposed. In other words, if the amount proposed was equal to or lower than their WTP, they chose to accept; otherwise, they did not. As noted above, we used the citizens' WTP from the results of our second analysis. The proposed payment levels varied in $10 increments, up to a maximum of $100. This payment would be an annual payment per household and was identical to the hypothetical valuation method scenario used in the analysis in Model 2.

We set up two different payment schemes. The first payment scheme was uniform payment, in which all citizens who accept the proposed amount pay the same amount. This means that the amount paid was uniform regardless of the participant's WTP. The second scheme was variable payment, in which citizens who accept the amount proposed pay an amount equal to their WTP. This means that the amount paid is the participant's WTP and can be higher or lower than the proposed amount. The citizens targeted by the policy were the 666 respondents who were the sample for this analysis.

Table 6 summarizes the simulated results for the uniform and variable payment schemes. As the table shows, the lower the amount proposed, the higher the number of participants (the number of people whose WTP is higher than the amount proposed). In total, 643 participants (96.5%) out of the total 666 participants were willing to pay the lowest proposed amount ($10). At the maximum proposed amount of $100, the participation is at its lowest ($n = 54$; 8.1%). Note that the average WTP of participants also increases in direct proportion to the amount, as those with low WTPs would be excluded.

[Table 6 about here]

According to this policy simulation, the trends in the amount proposed and the total amount paid (revenue in the policy) differed strikingly depending on the payment scheme. Under uniform payment, the lower the offer, the smaller the total revenue. This is because all participants paid the lower offer uniformly. As the proposed amount increased, the total revenue also increased. The total amount paid was the largest at $40 per household, with 70.9% of the total sample participating. Thereafter, the revenue declined as the proposed amount rose. This is because the effect of the decrease in revenue owing to reduced participation was larger than the increase in the amount paid per household.

Under variable payment, participants paid an amount equal to their WTP, regardless of the amount proposed. Therefore, the total revenue was maximized when the proposed amount was $10, as most of the sample participated.

[Insert Figure 6 here]

Figure 6 translates Table 6 and plots the relationship between the amount offered and the total revenue generated from uniform and variable payments. As this figure illustrates, the total revenue from variable payments decreases as the amount proposed increases. However, it is still consistently higher than the uniform revenue at all amounts, thereby demonstrating the cost-effectiveness of this payment scheme. The difference between the two schemes is particularly pronounced when the offer is low, with the total amount of revenue from variable payments at $10 being approximately five times the revenue of uniform payments. However, the difference between the two schemes is not so pronounced when the proposed amount is high. The total amount of revenue under the variable payment at $100 is about 20% more than the uniform payment. This is because when the proposed amount is large enough, the number of citizens whose WTP exceeds it is small.

Considered as a real-world policy, a completely flexible payment scheme would be difficult to implement. There are two reasons for this: First, it is nearly impossible to estimate WTP for all citizens, and second, there are technical difficulties in implementing a completely flexible payment scheme. Nevertheless, this simple policy simulation provides two important implications. The first is that flexibility in payment schemes can significantly improve the cost-effectiveness of the policy for achieving targeted GI enhancement.

Conversely, uniform payment is quite inefficient and is not a desirable policy in this regard. Although we are discussing voluntary payment schemes here, the same could be said for mandatory payment schemes such as taxes.

For the above reasons, even if variable payments are introduced in practice, the scheme will not be completely flexible. In that case, the cost-effectiveness of the policy will be somewhere between uniform and variable, depending on the degree of flexibility. In other words, there is a tradeoff between ease of policy implementation and cost-effectiveness. This tradeoff will need to be considered more seriously when participants are relatively limited, because our simulation predicts that the difference between the two schemes will be larger when the number of participants is smaller.

Lastly, let us consider the case where, for some reason, we have no choice but to adopt a uniform payment scheme. As noted above, revenue in this scheme is maximized ($141,200) when the proposed payment is $40, but about 80% of the maximum revenue ($112,000) can be obtained even when the proposed payment is only $20. This is because the participation rate when the proposed payment is $20 (84.1%) is significantly higher than the level at $40 (50.3%), offsetting the difference in per household payment by having more citizens participate.

This implies that an enrollment program that uses an opt-out design would be most effective at maximizing revenue. The $20 per year contribution would likely be below most households' *de minimis* level, and requiring them to opt out rather than opt-in would maximize enrollment. The GI program could begin with low-cost and highly popular measures such as urban trees and rain barrels. As the program gains prominence and public support, the annual contribution could be increased at the rate of inflation or other justifiable amounts, which would facilitate the introduction of more effective but expensive practices, or further expansion of GI in the region.

5. Conclusions

This study analyzed citizens' perception of the relative importance of six GI practices and estimated their WTP to enhance them. To this end, the study applied two types of stated preference methods (BWS and CVM) to citizen survey data collected in Portland, Oregon. The BWS quantified the relative importance of the six popular GI practices. Then, the CVM estimated their WTP for hypothetical GI enhancement.

Our results present important policy implications. First, as described in earlier sections, the support for GI programs was strong and widespread in our representative sample. While the survey question was framed around a hypothetical voluntary GI program (and not a mandatory tax that might have lowered support), the mean WTP value was approximately $50 per year per household. The histogram in Figure 4 indicates that the mean value is skewed higher owing to large WTP values. Nonetheless, the minimum WTP value of $5.30 suggests strong minimum support. As far as where the revenue could be spent, the BWS indicated that rain barrels and urban trees were the most favored GI measures, possibly because of their salient private benefits. Conversely, bioswales and rain gardens garnered the least support from amongst the listed measures. The mixed logit model in Table 3 illustrates the significant heterogeneity in the distribution of preferences with regard to these lower-ranked measures.

Second, while GI provides clear public benefits in mitigating urban runoff, there was significant heterogeneity in the support for program funding. The support from respondents who indicated that they trust their neighbors was higher, and these respondents might be more likely to fund other types of public benefit programs as well. The respondents' experience with flooding, perception of GI, and rain gardens were also found to be quite important. GI programs that initially roll out popular measures such as rain barrels and urban trees would be more likely to get citizens to talk to each other about how the program benefits them.

Third, flexibility in payment schemes can significantly improve the cost-effectiveness of the policy for achieving targeted GI enhancement. As shown from the policy simulation, variable payment scheme outperforms uniform payment, but there is a tradeoff between ease of policy implementation and cost-effectiveness.

Although this study presents insightful findings, it also has certain limitations. First, this study was conducted in three counties in Oregon, so the results of the analysis are geographically limited. In addition, the city of Portland has a relatively advanced GI, and it is not clear whether the findings of this study can be applied to other cities where GI is not sufficiently widespread. Therefore, it is important to generalize the findings by expanding the scope of analysis and conducting similar analyses in other cities.

Second, this study could not fully consider respondents' place of residence. Although this was done in consideration of the privacy of the respondents, it presented some analytical challenges. Because the preferences and demands with regard to GI are expected to vary greatly depending on individuals' residential environment and exposure to existing GI, it is desirable to include the environment of the region where respondents live in the model along with the respondents' attributes. We would like to explore a form of survey that can capture more detailed location information without infringing on respondents' privacy.

Third, we used voluntary donations as payment vehicles in CVM. As Boyle (2017) suggests, in CVM, a donation payment vehicle could yield an underestimate of the value because voluntary instruments are not incentive compatible for estimating a respondent's full WTP. In this regard, there is a possibility that we may have underestimated citizens' WTPs. Even if this is the case, our results indicate that citizens have a significant level of WTP, and the possibility that the true level may be even higher is encouraging as we consider further expansion of GI in the region.

Fourth, and perhaps most significant issue, is that we analyzed GI using two different models. Ideally, the relative importance and WTP of GI measures should be estimated using a single framework. However, there are several GI practices, and querying the relative importance of each one and citizens' WTP for them would place too much of a burden on the respondents. We believe that the method used in this study produced reliable and meaningful estimates by combining two different analytical models. Nevertheless, a simple analysis of the multi-functional aspects of GI in a single framework is important for both academic and practical purposes. The development of such a method and the generalization of the quantitative analysis of GI are critical future tasks.

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Declaration of conflicts

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 1

Characteristics of our Sample and Study Region

	Sample				Study region			
	Clackamas	Multnomah	Washington	All	Clackamas	Multnomah	Washington	All*
Sample size and population	163	321	182	666	375,992	735,334	529710	1,641,036
(%)	(24.5%)	(48.2%)	(27.3%)	(100.0%)	(22.9%)	(44.8%)	(32.3%)	(100.0%)
% of white population	77.3%	73.5%	70.3%	73.6%	81.1%	69.1%	64.6%	70.4%
% of black population	3.7%	3.7%	2.2%	3.3%	1.2%	6.0%	2.5%	3.8%
% of hispanic population	8.0%	5.9%	11.0%	7.8%	9.0%	12.0%	17.1%	13.0%
% of asian population	4.9%	5.0%	9.9%	6.3%	4.9%	8.1%	11.7%	8.5%
% of female population	62.6%	65.1%	64.8%	64.4%	50.7%	50.5%	50.5%	50.5%
% of people aged > 65	11.0%	11.5%	8.8%	10.7%	18.8%	13.9%	13.9%	15.0%
% of college graduates and higher	31.3%	36.4%	40.1%	36.2%	37.4%	45.9%	44.4%	43.5%
Persons per household	2.8	2.6	2.9	2.8	2.6	2.4	2.3	2.4
Median household income (USD)	67638.0	58901.9	69299.5	63881.4	80484.0	69176.0	82215.0	75977.1

* Population weighted average for three Counties

Table 2

Descriptive Statistics of Variables (*N=666*)

Variables	Definition	Unit	Mean	S.D.	Min.	Max.
ACCEPT	1 if accept and pay for hypothetical GI development	Binary	0.56	0.50	0.00	1.00
PAY	Annual payment per household	US Dollars	41.79	31.79	10.00	100.00
FEMALE	1 if female	Binary	0.64	0.48	0.00	1.00
COL	1 if college graduate or higher	Binary	0.36	0.48	0.00	1.00
OLD	1 if aged 65 or over	Binary	0.11	0.31	0.00	1.00
LOWINC	1 if annual household income < $25,000	Binary	0.22	0.42	0.00	1.00
FLOODEXP	1 if experienced floods	Binary	0.29	0.46	0.00	1.00
UNPREP	1 if unprepared for floods	Binary	0.68	0.47	0.00	1.00
UNPREP × GOVRESP	1 if unprepared becase preparation is a government responsibility	Binary	0.02	0.14	0.00	1.00
UNPREP×DONTKNOW	1 if unprepared because I don't know how to prepare	Binary	0.17	0.38	0.00	1.00
RISKATT	Risk attitude (the higher the riskier)	0–10	5.44	2.40	0.00	10.00
KNOW_GI	1 if knows green infrastructure	Binary	0.16	0.37	0.00	1.00
KNOW_RG	1 if knows green gardens	Binary	0.35	0.48	0.00	1.00
TRUST_NEIGHBORS	1 if trusts neighbors	Binary	0.62	0.49	0.00	1.00
TRUST_CIVIL	1 if trusts civil services	Binary	0.45	0.50	0.00	1.00

Table 3

The Estimated Results of the Conditional Logit (CL) and Mixed Logit (ML) Models

Dependent variable:		**Conditional logit (CL)**			**Mixed logitt (ML)**		
Choice		Coefficient		Std. error	Coefficient		Std. error
Mean Parameters	Rain gardens	0.525	***	0.059	0.689	***	0.155
	Rain barrels	1.235	***	0.060	1.968	***	0.110
	Bioswales	-		-	-		-
	Urban trees	1.204	***	0.057	1.835	***	0.098
	Ecoroofs	0.814	***	0.059	1.216	***	0.094
	Tree Boxes	0.896	***	0.059	1.416	***	0.139
S.D. Parameters	Rain gardens	-		-	3.371	***	0.172
	Rain barrels	-		-	1.800	***	0.121
	Bioswales	-		-	-		-
	Urban trees	-		-	1.535	***	0.111
	Ecoroofs	-		-	1.409	***	0.114
	Tree Boxes	-		-	2.961	***	0.153
	# of obs.	16,700			16,700		
	# of cases	4,175			4,175		
	Log-likelihood	-5,447			-4,644		
	AIC	10,904			9,309		

Note: *** indicates statistical significance at 1 percent.

Table 4

The Estimated Coefficients and their Odds Ratios in the Logit Model

Variables	Coefficient		Std. Error	Odds Ratio		Std. Error
Intercept	-1.199	***	0.372	0.301	***	0.112
PAY	-0.010	***	0.003	0.990	***	0.003
FEMALE	0.004		0.186	1.004		0.187
EDU	0.273		0.189	1.315		0.249
OLD	0.290		0.283	1.337		0.379
LOWINC	-0.488	**	0.210	0.614	**	0.129
FLOODEXP	0.665	***	0.198	1.945	***	0.385
UNPREP	0.467	**	0.203	1.595	**	0.324
UNPREP×GOVRESP	-1.630	**	0.654	0.196	**	0.128
UNPREP×DONTKNOW	0.697	***	0.249	2.009	***	0.501
RISKATT	0.087	**	0.038	1.091	**	0.041
KNOW_GI	0.688	**	0.275	1.990	**	0.548
KNOW_RG	0.548	***	0.197	1.729	***	0.341
TRUST_NEIGHBOR	0.750	***	0.181	2.118	***	0.383
TRUST_CIVIL	0.154		0.183	1.166		0.213
n	666					
Log likelihood	-401.192					
% correct prediction	65.3%					
Psudo R^2	0.121					

Note 1: The dependent variable is respondent's acceptance of the hypothetical payment.
Note 2: **, *** indicates statistical significance at 5% and 1%, respectively.

Table 5

The Estimated Willingness to Pay (WTP) for Green Infrastructure Development (*USD*)

County	N	Mean	S.D.	Min.	Max.
Clackamas	163	46.3	30.6	6.0	157.7
Multnomah	321	51.5	32.4	7.6	192.7
Washington	182	46.5	30.5	5.3	180.0
Total	**666**	**48.8**	**31.5**	**5.3**	**192.7**

Table 6

Results of Policy Simulation in Uniform and Variable Payment Schemes $(n = 666)$

Amount offered	# of participants	Rate of particiapation	Participants' mean WTP	Total payment	
				Uniform	Variable
10	643	96.5%	50.3	6,430.0	32,354.2
20	560	84.1%	55.5	11,200.0	31,104.0
30	446	67.0%	63.4	13,380.0	28,267.3
40	353	53.0%	70.9	14,120.0	25,022.0
50	258	38.7%	80.4	12,900.0	20,753.1
60	195	29.3%	88.5	11,700.0	17,256.3
70	138	20.7%	98.1	9,660.0	13,539.2
80	99	14.9%	107.5	7,920.0	10,639.1
90	71	10.7%	116.5	6,390.0	8,269.9
100	54	8.1%	123.1	5,400.0	6,647.1

Figure 1

Study Region

Figure 2

Sample Choice Card of Best–Worst Scaling

Note. Illustrations were taken from the Delaware Department of Natural Resources and Environmental Control (2016).

Community Green Infrastructure Hypothetical Question

Suppose that there is fundraising called "good community growth with green infrastructure."
This fund will improve your community's environment and reduce flood risk by enhancing green infrastructure.

If realized, the establishment will be made primarily using the practices you have rated highly in previous questions and will bring the following benefits to your community:

1. Flood risk reduction
This fund will reduce stormwater discharges and mitigate flood risks by slowing and reducing stormwater discharges.

2. Water quality improvement
This fund lowers discharge volumes that translate into reduced combined sewer overflows and lower pollutant loads. Green infrastructure also treats stormwater that is not retained.

3. Air quality improvement
This fund will reduce ground-level ozone or "smog" by reducing air temperatures and removing pollutants.

4. Biodiversity enhancement
This fund will increase urban vegetation and provide habitat for a variety of insects, mammals, and birds.

Your financial support is essential to make this fund a reality.
Would you be willing to support this fundraising to improve community green infrastructure at a cost of **$30** per household per year, or would you oppose this proposal?

○ Yes

○ No

○ I don't know

Figure 3

Hypothetical Question of the Community Green Infrastructure Enhancement

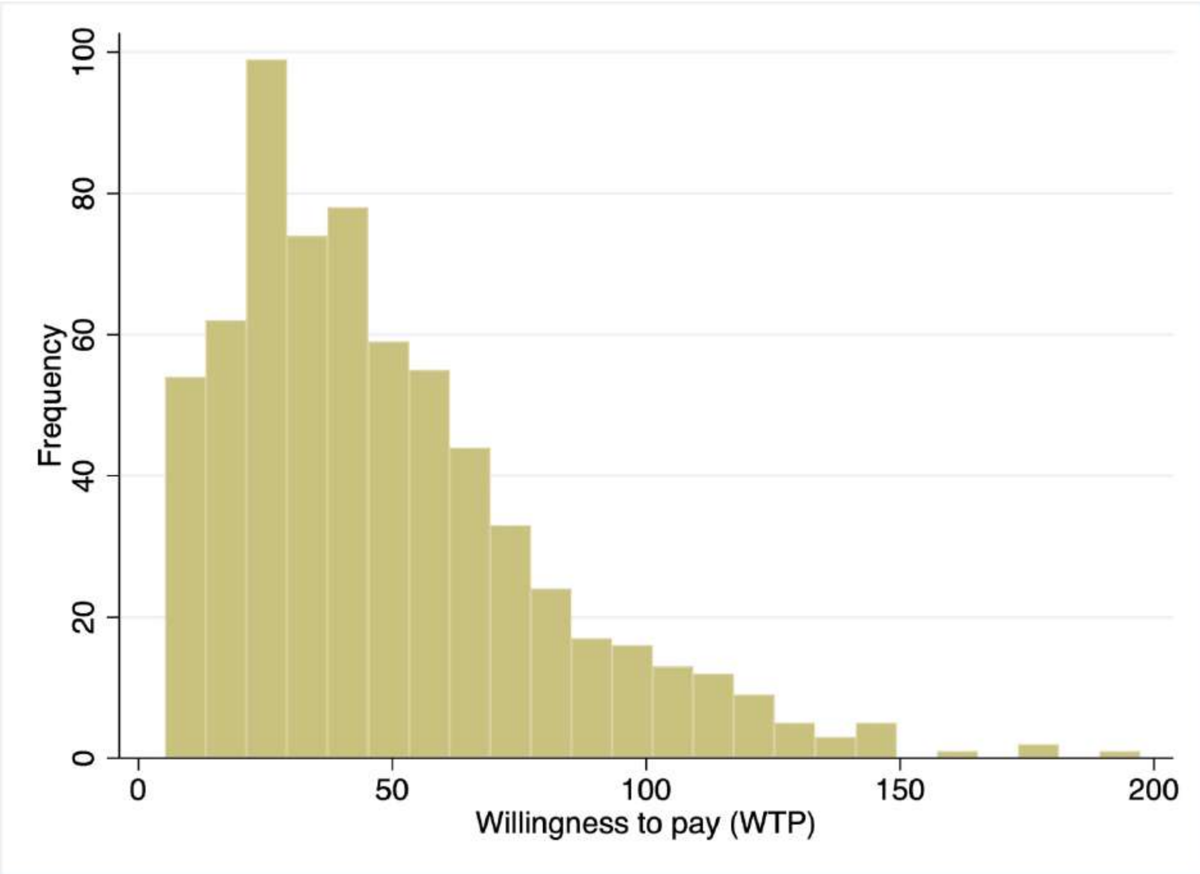

Figure 4

Estimated WTP for Green Infrastructure Enhancement

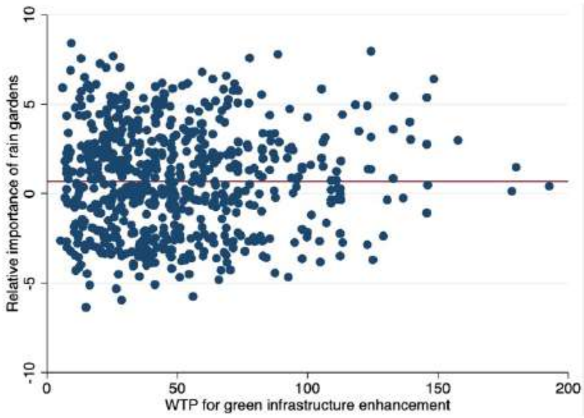

Figure 5a – Rain gardens

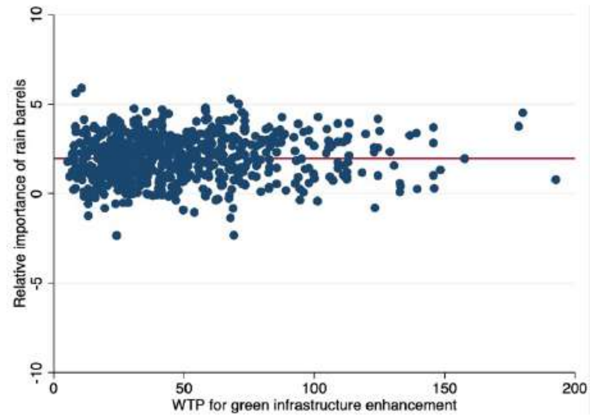

Figure 5b – Rain barrels

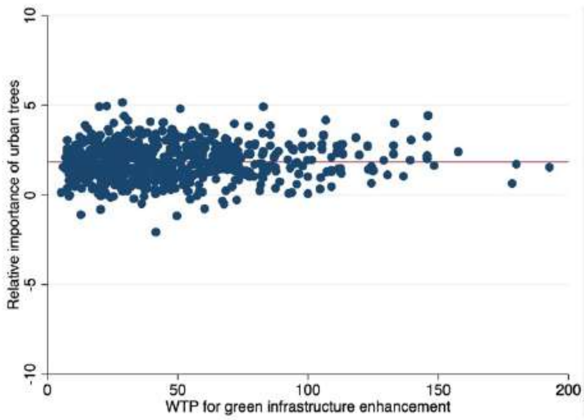

Figure 5c – Urban trees

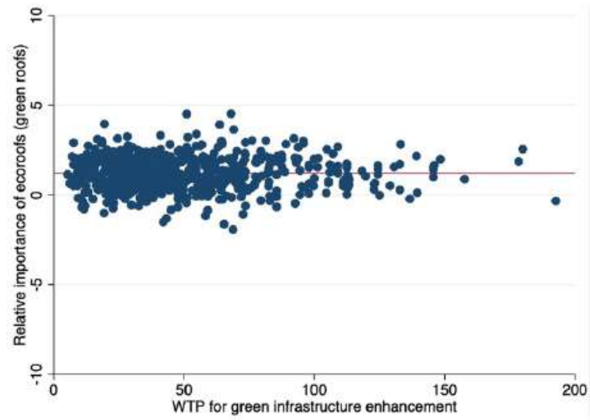

Figure 5d – Ecoroofs (green roofs)

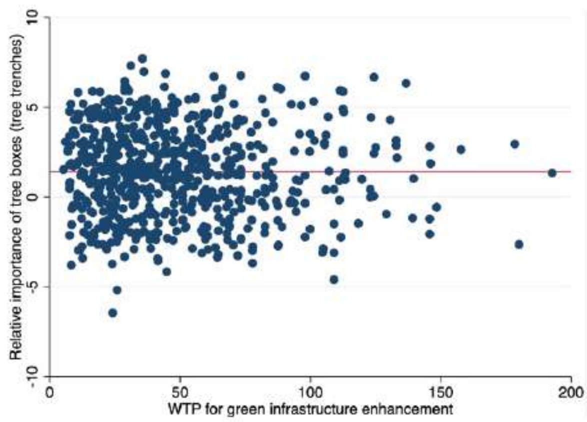

Figure 5e – Tree boxes (tree trenches)

Figure 5 (5a–5e)

Scatter Plots of the Estimated WTP and Relative Importance by Practice

Note. Bold horizontal lines indicate the value of the mean parameter

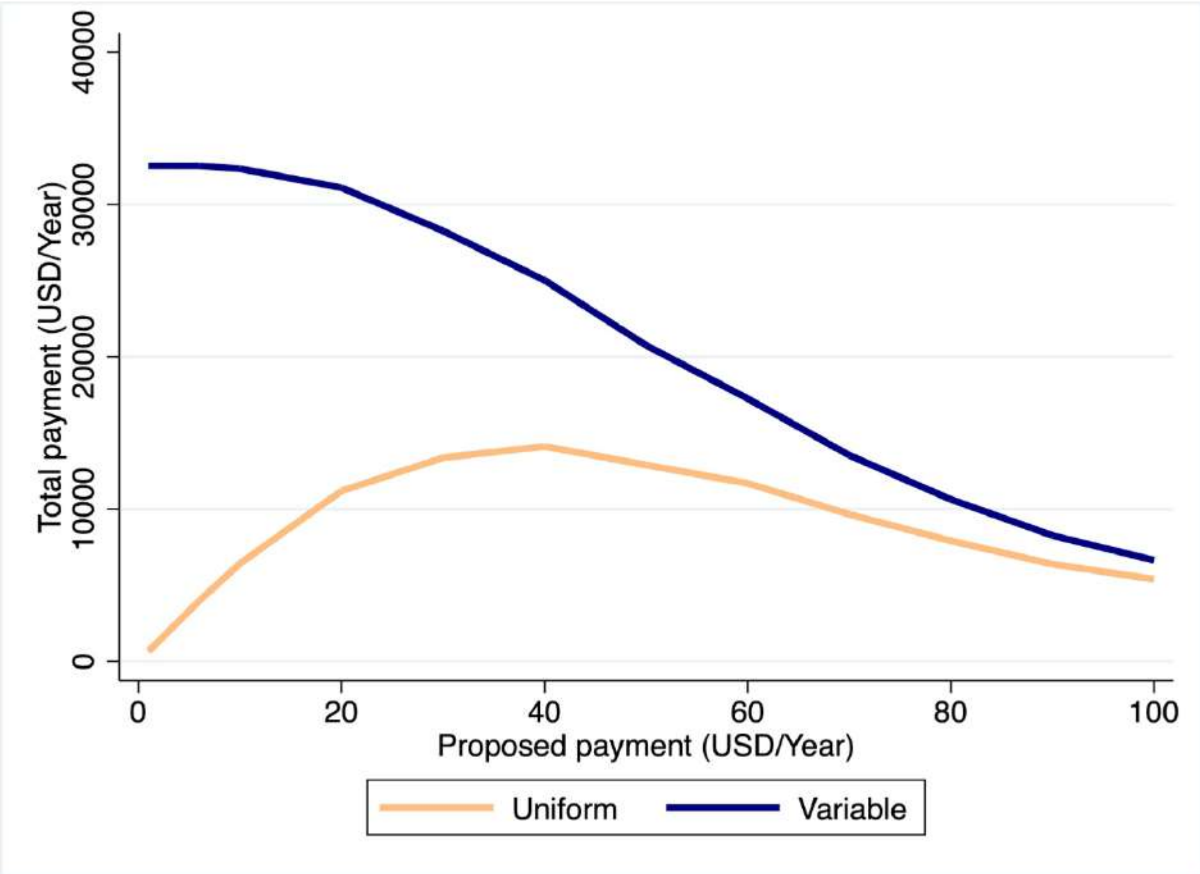

Figure 6

Simulated Relationship between the Amount of Proposed Payment and Total Payment (revenue) in Uniform and Variable Payment Schemes ($N = 666$)