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Analysis

Using Contingent Valuation and Numerical Methods to Determine Optimal Locations for Environmental Facilities: Public Arboretums in South Korea

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ABSTRACT

Because the social benefit generated from a public facility varies according to its accessibility, population density of location, local income level, local taste, and the existence of similar nearby facilities, the value of facilities can vary depending on their location. Therefore, determining the ideal location is an important problem. This study provides a new direction for solving this problem by combining the contingent valuation (CV) method and nested partitions (NP) algorithm using siting of public arboretums as an example. First, consumers' willingness to pay for environmental facilities considering household characteristics and distance to both newly built and existing facilities are estimated using the CV method. In this process, consumers are divided into two groups (active and passive users), assuming they have different willingness to pay for the facilities. Then, using the results of the CV, the NP algorithm, a simulation-based discrete optimization technique, is constructed to efficiently identify optimal locations that maximize social benefit considering regional characteristics. The results of the proposed algorithm exceeded the performance of the benchmark case, and this study's findings can be used to aid decisions about complicated multiple facility locations. Moreover, visualized results are provided, which can be useful for local and central decision makers.

1. Introduction

Public facilities are built and operated using public taxes, and every member of the public can benefit from them. However, the value of public facilities can vary depending on their location. This is because the social benefit generated from a facility varies according to its accessibility, the population density of the location, local income level, local taste, and the existence of similar nearby facilities.

Therefore, determining the location of public facilities is an important problem that sometimes induces conflict between different regions within a country. In the case of public facilities preferred by residents, such as train stations, stadiums, parks, or arboretums, it is appropriate to build facilities in locations with good accessibility to enable greater utilization. However, the land at such locations is usually expensive, and the opportunity cost is high. Therefore, when facilities require substantial land, there must be a compromise that considers both the potential benefit of the facility and its cost. For public facilities that are not preferred by residents but are considered essential, it is advisable to build them in a remote place. However, if the facility is too remote, its function may diminish, or operation costs can soar. Therefore, compromise is required that considers both the social conflict the facility will generate and its cost. For public facilities that can be categorized as environmental goods, the location cannot be decided based on a revenue maximization strategy, as is the case with factory or warehouse location decisions, since a market price for the service provided by the public facility does not exist.[1]

Public arboretums, for example, require more land and a tremendous amount of resources to build compared to other facilities. Moreover, once an arboretum is built, it is much harder to reverse (irreversibility) than other facilities. Therefore, location decisions should be carefully made. To evaluate an environmental good like an arboretum, we can use stated preference techniques, such as the contingent valuation method. In this study, the stated preference method is used to analyze the public benefit from building new public arboretums considering the amount of time required to travel to the arboretum (accessibility) and local characteristics. Additionally, the cost that differs according to site, which is the price of the land, is considered.

However, in the case where more than one facility is to be built, the location of one facility can affect the benefit generated by others. For example, if two arboretums are newly built 1 and 2 h away from a

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[1] Most public facilities do not charge fees for their use, and even when they do, the price is much lower than the true value. Therefore, fees charged for a public facility do not represent its value. Moreover, the objective of a public facility is not revenue maximization.

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consumer, the consumer will be more likely to use the closer arboretum than the one located further away. Similarly, when building multiple facilities, it is important to consider the effect of each facility on other facilities. However, in most cases, public facility construction is determined more by the political situation than by a reasonable decision-making process based on scientific evidence. In other words, strategic location planning considering social benefit is not properly practiced. This study finds the optimal location set for multiple public facilities that can maximize social benefit, given the number of arboretums to be built.

However, for a multiple location problem, as the number of candidate sites and facilities increases, it becomes more difficult to calculate every case. For example, if the number of candidate sites is 200, and 10 sites are to be chosen as locations for new facilities, there are more than $2 \cdot 10^{16}$ possible combinations. Therefore, when determining the optimal location set for multiple facilities, it is advisable to use an optimization algorithm that can efficiently solve the problem. This study uses a simulation-based optimization approach, the nested partitions (NP) method. This method can efficiently solve the complex optimization problem, find the optimal location set for the public arboretums, and analyze how much benefit can be attained from their construction. The remainder of this paper is organized as follows. Section 2 reviews previous studies related to this study, and Section 3 explains the methodology. Section 4 contains the results and discussion of the analysis. Finally, Section 5 first presents the key findings and implications of the study, and then provides limitations and directions for future studies.

2. Literature Review

2.1. Evaluation of an Environmental Good

Arboretums are public facilities and an environmental good. Valuation of an environmental good should be conducted differently than valuation of market goods. Studies that have attempted to evaluate environmental goods have mainly used the hedonic pricing method (Cho et al., 2011; Le Goffe, 2000; Loomis and Feldman, 2003; Snyder et al., 2007; Tyrväinen, 1997; Votsis, 2017), the travel cost method (Dwight et al., 2005; Harrington et al., 1989; Hernandez-Sancho et al., 2009; Leshem et al., 2008; Mayor et al., 2007; Willis and Garrod, 1991), the avoided cost method (Dwight et al., 2005; Harrington et al., 1989; Hernandez-Sancho et al., 2009; Kindermann et al., 2008; Leshem et al., 2008; Pirard, 2008), or the stated preference method (Amirnejad et al., 2006; Barrio and Loureiro, 2010; Carson and Mitchell, 1993; Christie et al., 2007; Dalton et al., 1998; Haefele and Loomis, 2001; Hanley et al., 2006; Mayor et al., 2007; Viscusi et al., 2008; Zhang, 2012).

This study uses a contingent valuation method (CVM), which is a type of stated preference method. Using a survey, CVM suggests a hypothetical alternative to respondents and assesses their willingness to pay (WTP) for the alternative. Although it is a controversial method (regarding its accuracy, response bias, etc.), CVM is widely used in the literature when evaluating the value of environmental public goods (Amirnejad et al., 2006; Barrio and Loureiro, 2010; Carson and Mitchell, 1993; Christie et al., 2007; Dalton et al., 1998; Mayor et al., 2007). This is because, in most cases, environmental public goods do not have appropriate market prices to represent their value. Also, environmental public goods usually have significant non-use values, which may be hard to estimate accurately using other methods. Moreover, CVM is useful when measuring consumers' WTP for hypothetical situations, such as construction of new public arboretums (Venkatachalam, 2004). Finally, Arrow et al. (1993) conclude that results of the CVM can produce “estimates reliable enough to be the starting point of a judicial process.” Likewise, the results of this study, and other CVM studies, can be a starting point for designing an optimal policy for environmental public facilities.

This study focuses on the change in WTP depending on the distance (travel time) to the arboretum. To be specific, the WTP for the preferred public facility will decrease as the distance (travel time) to the facility increases (distance decay). Previous studies using CVM to value non-market goods also considered this factor. Sutherland and Walsh (1985) estimated the WTP for the Flathead Lake water quality improvement program in Montana. The authors showed that as the distance from the respondent to the lake increased, the WTP decreased. Similarly, using CVM, Hörnsten and Fredman (2000) found that people in Sweden have higher WTP for a shorter distance to a recreational forest. In another study, Bateman and Langford (1997) measured the WTP for National Parks in the United Kingdom using CVM and observed distance decay. Finally, Pate and Loomis (1997) showed the same result for the quality improvement program in San Joaquin Valley in California, and Bateman et al. (2006) found a similar result for aggregation facilities.

Some studies, on the other hand, considered travel time rather than distance. Hanley et al. (2003) showed that the WTP for an environmental program to solve the river's low flow problems decreased as the travel time to the river increased. Jørgensen et al. (2013) showed that the WTP for the environmental program for the river was dependent on both travel time to the river and travel time to other water bodies or coastlines. In other words, the study considered the distance decay effect, and the effect of other substitutable goods. Based on the previous literature, this study examines the change in WTP considering the travel time to the good (distance decay) and the effect that multiple facilities have on each other (substitution effect) to draw the optimal location set for a multiple facility location problem.

2.2. Optimization Algorithm

The multiple location problem becomes exponentially complex as the number of site candidates and facilities increase. Therefore, considering all cases is inefficient and sometimes impossible, given time and budget constraints. This study, therefore, uses a simulation-based optimization method, the NP method. The NP method guarantees global convergence to the true optimal solution, and its efficiency has been demonstrated in many optimization problems (Shi and Ólafsson, 2000). The main concept of the NP method is to focus the computational power on the part where the global optimum is likely to exist. The method details are described in Section 3.

The NP method is widely applied in various fields such as resource allocation (Liu et al., 2016; Shi et al., 1999; Wu et al., 2012), job-shop scheduling (Yau and Shi, 2009), and beam angle optimization (D'Souza et al., 2008). Shi et al. (2004), Chen et al. (2009), and Xia et al. (2010) addressed the facility location problem. Shi et al. (2004) used the NP method to optimize the location of a warehouse for supply chain optimization, and Chen et al. (2009) used the NP method to solve the intermodal hub location problem. Xia et al. (2010) optimized the location of banking facilities using the NP method. The study divided the city area of Suzhou, China into 45,000 cells of $200\,\mathrm{m} * 200\,\mathrm{m}$, and provided an optimal location for three types of banking facilities considering the demand value of each cell (which was provided by a professional data vendor). However, the public arboretum is much larger and has wider coverage than most private facilities, which means that the setting for the analysis is different from that of previous studies. The specific setting for the analysis will also be described in the next section.

3. Methodology

3.1. Research Framework

This study first analyzes how the benefit gained from a newly built arboretum changes as the travel time to the newly built and existing arboretums changes, considering local characteristics. Then, using the results of the analysis, a performance evaluation function is constructed for a given location set for multiple facilities. Finally, this function is