

Research Article

Evaluation of Residential Parking Spots Sharing Effects Based on Practical Experience

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Making residential parking spots available to the public has become popularized in recent years. The sharing of residential parking spots can promote the further use of parking space and enhance the utility of parking resources in urban metropolitan areas. However, little is known about the relationship between spots' physical or temporal factors and rental effects from practical experience. This study aims to evaluate the effects of residential parking spot sharing from both individual and social benefit perspectives. One-year real behavioral records concerning parking spots' owners and borrowers were obtained, and the field survey of various parking spots' physical characteristics was conducted. Two Partial Least Squares Structural Equation Modeling (PLS-SEM) models emphasizing the individual and societal points of view were adopted. Results revealed that the spots' physical factors, including spot type, visibility, ease of parking, and distances to major surrounding buildings, along with owners' sharing willingness and preferences, tend to pose significant influences on the rental effects from both individual and social benefit perspectives. Some differences were also discovered between the two models. For the individual model, owners' sharing willingness was the dominant factor affecting the parking spots' sharing effects, while for the social model, parking spots' physical characteristics appear to be more important in determining the sharing effects. Based on these findings, suggestions were discussed to promote residential parking spot sharing and increase the benefits of sharing to individuals and society.

1. Introduction

Car parking has been a long-standing and problematic issue confronting numerous urban metropolitan areas. A crucial question is how to eliminate the mismatch between parking demand and supply. Thus, in order to rectify this problem, the most commonly held measure is to increase the parking supply by offering more parking spaces. However, such measures are quite costly [1] and, sometimes, may even result in safety issues, especially within the multistory car parks [2]. Some other measures are also found to be effective, such as dynamic parking pricing [3–5] and residential parking permit regulations [6–8]. Such measures could reduce the parking demand among low-wage individuals, which may be deemed as unfair to them. Moreover, the dynamic pricing policy is based on real-time parking effect information; however, it has been difficult to widely

ascertain in many regions to date. Apart from the straightforward methods of increasing supply and lowering demand, the shared parking strategy provides a less costly and more acceptable method to balance this mismatch and further promote the utility of parking spaces in metropolitan areas [9].

The rise of the shared economy and its global recognition has accelerated the reformation of the shared parking industry and its policies. Previously, the most traditional and simple shared parking pattern was to institute private contractual agreements between adjacent buildings [10]. However, in recent years, some high-tech companies act as matchmakers between parking spot owners and potential renters. These firms also help to allocate parking resources where they are needed [11] and charge a small percentage in return. Moreover, new technologies have been developed which now allow owners to provide rental services for their

residential parking spots to borrowers through the utilization of smartphone apps during the agreed time. Hence, the new parking sharing pattern is considered to be more flexible and applicable.

In recent years, one of the most popular residential parking spot sharing companies in China is “Ding Ding Parking” (DParking). The company allows parking spot owners to share their parking spots with borrowers via the smartphone app and matches smart parking locks (see Figure 1). By utilizing the smartphone app, the available parking timetable for each spot is flexible and determined exclusively by the owners. In other words, owners control the parking lock hardware up to and after they leave and announce the vacant state during a predetermined timespan. Concerning borrowers, they can select a desirable spot in the app by checking its location, open time, and parking price. Once the spot is booked by a borrower, he or she will be assigned the right to control the lockdown period and to park, according to the agreement. The borrower will then be automatically charged via the app after vacating the spot. However, an emergency strategy might be enforced if borrowers continue to park past the end of the open time. Based on our experiences, the proportion of these types of problems represents less than 1%.

This new residential parking spot sharing system adequately meets the needs of both individuals and society at large. For individual owners, sharing residential parking spots can provide extra income. As for the local urban society, the new sharing pattern can obviously increase the utilization of each single parking space and offer more parking choices for car drivers, which are significantly helpful in reducing the conflicts of parking demand and supply. Due to such obvious benefits, Chinese government agencies currently hold an open opinion toward this newly developed technology and also admit to its legality.

Although both individuals and society benefit from this new policy, they judge sharing effects quite differently. More specifically, individuals value paybacks, while society tends to be more concerned about the efficient utilization of parking resources. Both individuals and society are very interested and focused on how to increase their profits and optimize the social and individual benefits.

Until now, the practice-based research on the matching behavior between supply and demand of residential shared parking is rare; in particular, the data of unconstrained behavior not affected by differentiated charging policies and sharing time constraints is difficult to obtain. However, there are a few relevant papers that contribute to the matching mechanisms between private parking spot sharing and rental demand, but these studies did not validate their results with real or recent data [12–15]. In fact, there remain a lot of issues in the practice of shared parking that need to be addressed and studied. For example, even though the current pricing policy requires fixed charges for all spots, the available timetables of different spots vary significantly along with their physical characteristics. Thus, the sharing effects of different spots are quite distinctive. However, due to the lack of actual data, none of the previous studies have systematically evaluated the overall effects of residential parking

spot sharing with the consideration of the differences of physical and temporal characteristics of a single parking spot.

The primary objective of this study is to estimate the relationship between the various characteristics of shared residential parking spots and the sharing effects from both individual and social benefit perspectives, based on real data acquired from the DParking app and the field survey. In particular, this study includes the following tasks: (1) to identify the influential factors of parking sharing effects from the spots’ physical characteristics and owners’ temporal operational features, (2) to compare the empirical differences of the influential factors between the individual and social benefit models, and (3) to discuss suggestions that will increase the parking sharing benefits for both individuals and society. Moreover, the findings of this study can be used to enhance the understanding of the mechanisms in the operation and efficiency of the residential parking spot sharing system and improve the applicability of the emerging parking technology in larger regions.

2. Literature Review

In this section, we briefly review related work: (i) shared parking choice behavior and (ii) supply and demand matching method for shared parking.

2.1. Shared Parking Choice Behavior. Researches on shared parking choice behavior cover both supply and demand sides. To the authors’ best knowledge, there are few current studies based on empirical data, and the major data acquisition method is via interview or questionnaire. Based on the theoretical framework of the Combined Technology Acceptance Model and the Theory of Planned Behavior (C-TAM-TPB), some researchers conducted a questionnaire survey, to investigate the intention to use shared parking and to identify the influential intrinsic factors from both parking space suppliers and demanders perspectives [9]. In addition, the perceived value and risks among shared parking demanders were explored, and an analytical model was also proposed to verify the hypotheses associated with positive network externality and risks [16]. Yan et al. [17] provide insight into owners’ decision-making from a psychological perspective, by adopting a random-parameter hybrid logit-cumulative prospect theoretic model, with the uncertain parking demand. Notwithstanding the benefits derived from the use of shared parking, users may turn to conventional parking mode because of concerns about the performance of shared parking modes. Recent studies introspect the change of behavior and find that the repatronage of shared parking is significantly affected by its technology acceptance and the perceived risk is the key variable leading to change parking mode [18]. As an emerging parking management technology, the research on the mechanism of shared parking choice behavior has attracted much attention. But current studies put a major concern about the participants’ psychological factors, resulting in an insufficient consideration of the heterogeneity of shared parking spots’ physical characteristics, which may influence the effective disclosure of the mechanism of shared parking choice behavior.

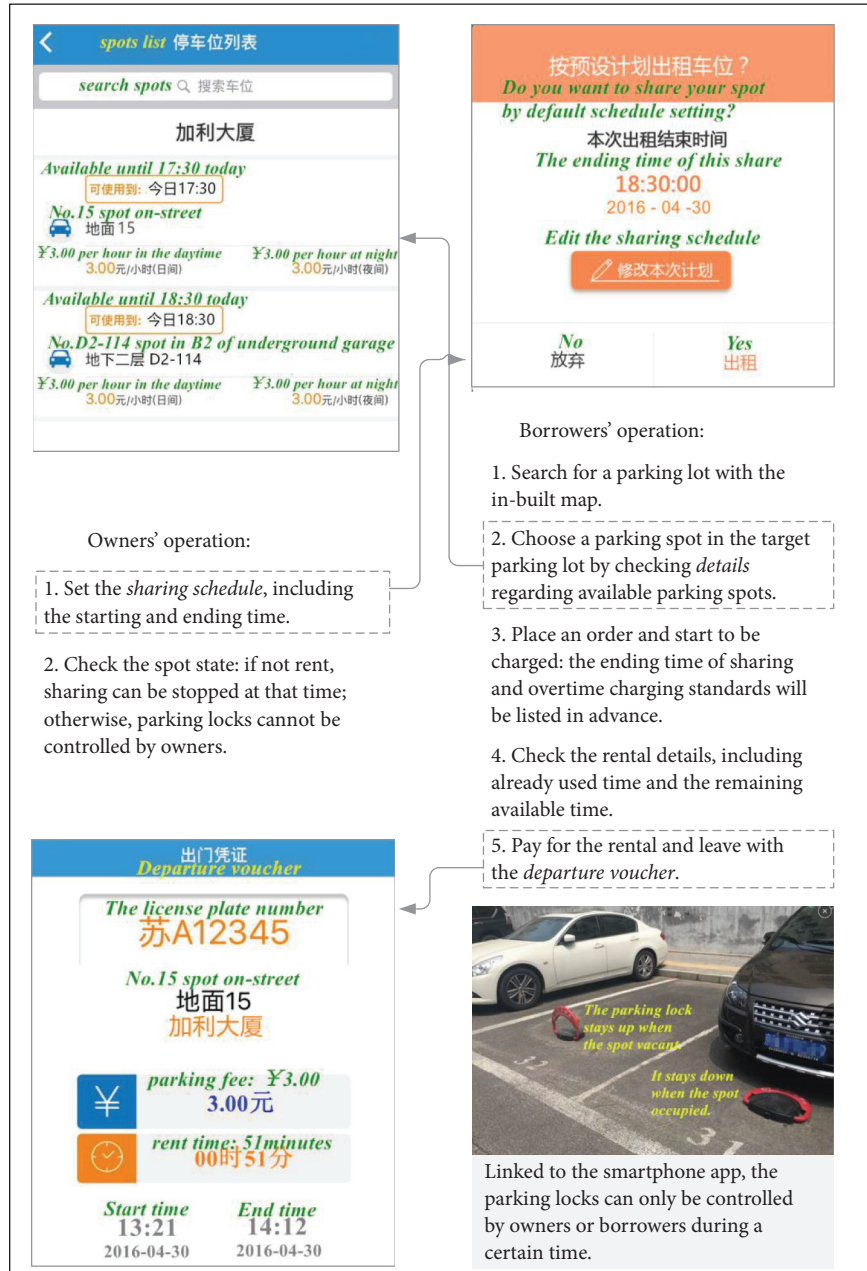


FIGURE 1: Operation of DParking app and parking locks.

2.2. Supply and Demand Matching Method for Shared Parking. In general, the parking supply and demand matching method, also known as the parking spots allocation method, is the key technology in parking management. The effective supply and demand matching methods for shared parking can further promote the utilization of idle parking resources, which has become a research hotspot in recent years. Traditionally, the time restriction greatly affects the matching mode of supply and demand of parking spaces [19]. With the development of e-parking platforms and technology, advanced booking is currently an important means of time management and first-book-first-serve is the dominant rule. Unlike the public parking space, the shared parking spots mainly have a sharing time uncertainty problem. Shao et al.

[13] propose a simple binary integer linear programming model to allocate the requests under parking space and time constraints. To effectively improve the success rate of supply and demand matching and the activity of the shared parking market, many scholars design matching strategies via pricing control tools and propose matching mechanisms considering money flow. Xu et al. [12] propose two top trading cycles and deal mechanisms for those who join the leasing mechanism as a lessor and those who “transfer” (rent) his parking slots to the platform. The time factor and the pricing tool are both considered in current studies. Tan et al. [20] propose a truthful reverse Vickrey auction to allocate and price parking spaces in a static setting and further analyze the effects of the key factors (e.g., dynamic arrival rate and

abandonment rate) in a dynamic setting, with the consideration of long-time or short-time parking demand in both public and private parking spaces. With the wide establishment of the parking management system, the combination of theoretical research and engineering practice in shared parking supply and demand matching has become popular [21]. However, current shared parking supply and demand matching researches, especially for private parking spots, mainly focus on the theoretical models; few have been tested in realistic shared parking practice. Moreover, the matching method lacks the consideration of participants' subjective preferences and willingness, possibly making the matching theory less applicable and practical.

3. Data

3.1. Study Area. This research was conducted in a residential building on the north side of the 2nd Ring Road of Beijing, adjacent to 2 commercial office buildings and 1 government office building. The prime parking demands were generated from the aforementioned buildings and the residential building itself, according to the field survey.

The target building consists of a two-level underground parking garage and some on-street parking spots. Moreover, the variety of parking lot types in the same residential building appropriately met our requirements for data analysis. As depicted in Figure 2, the on-street parking zone extends less than 200 m and lies along the alley across from the major buildings. The underground parking garage has an entrance and an exit for automobiles separately along the parking zone areas.

The borrowers' parking spot selection procedure follows specific guidelines or rules. The app also provides basic information regarding the available spots, including the parking spot type and the designated floor (i.e., No.2 spot in B1 of the underground garage). Users usually check the parking spots visually, before selecting the most desirable spot, and then place the order. Thus, the parking location decision is made according to the temporal and physical information of the shared spot. Parking prices are fixed at 5 yuan (0.8 USD) per hour throughout the day from 9:00 am to 7:00 pm and 1 yuan (0.2 USD) per hour for the remaining 24-hour period. The automatic charge unit is per 15 min, and the charging scheme is the same during workdays and weekends.

3.2. Data Processing. Study data was truncated from all continuous operation records for a whole year, spanning from 2015/11/01 00:00:00 to 2016/10/31 23:59:59. Eligible spots had to have open-time records. Since seasonal heterogeneity influences the travel behavior of both owners and borrowers, the samples were aggregated per spot per month. In the data preprocessing, a missing item check was firstly conducted. In this one-year record, rental records were complete and correct after comparing with the payment records. But the sharing time in open-time records cannot fully cover the rental time due to the missing of open-time records. To complement this data, we traced the operation

records of the parking lock and inferred the most likely opening time from the rise and fall records of the parking lock. In addition, the outlier check was also conducted. The condition of leaving time of borrowers' cars later than the ending time of owners' preset sharing time was manually corrected by adjusting to the actual departure time. Besides, the data-desensitization made more than one car with the same license plate number exist in the residential parking area at the same time. In that case, manual identification was required. Based on the confirmation of the accuracy of the data, duplicate data, due to users' repeated operation and hardware errors, were selected and deleted. As a result, a total of 506 samples were collated, representing 64 spots signifying various types of scenarios. Some spots are open for sharing but do not have rental records, thereby indicating that no borrowers chose these spots for parking. These samples are also included in our analysis, so as to explore potential reasons for nonselection.

Variables were cataloged into three specific types: the physical spot characteristics, the temporal spot characteristics, and the rental effect variables. Physical spot characteristics were adopted to assess the impacts from the parking spots' unchangeable features. Temporal spot characteristics depict owners' sharing behavior, while rental effect variables were proposed to evaluate the outcomes. Table 1 reflects the detailed descriptions of the variables.

The physical spot characteristics group includes 8 variables. The spot type and floor constitute the fundamental factors of the parking spots' physical characteristics. The ease of parking is determined according to the experiential judgment of local parking attendants and is mainly based on the parking direction and available parking area (see Figure 2). Visibility is also used to describe the difficulty of finding spots by whether they can be seen at the entrance of the floor. As for the distance variables, disO1, disO2, and disG represent the distances between spots to the gates of the three surrounding buildings, and disR is the distance to the nearest elevator in Residential Building A. Since Residential Building A has two gates, the shortest path was adopted as being the most convenient and popular.

The peak parking demand was defined and extracted from the records. It is also testified that vacant spots existed for any time during the day throughout the course of this study. Therefore, no spillover demand existed and the rental effects could also accurately reflect the actual demand. The statistics result also depicts the total rental time per day on workdays and was 2.35 times that of weekends. Furthermore, the total rental time per hour in the daytime (9:00 am to 7:00 pm according to the pricing standard) was 2.56 times that of night rentals. Moreover, the cumulative drive-in and drive-out vehicle counts for each hour were calculated from the rental records (as seen in Figure 3). If the drive-in vehicles outnumbered the drive-out at a certain hour, the difference between the drive-in and drive-out vehicle numbers remained positive for that hour. From the time distribution curve of the borrowers' in and out behavior in Figure 3, it appears obvious that the difference between the drive-in and drive-out vehicle numbers remained positive from 7:00 am to 10:00 am and then trended to zero. Thus, the

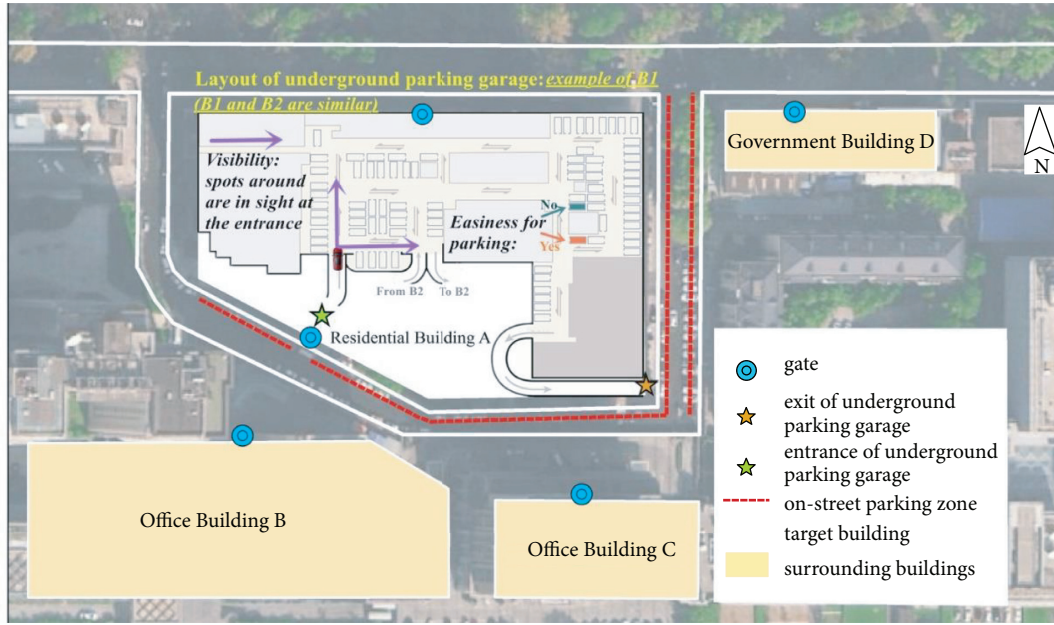


FIGURE 2: Location of the research area.

TABLE 1: Descriptive statistics of variables.

Variable	Description	Min	Max	Mean	SD	Skewness	Kurtosis
<i>Rental effect variables</i>							
rtprofits	Total profits from rental (¥)	0	2008	241.41	329.97	1.14	3.59
rtevents	Total rental events	0	93.00	13.08	15.30	1.72	3.63
rtdays	Total rental days	0	31	7.93	7.94	0.92	0.02
rtDtime	Total rental time in the daytime (hours)	0	309.61	42.08	54.58	1.80	3.50
rtPtime	Total rental time in peak hour of shared parking on workdays (hours)	0	69.00	8.25	12.84	1.99	3.72
rtATime	Average rental time per time (hours)	0	21.00	3.27	3.28	1.72	3.63
rtADtime	Average rental time per day (hours)	0	23.98	4.77	4.61	1.22	1.75
Turnover	Turnover rate per day	0	4.00	0.88	0.76	0.69	0.11
Utilization	Percentage of total rental time in total sharing time	0	1	0.26	0.25	0.73	-0.49
Putilization	Percentage of rental time in sharing time during peak hour	0	1	0.25	0.28	0.78	-0.67
<i>Temporal spot variables</i>							
osTime	Total sharing time (hours)	0.10	743.99	199.33	191.66	1.44	1.37
osDtime	Total sharing time in the daytime (hours)	0	310.00	115.36	81.06	0.61	-0.28
osWDtime	Total sharing time on workdays (hours)	0	551.99	159.56	140.47	1.17	0.57
osWDDtime	Total sharing time in the daytime on workdays (hours)	0	230	95.89	64.37	0.28	-1.02
osPtime	Total sharing time in peak hour of shared parking on workdays (hours)	0	69.00	23.49	19.86	0.64	-0.76
osdays	Total sharing days	1	31	14.01	8.59	0.26	-0.86
ostimes	Total sharing times	1	44	14.89	9.41	0.45	-0.37
osATtime	Average sharing time per time	0	24	11.67	5.69	0.70	-0.13
osADtime	Average sharing time per day	0	24	12.23	5.85	0.59	-0.43
osFre824	Percentage of sharing records of more than 8 hours in workday records	0	1	0.74	0.32	-1.22	0.27
<i>Physical spot variables</i>							
Type	0: underground/1: on-street	0	1	0.53	0.50	Dummy variable	
Floor	1: on-street/2: basement 1(B1)/3: basement 2(B2)	1	3	1.71	0.82	0.59	-1.27
Ease	0: not easy for parking/1: easy for parking	0	1	0.27	0.45	Dummy variable	
Visibility	0: not visible at entrances of each floor/1: visible at entrances of each floor	0	1	0.56	0.50	Dummy variable	
disO1	Distance between spot and gate of Office Building B (meters)	6	167	104.96	39.40	-0.78	-0.20
disO2	Distance between spot and gate of Office Building C (meters)	6	245	119.19	79.56	-0.057	-1.764
disG	Distance between spot and gate of government building D (meters)	58	259	161.34	60.91	-0.59	-1.28
disR	Distance between spot and nearest elevator of residential building a (meters)	20	197	88.21	59.16	0.51	-1.36

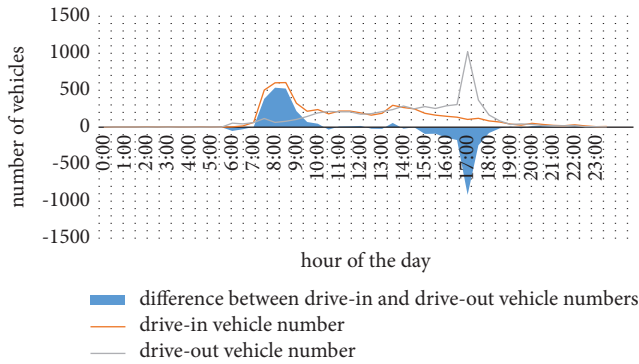


FIGURE 3: Time distribution of borrowers' in and out behavior.

supply ability from 7:00 am to 10:00 am is quite crucial for sharing effects. In this paper, the timespan from 7:00 am to 10:00 am is defined as the peak hours for shared parking. Other time-related variables include workdays and daytime hours.

The temporal spot group comprises 6 accumulative factors, including $osTtime$, $osDtime$, $osWDtime$, $osWDDtime$, $osPtime$, and $osdays$, in order to accurately calculate the total sharing time at different statistical periods, especially at the predefined peak of parking demand. Moreover, two more factors, $osATime$ and $osADTime$, represent the average sharing time span per time and per day and are also included in the study. Moreover, $osFre824$ depicts the percentage of long-time sharing behavior of the total sharing times during workdays. Since the records are truncated by day, the long-time sharing behavior had to occur in a day without a break.

The rental effects were judged from both individual and societal perspectives. Individuals tend to focus more on the total profits and other factors that may influence profits. Both the frequency and duration of rental events were considered. The influential factors include the total profits ($rtprofits$), the total rental events ($rtevents$) and days ($rtdays$), and total rental time at the predefined peak of parking demand ($rtDtime$, $rtPtime$), along with the average rental time per time ($rtATime$) and per day ($rtADTime$), respectively. The collective society assesses the rental effect differently by using four influential factors consisting of the following: the total profits ($rtprofits$), turnover rate ($turnover$), the utilization rate throughout the day ($Utilization$), and the predefined peak hour of shared parking ($PUttilization$). The profits are adopted on behalf of the revenue, which is highly related to the profits and also a major concern of society, whereas the utilization describes the percentage of rental time during the sharing time period. The turnover rate, which represents the number of borrowers the spot served in a day, is the value of the total rental events divided by the total sharing days.

4. Method

The interrelationship among the aforementioned variables is complex. The rental effects are represented by multiple variables, and every variable might pose a direct or indirect

influence on the rental effects. Thus, in order to adequately explore the complex interrelationship among the aforementioned variables and estimate their influence on rental effects more precisely, Structural Equation Modeling (SEM) was adopted in this study. SEM has been widely employed in empirical research to investigate relationships between measured variables (observed) and unmeasured variables (unobserved). The methodology for our study purpose is briefly introduced in this section.

SEM models focus on a series of regression equations, which are ascertained by analyzing covariance structures. SEMs have two components, a measurement model and a structural model. Moreover, there are two types of measurement models, i.e., reflective measurement and formative measurement (see Figure 4). In reflective measurement, measures denote effects (or manifestations) of an underlying latent construct [22]. A fundamental characteristic is that a change in the latent variable initiates a variation in all measures, simultaneously; furthermore, all measures must be positively intercorrelated [23]. Therefore, causality is reflected from the construct to the measures. For example, the latent variable η represents the owners' sharing willingness shared by all items x_i , such as the owners' total sharing time and total sharing days, thereby reflecting the construct, with each item corresponding to a linear function relating to its underlying construct plus measurement error:

$$x_i = \lambda_i \eta + \varepsilon_i, \quad (1)$$

where x_i is the i^{th} indicator of the latent variable η , ε_i depicts the measurement error for the i^{th} indicator, and λ_i represents a coefficient (loading) capturing the effect of η on x_i . Generally, reflective measurement models having three or more indicators are identified and can also be estimated [24].

The formative measurement model was proposed since, in specific cases, measures exhibit negative or zero correlations, despite capturing the same concept [25]. In this model, measures are causes of the construct, rather than its effects [26]. Some typical examples are socioeconomic status [27] or quality of life [28]. In this study, the spots' physical factors were measured by their types, floors, space, etc. The formal specification of the formative measurement model is

$$\eta = \sum \gamma_i x_i + \zeta, \quad (2)$$

where γ_i is a coefficient capturing the effect of indicator x_i on the latent variable η , and ζ represents a disturbance term. It is believed that any validity assessment for formative indicators is unnecessary [29]. In the formative model, the latent variable is the dependent variable and the indicators are the explanatory variables.

The structural model is concerned with how the model variables are related to one another. In this study, the rental effect is assumed to be affected by unchangeable, physical spot variables and the changeable owners' behavioral variables. The interrelationship between the latent variables is described by the structural model, which is expressed as follows:

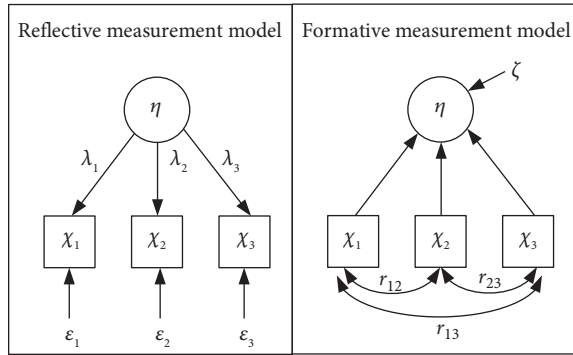


FIGURE 4: Illustration of reflective and formative measurement models.

$$\eta = B\eta + \Gamma\xi + \varepsilon, \quad (3)$$

where B is an $n \times n$ matrix of the coefficients relating the endogenous latent variables η to each other through a structural relationship, Γ is an $n \times m$ matrix of coefficients relating the exogenous latent variables ξ to the endogenous latent variables η , and ε is an $n \times 1$ random vector of the residual errors in the equations.

SEMs allow for direct, indirect, and associative relationships to be explicitly modeled. Consider the rental effect may be directly affected by the spots' physical-temporal factors. Spot-physical factors probably pose an influence on other spot-temporal factors. That makes rental effects indirectly affected by spot-physical factors.

In this study, multivariate normality of Rental Effect Variables and Temporal Spot Variables was checked, along with absolute values for skewness below 2 and kurtosis below 4, as justified by the size of the sample. Both the reflective measurements and formative measurements were concluded in the SEM model.

In the SEM model, the traditional method of parameter estimation is linear structural relationships (LISREL), which assumes that all observations are independent, and the manifest variables obey the multivariate normal distribution [30]. However, the distribution of spots' physical characteristics can hardly obey the rule. In addition, the correlation among spots' temporal characteristics is significant. An alternative method is Partial Least Squares (PLS), which relaxes the assumption of normal distribution and can obtain explicitly estimated latent variable scores directly in the process of parameter estimation [31]. Moreover, PLS can effectively overcome the problems of the small sample size and multicollinearity. Due to these advantages, PLS-SEM is often adopted in shared parking behavior-related researches [9, 16]. Even so, the ten times rule, suggesting the sample size should be at least ten times greater than the maximum number of inner or outer model links pointing at any latent variable in the model, which is the most frequently used rule-of-thumb to estimate minimum sample size in structural equation modeling, should be obeyed [32, 33]. In this regard, our sample size fully satisfies this requirement. As a result, the Partial Least Squares (PLS) algorithm for parameter estimation was deemed suitable. Thus, the software SmartPLS was adopted.

5. Results

5.1. Factors Affecting Rental Effects from Individual Benefit Perspective. The PLS-SEM structure is designed as follows. The latent subjective variables such as owners' sharing willingness and preferences are depicted by Temporal Spot Variables (in Table 1), sourced from owners' one-year operation records. To be specific, owners' sharing willingness is depicted by accumulative temporal factors, since the accumulated sharing time is mostly decided by their mentality. Comparing the accumulated sharing time at fixed periods can represent the differences between owners' sharing willingness while owners' sharing preferences are depicted by average temporal factors, to show owners' behavioral habits of single sharing, such as preference for long-time sharing or short-time sharing. Besides, owners' sharing preferences may also reflect their sharing restrictions due to travel characteristics, like commuting. Of particular note is that owners' sharing preferences are not owners' sharing willingness divided by a fixed number, but the effective frequency varies from sample to sample. For example, osADtime (Average sharing time per day) in owners' sharing preferences is calculated by osTtime (Total sharing time) in owners' sharing willingness divided by total effective sharing days in a month, instead of 30/31 (total days in a month). The spots' physical variables and rental effects variables contribute to two latent variables: formative and reflective, respectively. Finally, four measurement models were built, and the latent variables, including the spots' physical characteristics, owners' sharing willingness, and owners' sharing preferences and rental effects, were defined.

The interrelation between three latent variables has been carefully depicted. Rental effects were influenced by all other variables, while parking spots' physical factors were fixed and could not be affected. However, owners' willingness might be influenced by their own judgments regarding their potential sharing value revealed from their physical characteristics. Furthermore, owners' willingness, as a subjective attitude, may also pose an impact on owners' preferences.

In the individual model, the values of the average variance extracted (AVE) demonstrated the existence of convergent validity by presenting values obviously more than the reference values of 0.5 (AVE for the factor "rental effects" from an individual benefit perspective = 0.843, AVE for the factor "owners' preferences" = 0.825, and AVE for the factor "owners' willingness" = 0.904). The results also prove the existence of a discriminant validity concerning these factors and were evaluated by comparing the values of AVE with the highest square of the correlation among the factors ($r^2 = 0.560$), since all AVE values were higher than 0.560. From the values of the composite reliability (CR), we assessed the existence of a good internal consistency, since the values were higher than 0.7 in all cases (CR for the factor "rental effects" from an individual benefit perspective = 0.975, CR for the factor "owners' preferences" = 0.955, and CR for the factor "owners' willingness" = 0.986). The overall model depicts a good fit with $NFI = 0.92$.

As shown in Figure 5, each latent variable was measured by at least three observed variables. The numbers on the arrows represent parameter estimates of the standardized loading factors, while the numbers in parentheses indicate standard errors and t -values. Apart from the three observed variables titled floor, disO1, and disG, the obtained t -values revealed that other factor loadings were significant at a 95% confidence (t -values were greater than 1.96).

Figure 5 also presents that “owners’ willingness” is the most significant factor which directly affects “rental effects” from an individual benefit perspective (factor loading = 0.60, t -value = 18.89). Additionally, the factor “owners’ preferences” was proved to have a weak but significant connection with “rental effects” (factor loading = 0.09, t -value = 2.67). Moreover, the spots’ physical factors consisted of eight observed variables and had a moderately direct influence on the “rental effects” factor (factor loading = -0.25, t -value = 7.53). The result reveals that type, ease of parking, and visibility exhibit an indirect influence on rental effects; they negatively affected “rental effects”. On-street spots were strongly preferred over underground spots (factor loading = -0.78, t -value = 3.87) and those visible at the entrance of parking floors obviously outweighed those that were not visible at the entrance (factor loading = -0.70, t -value = 4.37). Although ease of parking was also preferred, its influence was quite weak (factor loading = -0.13, t -value = 3.52). The model estimates for the four distance factors imply an existence of imbalance of spots’ location judged by the individual “rental effects.” As in this case, the distance between the spots and Office Building B (disO1) was proved significant at 95% level with a t -value greater than 1.96, while the distances to Office Building C (disO2) and Government Building D (disG) were nonsignificant even at 90% level with t -values lower than 1.65. Moreover, distances to Residential Building A (disR) showed a negative but significant relationship with the latent physical variable. All results suggest that parking spots near Office Building B and away from the center of Residential Building A were preferred by borrowers. In addition, parking spots’ physical factors also revealed a significant influence on “owners’ willingness” (factor loading = -0.33, t -value = 6.50) while “owners’ willingness” had a strong influence on “owners’ preferences” (factor loading = 0.70, t -value = 29.03). Consequently, “spots’ physical factors” and “owners’ willingness” may indirectly affect “rental effects” through changing the sharing preferences.

The total effects among latent variables are listed in Table 2. Finally, the individual model explained 63% of the “rental effects” from an individual benefit perspective through the physical-temporal factors. Among three crucial latent factors, “owners’ willingness” occupied the major responsibility with a total effect of 0.66 ($0.60 + 0.70 * 0.09 \approx 0.66$). “Spots’ physical factors” and “owners’ preferences” contributed to total effects of -0.47 (which is calculated by $-0.25 + (-0.33 * 0.60) + (-0.33 * 0.70 * 0.09) \approx -0.47$) and 0.09, respectively. For owners, considering the physical factors are settled,

improving their willingness to share along with optimizing their sharing preferences would definitely benefit rental paybacks.

5.2. Factors Affecting Rental Effects from a Society Benefit Perspective. Following the same rule as introduced in the section above, the PLS-SEM in the society model was determined as shown in Figure 6. Except for the fact that the definition and observed factors for “rental effects from social benefit perspective” is different from that in the individual model, the latent variables have the same measurement variables and interrelations as in the individual model, so that the factor loadings between the same latent variables can be compared.

The values of the average variance extracted (AVE) demonstrated the existence of convergent validity by presenting values obviously more than the reference values of 0.5 (AVE for the factor “rental effects” from a social benefit perspective = 0.769, AVE for the factor “owners’ preferences” = 0.825, and AVE for the factor owners’ willingness = 0.904). The results also prove the existence of discriminant validity of the factors, which was evaluated by comparing the values of AVE with the highest square of the correlation among the factors ($r^2 = 0.484$), since all the values of AVE were higher than 0.484. From the values of the composite reliability (CR), we assessed the existence of a good internal consistency since the values were in all cases higher than 0.7 (CR for the factor “rental effects” from a society benefit perspective = 0.930, CR for the factor “owners’ preferences” = 0.933, and CR for the factor “owners’ willingness” = 0.985). The overall model shows a good fit with NFI = 0.93.

Regarding the direct influence in the society model (view Figure 6), the order of the influences concerning the latent variables on “rental effects” is listed as follows. The most significant influential factor for “rental effects” was the “spots’ physical factors” (factor loading = -0.40, t -value = 10.04). Furthermore, “owners’ willingness” (factor loading = 0.34, t -value = 7.68) and preferences (factor loading = 0.12, t -value = 2.78) exhibited weaker direct impacts on “rental effects.” Besides, the indirect effects caused by the connections among other latent variables were also significant. “Owners’ willingness” was moderately affected by “spots’ physical factors” (factor loading = -0.30, t -value = 5.64) and then greatly influenced “owners’ preferences” (factor loading = -0.70, t -value = 27.4). These connections contributed to an indirect effect on “rental effects” of -0.13 from the “spots’ physical factors” and 0.09 from “owners’ willingness,” respectively. For factors in spots’ physical characteristics, type (factor loading = -0.87, t -value = 3.14), visibility (factor loading = -0.78, t -value = 4.16), disR (factor loading = -0.50, t -value = 2.96), disO1 (factor loading = -0.47, t -value = 2.05), and ease of parking (factor loading = -0.22, t -value = 2.37) all demonstrated significant connections with the latent physical variable, which subsequently influenced the other latent variables.

The total effects among latent variables are illustrated in Table 3. Finally, the society model explained 45% of the

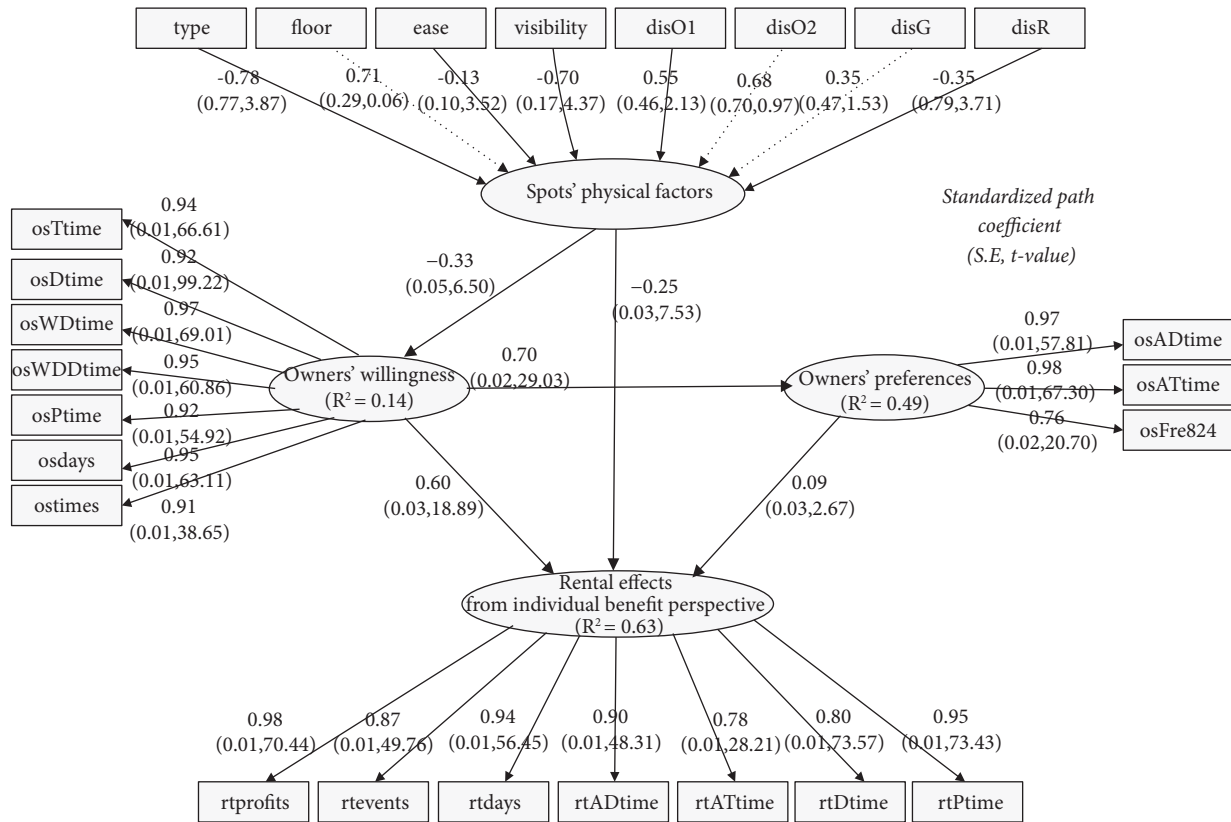


FIGURE 5: Model structure from an individual benefit perspective.

TABLE 2: Effects of latent variables in the individual model.

Path	Total effect	Direct effect	Indirect effect
Owners' willingness \geq rental effects from an individual benefit perspective	0.66	0.60	0.06
Spots' physical factors \geq rental effects from an individual benefit perspective	-0.47	-0.25	-0.22
Owners' preferences \geq rental effects from an individual benefit perspective	0.09	0.09	0

“rental effects” by means of the physical-temporal factors of spots. More specifically, the most significant factor affecting the rental effects is the “spots’ physical factors”, with a total effect of -0.53 . “Owners’ willingness” and “preferences” contributed total effects of 0.43 and 0.12 , respectively. This model reflects the effect of unconstrained behavior choice of both parties on social benefits. Due to the authority of the government, all three latent variables might be changeable with economic tools and administrative measures.

5.3. Comparison between Individual and Society Models. For both the individual and society models, the three independent latent variables are described by the same observed variables along with their interconnection among each other. By building the two PLS-SEM models, our assumptions were confirmed that “rental effects” are impacted by both the physical and temporal characteristics of the spots. Furthermore, the path coefficients between the observed variables and “rental effects” concerning the two models from both perspectives are listed in Table 4. For details, the identical physical variables, including

construction type, visibility, ease of parking, and distances to Residential Building A and Office Building B, were found significant to “rental effects.” However, the other three variables, which include floor, distances to Office Building C, and distances to Government Building D, were found nonsignificant in both models. Thus, on the terms of time usage, “owners’ willingness” played a more important role than “owners’ preferences” on “rental effects” in both models.

As individuals are more concerned about their economic benefits and society pays more attention to the public benefit, while the definition and constitution variables of the dependent latent variable “rental effects” differed in the two models. In other words, different assessment criteria lead to diverse results. The major difference in the two models is the order of dominance of the latent variables. In the individual model, “owners’ willingness” contributed most, followed by “spots’ physical factors” and “owners’ preferences.” The result demonstrates that owners’ recognition of sharing their private parking resource and their practical open-up behavior are rewarded with economic paybacks. However, in the society model, “spots’ physical factors” contributed more

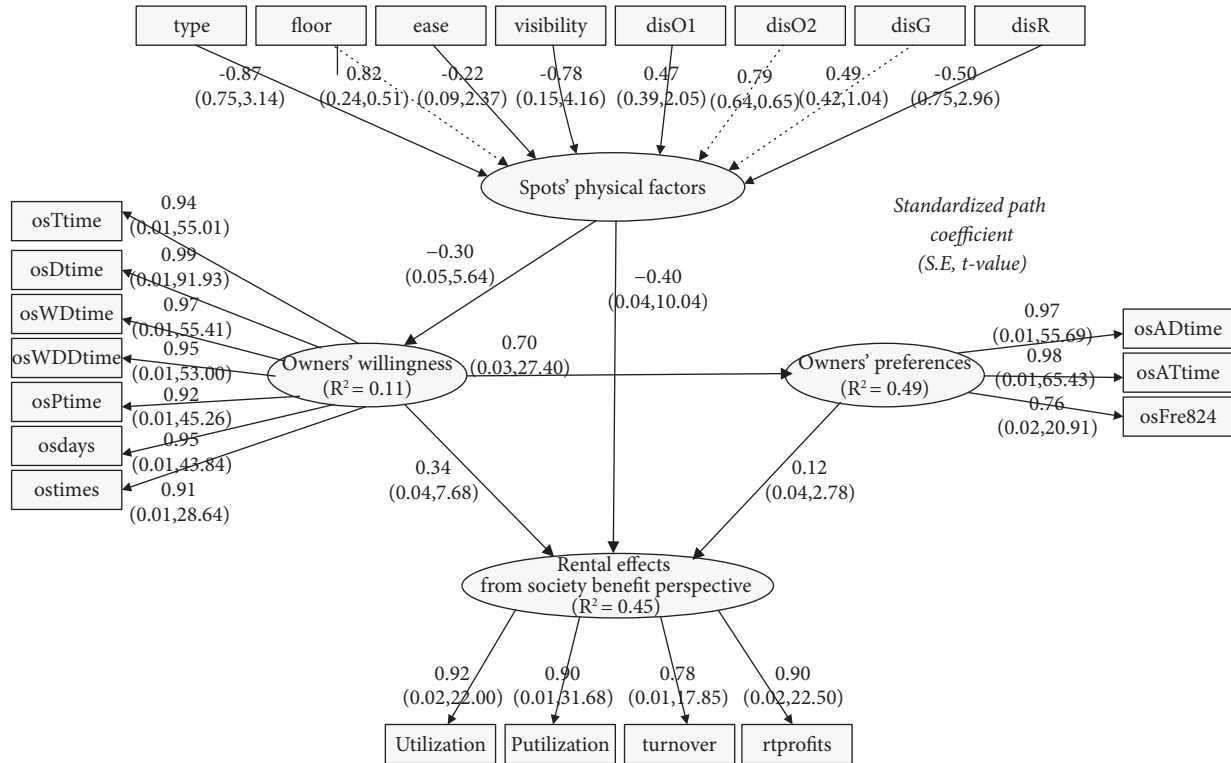


FIGURE 6: Model structure from a society benefit perspective.

TABLE 3: Effects of latent variables in society model.

Path	Total effect	Direct effect	Indirect effect
Spots' physical factors ≥ rental effects from a society benefit perspective	-0.53	-0.40	-0.13
Owners' willingness ≥ rental effects from a society benefit perspective	0.43	0.34	0.09
Owners' preferences ≥ rental effects from a society benefit perspective	0.12	0.12	0

TABLE 4: Effects of observed variables on rental effects.

Observed variables	Individual benefits	Society benefits	
Spots' physical characteristics	Visibility	0.33	0.40
	Construction type	0.37	0.44
	Ease of parking	0.06	0.11
	Distance to Office Building B	-0.26	-0.24
	Distance to Residential Building A	0.16	0.26
	Total sharing time	0.70	0.46
	Total sharing time in the daytime	0.72	0.43
Owners' sharing willingness	Total sharing time on workdays	0.68	0.44
	Total sharing time in the daytime on workdays	0.69	0.45
	Total sharing time in peak hour on workdays	0.72	0.47
	Total sharing days	0.69	0.45
Owners' sharing preferences	Total sharing times	0.73	0.47
	Average sharing time per day	0.09	0.12
	Average sharing time per time	0.09	0.12
	Percentage of sharing records of more than 8 hours on workdays	0.12	0.16

Note: spots' physical characteristics adopt equation (1) of the formative model, such as $-0.70 * (-0.25 + (-0.33 * 0.60)) + (-0.33 * 0.70 * 0.09) \approx 0.33$ for visibility in the individual model; owners' sharing willingness and preferences adopt equation (2) of the reflective model, such as $(0.60 + 0.70 * 0.09) / 0.94 \approx 0.70$ for total sharing time in the individual model.

than “owners’ willingness” and “preferences.” It reflects that preferred spots exhibit similar physical characteristics and that they are better utilized during sharing time and serve more borrowers.

Moreover, despite the strong connection between “owners’ willingness” and “preferences,” their influences on two “rental effects” trended quite differently (as seen in Table 4). The direct effect of “owners’ willingness” revealed an obvious decline from 0.60 in the individual model to 0.34 in the society model, while the “owners’ preferences” slightly increased from 0.09 in the former model to 0.12 in the latter. Hence, a high sharing willingness may generate more opportunities to attract borrowers and increase incomes, which benefit the individuals involved more than society. On the other hand, appropriate sharing preferences contribute more to society’s interests than that of individuals, since they may better facilitate borrowers’ parking plans and effectively promote resource utilization.

6. Discussion and Policy Suggestion

Residential parking spot sharing is a new method to balance parking demand and supply. According to the results in Table 4, an improvement in the observed variables would benefit the rental effects from both sides. Thus, based on the findings in our study, suggestions will be proposed to increase individual and social profit, and are discussed in this section.

The results illustrate that the utilization and turnover rates of on-street residential spots are higher than those underground. It is a great waste that large amounts of underground parking resources are vacant, while those occupying road resources are almost full. Therefore, improving the price or the revenue of on-street spots and decreasing that of underground spots might be beneficial for this situation. The visibility of parking spots also matters. Currently, the precise locations of the spots are not available on the app, and borrowers attempt to locate these spots mainly by themselves, thereby leading to spots that are hard to find being unpopular. We believe that, with the help of indoor parking guidance facilities or the spot map on apps, this situation might be improved. The test regarding the distances to surrounding buildings revealed that spots far away from the center of Residential Building A and near Office Building B were more welcomed in this study area. Hence, a differential pricing scheme might be adopted, so as to balance the popularity that stems from the distances to the surrounding buildings.

Furthermore, the findings of our study can also assist owners in predicting the benefit of engaging in parking spot sharing or for new residents to select the best parking spot for a future rental. For example, some owners have not decided to install a lock and share their parking spot, because they are highly unsure about the rental effects and potential profits. Based on the models constructed in this study, the potential rental effects can be predicted quantitatively by inputting the detailed physical characteristics of the spots and the owners’ sharing time plan. This will allow the owners to reevaluate their decisions and appropriately adjust their

sharing strategies. For the residents who plan to own parking spots and want to share their parking resources in the future, the discoveries in this paper might be beneficial when selecting the location of spots. Therefore, it is advised to select an on-street parking spot, or not-on-the-street but easy-to-find spot. Strong preferences include areas that are easier for parking and closer to certain surrounding buildings.

Moreover, the suggestions above would probably benefit society but may also raise conflicts among individuals. Specifically, it serves society’s interests to charge for the more desirable spots over those less desirable, in order to boost the total utilization and, furthermore, balance the profits of the different spots. However, owners may feel this is unfair since they cannot decide on their own price for their private resource, especially for owners of those welcomed spots whose interests might be harmed. In addition, as the cost of a parking spot is only decided by the spots’ type under the current circumstances, a compulsory differential parking scheme based on more physical characteristics might be unacceptable for some owners. As a result, it may be more reasonable to charge the owners diverse prices for different spots and encourage them to set a rental price based on their own costs.

Unlike the physical features, the temporal features of parking spot sharing can be wholly decided and changed by the owners’ subjectivities. Hence, a smart sharing strategy will refine the sharing schedule and benefit both society and individuals without significantly affecting owners’ daily life. Moreover, the rental effects would be improved if the sharing time is in accordance with the peak of parking demand, like in the daytime, on workdays, or from 7:00 am to 10:00 am. Additionally, the result of this study determined that a longer sharing time will boost the rental effects. Apart from rental paybacks generally growing with the total sharing time, spots with a longer sharing time stand better chances since they may better serve borrowers’ parking plans and be more accessible for selection by the borrowers as borrowers will determine an appropriate ending time for the sharing when they select a targeted parking spot.

Furthermore, a differential pricing scheme based on the timespan of the sharing behavior may also be considered. For society, charging the unit price of those long-opened over those short-opened spots may be an effective way to optimize parking demand distribution among available parking resources. It would also encourage borrowers to refine the parking plans and make logical decisions for their spot selection. Thus, the parking resource would be better utilized with less manual interventions. However, for individuals, a differential pricing scheme may offer a more fair opportunity to those owners with a high sharing willingness but scattered available sharing time. Since their spots are less possible to be chosen with a unified price, a lower parking price may increase the attraction of the spot and promote their profits. However, it may result in complaints from those long-open owners, since they may lose a portion of their customers. Therefore, it may be more effective and fair to adopt a differential pricing scheme based on the timespan of sharing behavior during the peak times of parking demand and maintain a unified price during other times.

7. Conclusions

This study evaluated the residential parking spot rental effects from individual and beneficial social perspectives. Based on a one-year behavioral record of both owners and borrowers that was obtained from a parking app and the field survey, the PLS-SEM models were estimated to analyze the data. The influential factors concerning parking sharing effects from parking spots' physical characters and owners' temporal operational aspects were first clarified. Next, the contributing factors and their influences on the rental effects from an individual and society's perspectives were calculated, respectively.

The results revealed that the parking spots' physical factors, along with owners' sharing willingness and preferences, all posed significant influences on the rental effects from both perspectives. The physical factors, including type, visibility, ease of parking, and distances to certain buildings, were proved significant to rental effects, while the floor and distances to other buildings were nonsignificant. The major contributing factors were different in the two models. For the individual model, owners' sharing willingness was the main reason, while pertaining to the society model, spots' physical characteristics appeared to be more important than others.

The study helps to introduce a clearer understanding of the relationship between the physical-temporal factors and rental effects. Findings toward the influences of spots' physical factors and owners' sharing behavior on rental effects provide tangible and useful information in developing strategies to promote rental effects. Particular strategies that would benefit both individuals and society were also discussed. In our future studies, a dynamic charging strategy will be proposed to better balance the parking demand and supply and increase the benefits for both individuals and society.

Data Availability

The data that support the findings of this study are available from Beijing Tongyudao Technology Co., Ltd. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the corresponding author with the permission of Beijing Tongyudao Technology Co., Ltd.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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