Transportation Research Part C 77 (2017) 67–79

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Evaluation of spatial heterogeneity in the sensitivity of on-street parking occupancy to price change

Ziyuan Pu [a], Zhibin Li [b], John Ash [a], Wenbo Zhu [a], Yinhai Wang [a,*]

[a] *Department of Civil and Environmental Engineering, University of Washington, Seattle 98195-2700, United States*
[b] *School of Transportation, Southeast University, Si Pai Lou #2, Nanjing 210096, China*

ARTICLE INFO

Article history:
Received 22 March 2016
Received in revised form 11 December 2016
Accepted 12 January 2017

Keywords:
Parking demand
Spatial heterogeneity
Geographically weighted regression

ABSTRACT

Adjustment of parking price has long been considered an effective way to control parking demand and demand has often been shown to be affected by spatial factors. The primary objective of this study is to investigate the spatial heterogeneity in the sensitivity of parking occupancy to price change using data obtained in downtown San Francisco between 2011 and 2014. The performance-based pricing implemented in the study area allows parking rate to increase, decrease or remain unchanged in neighborhoods with parking occupancy levels higher than, lower than, or within a desired range. As such, the relationship between change in occupancy and change in parking rate is explored. The geographically weighted regression (GWR) method was used to capture the spatial heterogeneity in sensitivity in different blocks and modeling results showed that there is a significant negative correlation between occupancy change and parking rate change. Thus, sensitivity of on-street parking occupancy to price change has an obvious trend of spatial variation. By capturing the spatial heterogeneity in the dataset, the GWR model achieved higher prediction accuracy than a global model. Variables including time of day, block-level features, and socio-demographic characteristics were also found to be correlated with occupancy change. Based on the GWR outputs, a generalized linear model was estimated to further identify how various factors affect sensitivity in different block areas. Findings of this study can be used to help parking authorities with tasks such as identifying which blocks are suitable for balancing parking demand and supply by adjusting price and designing optimal parking rate schemes to achieve desired on-street parking occupancy levels.

1. Introduction

In a parking system, the parking price is a crucial element which highly influences drivers' parking decisions (Shoup, 1999; Verhoef et al., 1995). In most situations increasing parking price causes parking demand to decrease. Nonetheless, determining an optimal parking price is a complicated issue that requires balancing of competing demands. When parking is underpriced, available parking spots are hard to find which increases the time drivers spending cruising to find available spots (Marsden, 2006; Higgins, 1992; Shoup, 2006). Overpricing of parking, on the other hand, may potentially hurt an area's economic vitality (Shiftan and Burd-Eden, 2001; Hensher and King, 2001; Taylor, 2002; Shiftan and Golani, 2005; Joncas et al., 2011). Thus, the main goal in a parking pricing scheme is to determine an appropriate price to achieve a desired level

* Corresponding author.
E-mail addresses: ziyuanpu@uw.edu (Z. Pu), lizhibin@seu.edu.cn (Z. Li), jeash@uw.edu (J. Ash), wbzhu@uw.edu (W. Zhu), yinhai@uw.edu (Y. Wang).

http://dx.doi.org/10.1016/j.trc.2017.01.008

of parking occupancy. Shoup (2005) advised that the optimal parking occupancy level should be around 85%, or at level leaving at least one or two open parking spots per block, allowing motorists to find a parking spot quickly.

Recently, smart parking technology, which is considered as an important part of smart cities, has attracted much attention from transportation researchers, government officials, and industry. In particular, robust pricing strategies have been employed as tools for managing the demand of users (Zhang et al., 2014), especially for increasing the availability of on-street parking spaces in large cities. For example, Seattle's Department of Transportation implemented a performance-based on-street parking price adjustment system for a total of 10 neighborhoods surrounding the commercial core in between January and April 2011 (SDOT, 2011). Between August 2011 and June 2014, the San Francisco Municipal Transportation Agency (SFMTA, 2014) adjusted parking rates 13 times based upon demand at a quarter of the city's total on-street metered parking spaces. According to the evaluation reports from both of the aforementioned agencies, on-street parking occupancy in the majority of the study areas was successfully controlled and remained at the target level during the study periods (SDOT 2011; SFMTA, 2014).

In order to achieve the desired occupancy level precisely, understanding how drivers respond to parking price change is of the utmost importance. Previously, several studies have evaluated the sensitivity of parking demand in response to price change (Kelly and Clinch, 2006, 2009; Pierce and Shoup, 2013; Ottosson et al., 2013). The majority of such studies reported that there was a negative relationship between parking demand and price rate, though some positive relationships were found in Ottosson et al. (2013). The aforementioned studies also demonstrated that demand sensitivity is closely connected with temporal attributes. For example, Kelly and Clinch (2009) estimated the price elasticity of parking demand by time of day in the central area of Dublin, Ireland, and found it to range from −0.15 (at 9 am) to −0.61 (at 12 pm) during weekdays.

In addition to the temporal attributes, sensitivity can also be affected by spatial attributes such as block characteristics. Understanding spatial features and their impact on sensitivity can help city planners identify which blocks are suitable for balancing parking demand and supply through price adjustment. Previously, most studies focused on how spatial variables affect parking demand (Tsamboulas, 2001; Vaca et al., 2005; Kelly and Clinch, 2006). However, such studies did not evaluate how spatial factors may affect sensitivity. Impact of spatial variables on parking demand and their impact on sensitivity in response to price change could be very different. For example, it is easy to envision a scenario where income level has a positive correlation with parking demand while simultaneously being negatively correlated with the sensitivity.

Previously, one study evaluated the spatial variation in the sensitivity of parking demand to parking price change (Ottosson et al., 2013). The distance from the downtown core, the number of bus stops, and nearby off-street parking cost were selected as location attributes to model spatial variation. A linear regression model was then developed with parking demand as the dependent variable and price rate at different locations as independent variables. The results showed that spatial areas are associated with different sensitivities. However, only a few spatial attributes were considered in the study by Ottosson et al. (2013), thus the study did not fully examine the spatial heterogeneity in the sensitivity of parking demand to parking price change. Further, the study did not examine the degree to which the sensitivity was associated with various socio-demographic and block-level characteristics.

To better understand the effect of spatial features on sensitivity, appropriate data and modeling techniques are essential. Previously, most studies used parking transaction data to estimate parking occupancy. However, the parking occupancy calculated by transaction data is usually lower that the actual occupancy which can certainly impact modeling accuracy (Heffron Transportation Inc, 2002; Weinberger et al., 2010). In addition, previous studies often used generalized linear model (GLM) in which model parameters are globally fixed and do not vary spatially. Thus, in such models, outputs do not provide insight into the spatial features in the sensitivity. In our study, sensor data from the SFpark Pilot project was used to obtain accurate parking occupancy data. With a quality dataset in hand, an advanced statistical model, the geographically weighted regression (GWR) model, was then adopted to capture the spatial heterogeneity in the sensitivity.

The primary objective of this study is to evaluate the spatial heterogeneity in the sensitivity of parking occupancy in response to price change. More specifically, this study includes the following tasks: (1) develop the GWR model to capture the spatial heterogeneity in the sensitivity of parking occupancy to price change; (2) evaluate if predictions from the spatial model are more accurate than those from the global model; and (3) evaluate how various factors affect the sensitivity in different blocks within a given area. Findings of this study can be used by parking authorities to help predict the sensitivity of on-street parking demand to parking price change. This information can further be used to determine the optimal parking rate in different spatial areas within a given jurisdiction that applies dynamic pricing policies in order to achieve a desired level of parking occupancy.

2. Data

2.1. Study area

For this paper, the study site was chosen as the SFpark Pilot project area in downtown San Francisco, California. Specifically, SFpark is the name of the San Francisco Municipal Transportation Agency's approach to parking management (SFMTA, 2014). In the SFpark pilot project, SFMTA used several strategies in an attempt to improve the parking experiences of customers, including a demand-responsive pricing strategy and other strategies to make it easier to find a parking place and pay at meters. During the SFpark pilot study, SFMTA made use of several novel technologies and methodologies including smart