EMPIRICAL EVALUATION OF AN ON-STREET PARKING PRICING SCHEME IN THE CITY CENTER

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ABSTRACT

Parking pricing policies can be used as a policy instrument to steer the parking market and reduce the externalities caused by traffic in general and parking in particular. A more efficient management of parking demand can improve the utilization of the limited parking capacity at high-demand areas. Even though parking policies are often a topic of public debate, there is lack of systematic empirical analysis of various parking measures. This paper proposes a methodology to empirically measure and evaluate the impacts of on-street parking policies. The utilization of on-street parking demand is computed based on transaction data from 70 ticket vending machines which is calibrated using floating car films. Measures of parking utilization such as occupancy and its temporal variation, throughput, parking duration and turnover are compared prior and following the introduction of a new parking scheme in the center of Stockholm, Sweden, in September 2013. The results indicate that the policy led to a reduction in parking occupancy although it did not yield the 85% occupancy level objective. Furthermore, the price increase has contradictory effects on throughput and turnover due to the interaction between parking occupancy and duration. The results also question the transferability of price elasticity. It is thus recommended to consider multiple measures of parking utilization when carrying out policy evaluation.

1. INTRODUCTION

The rapid growth of motorization in combination with urbanization has led to an increase in traffic demand and consequently increased saturation of the road network. Transport systems are characterized by limited supply due to financial, physical, urban and ecological reasons. It is therefore essential to effectively manage transport demand. One of the major problems associated with increase of traffic is the acute shortage of parking space. This shortage arises even though parking facilities consume a substantial share of the urban environment. In Stockholm, Sweden, about 15% of street surface in the city is used for car parking [*1*].

Pricing policies constitute a set of transport demand management aimed to improve the utilization of a limited capacity. Parking fees can potentially be a useful policy instrument to steer the parking market and reduce the externalities caused by traffic in general and parking in particular. Pricing policies provide a directly accessible and important supply management tool that could be adjusted to adhere to changes in demand levels in order to improve the utilization of the limited parking capacity at high-demand areas. In the case of an underpriced parking, negative impacts include the additional cursing traffic and related accessibility and environmental impacts in addition to its influence on the primary modal choice. Compared with congestion pricing, the introduction of parking policies is simpler, cheaper and politically acceptable [*2*] and hence common-place.

Although charging parking fees is a common practice in urban areas, there is no common framework for evaluating the impacts of on-street parking pricing. Arguably, this stems from the fact that most studies relied on either manual parking counts or stated preferences surveys. This hinders the systematic analysis of changes in parking utilization and a robust empirical assessment of parking measures. Moreover, even though parking policies are often a topic of public debate and policy making, there is lack of systematic empirical analysis of parking pricing measures.

This paper proposes a methodology to empirically measure and evaluate the impacts of on-street parking policies. We investigate the utilization of on-street parking demand through automatic transaction data from ticket vending machines which is calibrated using films collected by a floating car. Measures of parking utilization such as occupancy and its temporal variation, throughput, parking duration and turnover are compared before and after the introduction of a new parking scheme in Stockholm in September 2013. The objective of this scheme is to reduce the pre-experiment level of parking occupancy which indicated that parking is underpriced and to reduce related externalities. The method presented in this paper could be applied in other urban areas that utilize a similar ticketing system.

The remainder of this paper is organized as follows: methods to analyze parking policies and previous findings on the impact of parking pricing measures are reviewed in Section 2. The methodology proposed in this study for measuring the impact of parking policy on parking utilization indicators are then presented in Section 3 followed by their application to a case study in Stockholm. The paper concludes with a discussion on the impact of the policy and suggestions for further studies.

2. LITERATURE REVIEW

On-street parking limits street capacity since it preempts lanes that otherwise would be used by moving traffic. Furthermore, parking maneuver reduce the capacity and the average speed of the adjacent lanes [*3*]. On-street parking is often underpriced [*4*]. The inefficient management of parking demand results in excessive search time for parking [*5*] and constitutes a significant contributor to urban congestion [*6,7*]. Based on previous findings, Shoup [*8*] estimated that 30% of the traffic in the city center is attributed to cruising traffic.

Previous studies highlighted the role of regulating on-street parking policies by charging fees or enforcing a maximum parking duration as measures to reduce cruising traffic or as a second-best strategy to effect transport demand [*7*,*9*-*15*]. These studies deployed different approaches to investigate the elasticity to a change in parking fees including the development of analytical economic models and estimating elasticity based on empirical stated or revealed preference survey.

Parking pricing policies, their design and impacts have attracted a significant research attention. Parking guidelines suggest that the optimal pricing will obtain a 85% parking occupancy [*8*,*16*]. Using a simulation model, Levy et al. [*17*] demonstrated how an occupancy rate above 92-93% result with a sharp increase in cruising time which depend on spatial dynamics. However, parking occupancy level may not reflect the overall parking utilization level as the same occupancy might correspond to different parking circulation (e.g. number of cars using a parking place throughout the day).

A large range of parking fee elasticity values was reported by previous studies. A TCRP review concluded that parking demand is generally inelastic to price and emphasized that price elasticity could be deceptive without considering the specifics of the price change circumstances [*18*]. The original pricing level, the possibility to shift parking location and availability of parking substitutes, as well as accessibility by other transport modes will all influence the behavioral response to parking policies [*12*,*19*].

Behavioral adaptation can take place throughout the parking decision process. Hilvert et al. [*20*] distinguished between three stages: pre-trip, en-route passive search and local search strategy. While modal shift, trip cancellation and destination choices may take place at the pre-trip phase, substituting on-street with off-street parking and parking in lower priced streets further away can take place at the tactical and local levels [*21*]. The extent of these adjustments as well as parking duration depends on individual and trip characteristics [*22*,*23*].

The trade-off between parking alternative attributes were estimated by previous studies. Axhausen and Polak [*6*] found that the walking time from the parking place to the destination is valued more than the in-vehicle access time. This presumably underlies the cruising traffic that circulates within a small radius from the destination. Hilvert et al. [*20*] concluded based on stated and revealed preference data that price – both in terms of the overall parking cost as well as the hourly fee - is the dominant factor in parking-related decisions.

Several recent studies analyzed parking pricing policies based on ticket machines data. Kelly and Clinch [*24*] analyzed the impact of a 50% price increased in the commercial core of Dublin on the total number of cars parking during different time periods. Their results highlight the importance of considering temporal variations in parking demand and price elasticity with the average price elasticity being -0.29. Similarly, Ottosson et al. [*25*] estimated the elasticity based on before-after analysis of ticket machines data in Seattle. The performance-based policy implied an increase, decrease or no change in parking fees based on the discrepancy between measured and desired occupancy levels. Parking elasticity was found to change by time of day and neighborhood characteristics. They also note that average parking duration also changes as a result of price changes. Similarly to these two studies, this paper utilizes data from on-street ticket machines to perform a before-after analysis of a parking pricing policy. An enriched analysis approach calibrates the machine data with floating car data for calculating a series of parking utilization indicators as detailed in the following section.

3. METHODOLOGY

This section presents a methodology for measuring parking utilization. Three data sources are considered in this study: (a) transactions from on-street ticket vending machines; (b) floating car video films, and; (c) on-street parking supply repository. The following explains how these data sources are processed, integrated and used for computing measures of parking utilization.

On-street ticket vending machines provide a direct and automatically collected data on revealed-preference parking choice. This enables a wide spatial coverage throughout a long time period without an additional cost. Each transaction on a vending machine is recorded in a parking database management system. A record on machine j contains information on the incoming and outgoing time stamps for transaction $i \in I_j$, $\tau_{i,j}^{+}$ and $\tau_{i,j}^{-}$, respectively. I_j denotes the set of transactions of a vending machine situated at street block j.

The load on street block j at time t based on the ticket machine data, $\widetilde{l_{j,t}}$, is the residual between the sum of all incoming and outgoing flows. Alternatively, it could be calculated as the sum of transactions that started prior to t and finished later than time t:

$$\widetilde{l_{j,t}} = \sum_{i \in I_j} \delta_{i,j}^{+}[0,t] - \sum_{i \in I_j} \delta_{i,j}^{-}[0,t] = \sum_{i \in I_j} \left(\delta_{i,j}^{+}[0,t] \cdot \delta_{i,j}^{-}[t,\infty]\right) \qquad (1)$$

Where $\delta_{i,j}^{+}[t_1,t_2]$ and $\delta_{i,j}^{-}[t_1,t_2]$ are dummy variables that indicate whether the incoming or outgoing record, respectively, occurred within the respective time window. This implies that $\delta_{i,j}^{+}[t_1,t_2]$ equals 1 if $t_1 < \tau_{i,j}^{+} < t_2$ and 0 otherwise and similarly for $\delta_{i,j}^{-}[t_1,t_2]$.

The parking load derived from the ticketing machines may not reflect the actual parking load on the corresponding street block. Vending machine data does not contain information on vehicles that are exempted from paying a fee (e.g. street residents, hybrid vehicles), those paying with other means (e.g. SMS) and illegal parking. In addition, it contains the time stamps corresponding to the ticket issuing and the expected departure time which may differ from the actual departure time. Furthermore, drivers may issue a ticket from a vending machine that is not located directly next to where they parked. Assuming that drivers use the closest vending machine and a good coverage of vending machines, this should not distort the analysis.

Floating car data is used in this study to calibrate data collected by ticketing machines. We start by processing the vending machine data to calculate the momentary parking load on each street segment. The actual number of vehicles parking on each street block is then obtained from video films collected by the floating car on several weekdays. Data from manual parking survey could be used for the same purpose. By comparing the actual load on block j at time t, $l_{j,t}$, and the respective $\widetilde{l_{j,t}}$, *measurement ratios* between machine and ground-truth are established

$$\omega_{j,t} = l_{j,t} / \widetilde{l_{j,t}} \qquad (2)$$

$\omega_{j,t}$ is used to correct the parking load obtained from machine data for the respective street block and time-of-day periods. Weights may vary for example because of the composition of the parking population (e.g. share of residents) and the prominence of illegal parking. Moreover, weights are computed separately for the before and after periods in order to control for changes in fare collection methods (e.g. new SMS service).

Parking occupancy is an important measure of parking performance as it reflects the intersection between parking demand and capacity for a given price. The calibrated *occupancy rate* is thus calculated as

$$k_{j,t}(p_{j,t}) = l_{j,t} / c_{j,t} \qquad (3)$$

Where $c_{j,t}$ and $p_{j,t}$ are the parking supply capacity and price on street block j on the respective time period. Note that number of available parking places could vary over the day depending on the parking regulation.

The evaluation of parking utilization is not limited to parking occupancy. *Throughput* is a measure of parking circulation and is defined as the number of vehicles that arrive within a certain time window $[t_1, t_2]$ per number of parking places on a certain street block j

$$v_j[t_1,t_2] = \frac{\sum_{i \in I_j}\left(\delta^+_{i,j}[t_1,t_2] \cdot \omega_{j,\tau^+_{i,j}}\right)}{c_{j,t_1}} \tag{4}$$

The *average parking duration* at time t is computed based the elapsed time between incoming and outgoing time stamps of cars currently parking at the respective street block

$$\overline{d_{j,t}} = \frac{\sum_{i \in I_j}\left(\delta^+_{i,j}[0,t] \cdot \delta^-_{i,j}[t,\infty] \cdot \left(\tau^-_{i,j} - \tau^+_{i,j}\right)\right)}{\widetilde{l_{j,t}}} \tag{5}$$

Finally, the *turnover* during a certain time window is calculated as

$$z_j[t_1,t_2] = \sum_{i \in I_j}\left(\delta^+_{i,j}[t_1,t_2] \cdot p_i(\tau^+_{i,j},\tau^-_{i,j}) \cdot \omega_{j,\tau^+_{i,j}}\right) \tag{6}$$

Where p_i is the price associated with parking instance. It might be directly available from the vending machine data or could be assigned based on the pricing policy and as a function of $\tau^+_{i,j}$ and $\tau^-_{i,j}$.

4. CASE STUDY AND DATA COLLECTION

The City of Stockholm implemented a new parking scheme in Stockholm's inner-city in fall 2013. This scheme is designed to address some of the objectives that the city has defined in its overarching mobility program. In line with results from analytical models, the City of Stockholm aims to reach the desirable 85% parking occupancy rate compared with the current level of 90% as measured in the 2011 parking survey [*1*]. The high occupancy level indicated that parking was under-priced, hence leading to an inefficient utilization of parking supply and inducing externalities such as increase in cruising traffic and reduced accessibility. The City of Stockholm decided therefore to increase parking fees on high-demand street blocks in the inner-city. The new scheme was implemented in August 2013.

Figure 1 displays the parking fee areas. The dark green area is the most expensive area with an hourly fee of 41 SEK (1 USD worth approximately 7 SEK). This area extends from the central station surrounding to the central business district (light green). The dark red area covers the commercial citer centre where parking costs 26 SEK per hour. Following the new scheme, this area extends to adjacent streets (light red) as well as the main arterials across the inner-city (Figure 1, right). Hence, the new scheme extends geographically the current parking area borders so that parking fees increase where these areas are extended and remain unchanged on all other streets. Street blocks in the inner-city could therefore be classified into three price change categories:

- *High increase* – hourly parking fees increased by 15 SEK (from 26 to 41 SEK), includes the streets within the light green area
- *Low increase* – hourly parking fees increased by 11 SEK (from 15 to 26 SEK), includes the streets within the light red area and the arterials marked with light red
- *Unchanged* - hourly parking fees remain unchanged, includes all other streets with various price levels ranging from 15 to 41 SEK

The 'Unchanged' category is used in this study for control purposes but has to be treated with caution. In a complex urban area it is not possible to design a perfectly controlled experiment with otherwise identical street blocks simultaneously subject to alternative policy measures. While referring to street categories, the parking demand for individual street blocks is influenced by its micro-environment (e.g. businesses, private parking lot or turning permissions). The 'Unchanged' category consists of streets located in direct proximity to the parking taxation zones; perpendicular or parallel to arterials, or; elsewhere within the inner-city. These street blocks share in common that parking prices remained unchanged during the study period. Nevertheless, it is expected that for those located in proximity to price changes parking utilization will increase as their prices became more attractive in relative terms. The comparison of parking utilization on these streets can be used as a benchmark and shed light on the overall changes in parking patterns. Residents in each area can apply for purchasing a parking card for 800 SEK per month without a guaranteed parking place.

Data concerning street blocks belonging to each of the three street categories was collected. Based on the vending machine coverage and while ensuring the spatial and street category coverage, 70 street blocks and corresponding vending machines were selected for this study. As mentioned in the methodology section, three data sources are considered in this study. Detailed transactions data for the entire *Before* (April-May 2013) and *After* (March-April 2014) periods were extracted and processed using R software environment. The time lag between policy implementation and the *After* analysis period (6 months) was designed to allow behavioural changes to stabilize. The transaction data contains information on ticket id, enter and exit times, total fee and payment details. The corresponding parking supply data includes the total parking length available in meters which was then converted into number of vehicles based on an average vehicle length. Both data sources were made available by the Traffic Office of Stockholm City. In addition, film data was collected through a floating car that is equipped with data logger and GPS system on the following dates: May 7 and May 22, 2013 and April 1 and 3, 2014. In total, 165 and 150 block-level parking load observations were obtained in 2013 and 2014, respectively. The car traversed each of the street blocks at least once per morning, noon and afternoon on both before and after period. The films were then manually analysed to record the number of parking cars per street block. Potential sources for discrepancy between floating car and vending machine data include alternative payment methods, residents with monthly tickets and groups that are exempted from paying parking fees, the parking duration issued in the ticket is longer than the actual parking time, illegal parking and tickets issued by cars parking elsewhere. Since these elements will result in either under- or overestimation of the parking occupancy it is not impossible to determine their overall effect a-priori. Moreover, some of these effects are expected to vary considerably over street blocks.

Other changes in the parking market might take place simultaneously to the introduction of the new parking scheme. For example, the City of Stockholm upgraded a new text messaging payment service. In order to control for the potential changes in the measurement ratios between vending machine data and the ground-truth, the former was calibrated separately for the before and after periods based on the corresponding floating car data. Alternative travel choices may also change during the analysis period. In particular, no considerable changes in public transport and off-street parking supply took place between 2013 and 2014. Off-street prices remained unchanged in parking lots owned by the municipality (blue icons in Figure 1) which make up 40% of the off-street parking supply. It is not clear whether privately owned parking lots changed their fees during the analysis period.

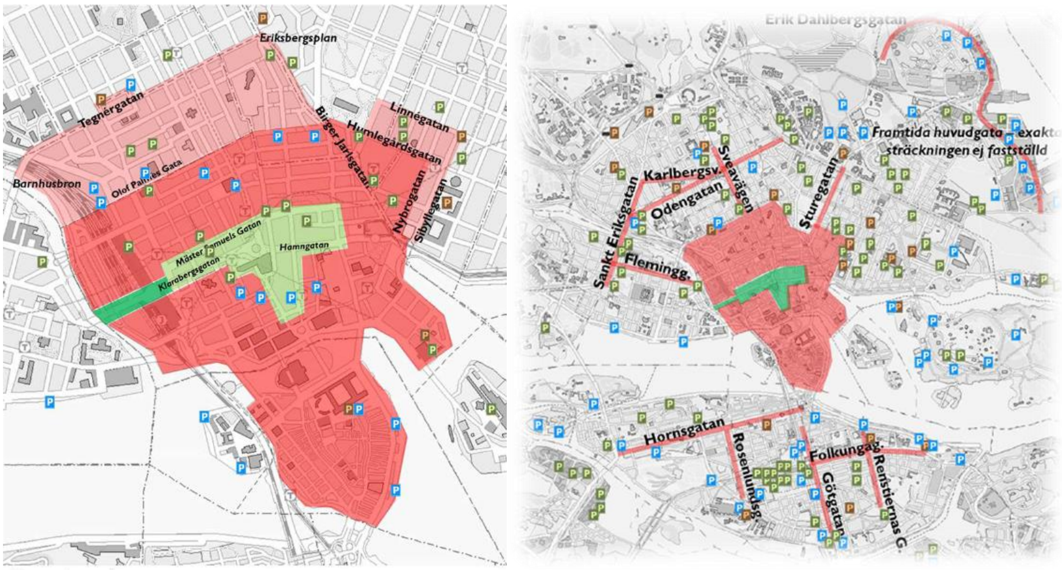

Figure 1 Parking price areas in the city centre (left) and the entire inner-city (right); Source: Stockholmsstad, 2013 [*1*]

5. RESULTS

5.1 Calibrating Vending Machine Data

As explained in the methodology part, the vending machine data was calibrated by comparing floating car data with the corresponding occupancy rates computed based on ticketing transactions. Weight factors were calculated for six different street types based on their location, characteristics and pricing policy. No significant variations were found for different time of day periods for a given street type. Figure 2 presents the average weight factors computed for each set of street blocks in the before and after periods. The weight factors in spring 2013 varied between 0.96 for the high price increase group and 1.06 for the group where price remained unchanged. This suggests that the aggregate occupancy rates obtained from the automatic machines replicates very closely the ground-truth parking conditions for all street types in the before period. As evident in Figure 2, this changes in 2014 as the data processed from the vending machines systematically underestimates the ground-truth occupancy by 20-22 % on blocks where price has changed. This is presumably attributed to the increasing popularity of the abovementioned alternative payment methods. Interestingly, this trend was not observed for the control group where the data sources corresponded very well. A closer investigation revealed that machines located in the city centre followed by the same trend as those where price has changed, while weights for machines located on local and residential streets further out remained at the same level. Based on the results of this data processing phase, a weighting factor was assigned to each street block to calibrate the respective datasets from fall 2013 and fall 2014.

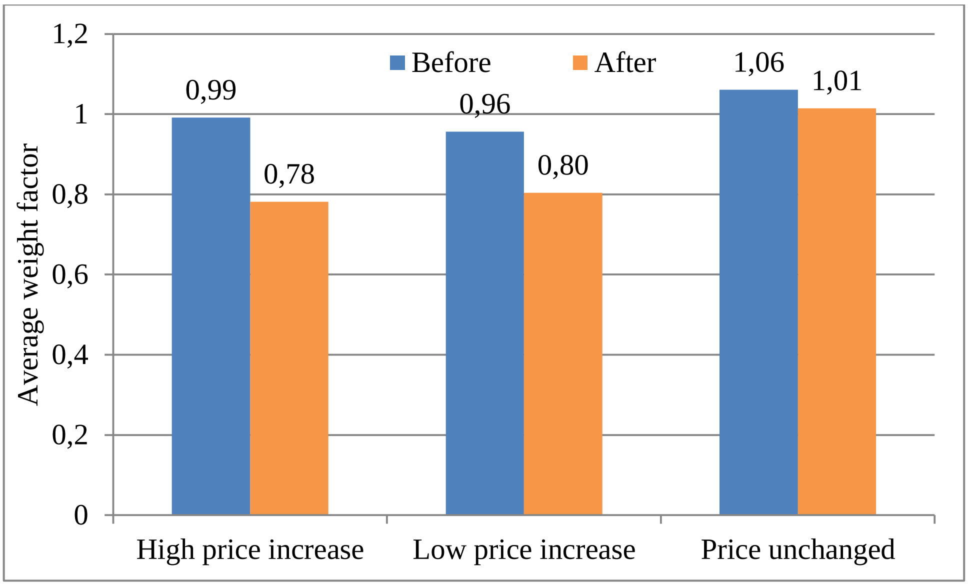

Figure 2 Before and after weight factors by price group

5.2 Overall Parking Occupancy Levels

Although, location and price are inseparable the difference in parking utilization between the before and after periods can arguably indicate the impact of price on parking demand while using the simultaneous change for street blocks without price change as a reference. Figure 3 presents the overall occupancy rates for each street blocks group prior and after policy implementation. In spring 2013, the highest occupancy rate was observed for the 'High price increase' category followed closely by 'Price unchanged'. A pronounced decrease in the average occupancy rate occurred on both categories that were influenced by the increase in parking fees. Hence, it became easier to find a vacant parking space along these street blocks. The magnitude of the decrease in parking utilization corresponds to the degree of price increase. In contrast, the 'Price unchanged' category experiences a moderate increase in parking occupancy which results with an occupancy rate surpassing 0.85.

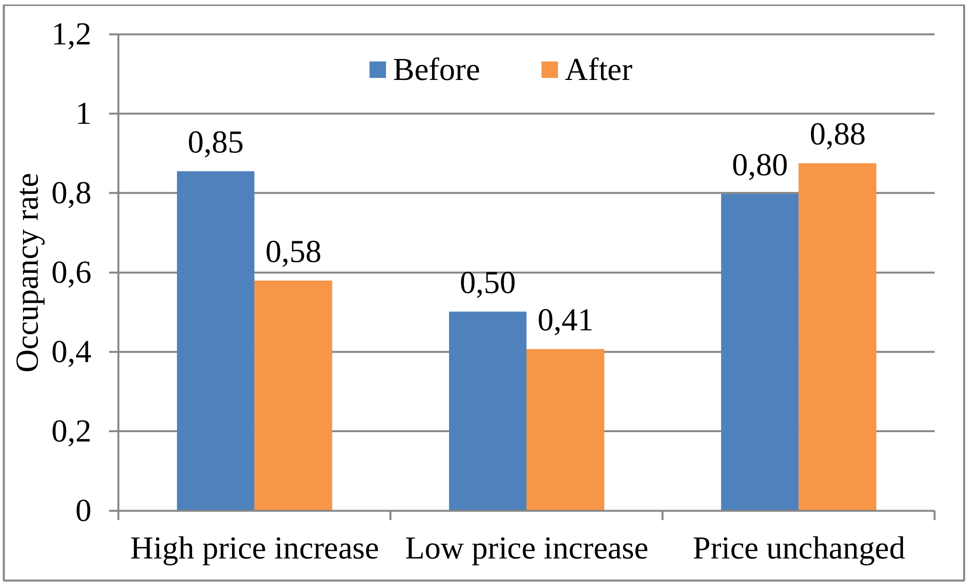

Figure 3 Before and after average occupancy rates by price group

5.3 Temporal Variations

While average occupancy levels are indicative of overall parking utilization, temporal variations in demand are expected to lead to an even parking utilization along the day. Figure 4 plots the average occupancy rate for each street block group over an average weekday before vs. after the policy implementation. It is evident that the aggregate changes observed in Figure 3 occur constantly throughout the day. All of the parking occupancy curves follow the same trend with a sharp increase in occupancy levels in 7-9 that ends with an abrupt decrease that is followed by a further increase (more moderate in the case of 'Low price increase' and 'Unchanged Price') until midday and then small fluctuations between 12:00-15:00 are followed by a gradual decrease. The fluctuations are caused by time lags in the exchange of outgoing and incoming flows.

The noticeable decrease at 9:00 is caused by the way the vending machine handles night parking. Tickets that are issued with a late departure time - when parking is cheaper or even free - are automatically defined to be valid until 9:00 on the following day. This data recording issue results with an inflated occupancy level between 7:00-9:00 but does not hinder the correct clearance of overnight parking from one day to the other and the integrity of parking balance.

It can hence be reasonably argued that for all street blocks the peak in parking utilization is in midday 12:00-15:00. In the before period, the street blocks that were most highly taxes were also the most utilized with the occupancy rate approaching 100% during the peak hours. This changed in 2014 as maximum occupancy on 'High increase' decreased to 70% while 'Unchanged' became the most heavily utilized with a maximum occupancy level close to 100% in the peak hours. The occupancy rates for 'Low price increase' are consistently lower with an occupancy level hovering around 45-50 % for most of the day.

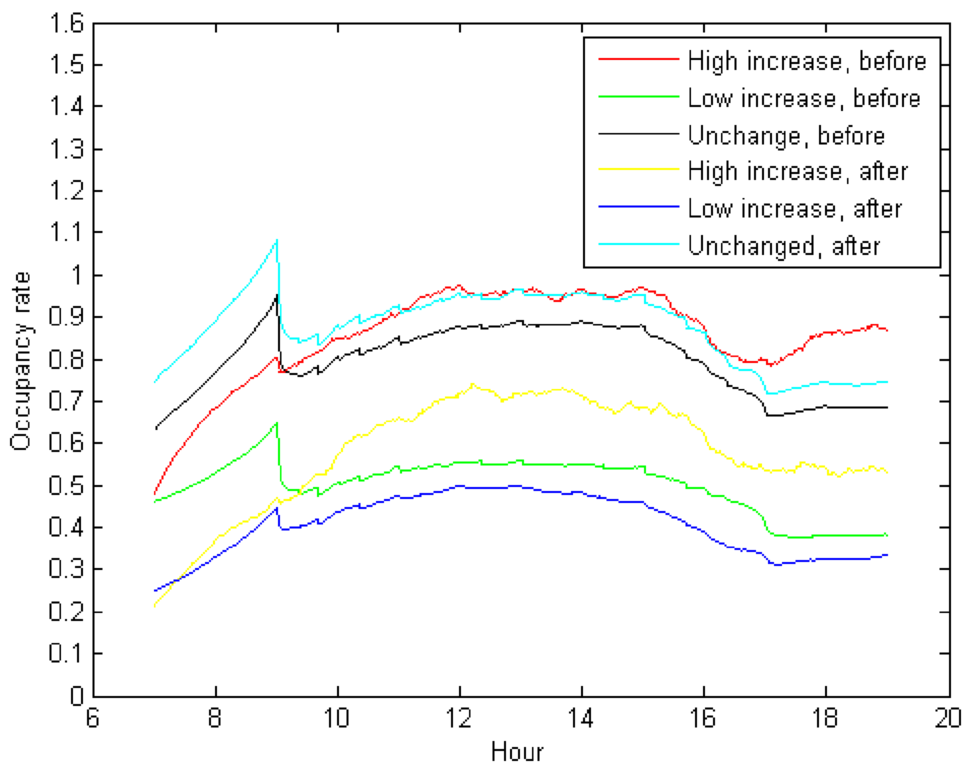

Figure 4 Temporal variations in average occupancy rates by price group and time-of-day, before and after the policy implementation

5.4 Before-After Parking Duration, Throughout and Turnover

A lower parking occupancy does not necessarily imply that fewer cars utilize the parking supply. Table 1 compares the average parking duration, daily throughout – the number of cars using a parking place on an average day, and the daily turnover from ticketing transactions per parking place. Daily figures refer to the analysis period of 7:00-19:00. In the following we will compare the before-after changes for different categories rather than comparing the absolute values because street categories are defined based on the price change that occurred and may be composed of various street types in terms of centrality, land-use etc.

It is evident that all parking measures of performance changed dramatically on those street blocks that were subject to a price increase, while remained almost unchanged where no price changes occurred. This suggests that the price change is the prime driver of behavioural change in parking habits rather than external factors. The average parking duration decreased to less than 1 hour and 5 hours for the 'High increase' and 'Low increase' categories, respectably. The corresponding percentage decreases for these two street types are 72% and 58%, while the parking duration on 'Unchanged' remained at the same level. The average fee per parking car (not shown in the table) decreased by 29% (from 46 to 33 SEK) for 'High increase' and increased by 19% (from 37.5 to 44.5 SEK) for 'Low increase' due to the conjunction of average parking duration and parking fees. Interestingly, people are willing to pay less than they used to on the 'High increase' blocks now that prices have increased substantially resulting with an 'overreaction' – an average payment lower than the initial level.

While the percentage change in parking occupancy and duration corresponds to the percentage change in parking fees, this does not hold true for throughput and turnover. Compared with the 'Before' period, the 'Low increase' streets accommodate more vehicles and generate a higher revenue while 'High increase' sees the opposite, although milder, effect. Throughout is the constantly the highest in the 'High increase' category (3.5-4 vehicles per parking place per day) although it experienced an 11% decrease from 2013 to 2014. Hence, fewer cars parked for a shorter period on these street blocks resulting with a lower parking occupancy. This is also reflected in the 37% decrease in turnover as the higher parking fee per parking car did not compensate for the decrease in total parking hours. In contrast, throughput and turnover on the 'Low increase' streets more than doubled. Throughput levelled from a very low level of half a vehicle per parking place per day prior to the price increase. This stems from the interaction between the long parking duration and the low circulation led to a low turnover. The greater circulation and the higher fees resulted with a 152% increase in the turnover. Although the average parking fee per parking car is now higher for 'Low increase' than for 'High increase', the latter is more profitable due to the greater throughput.

Table 1 Before and After Comparison of Performance Indicators

Street category	Parking Duration [hour]			Throughput [veh/parking place/day]			Turnover [SEK/parking place/day]		
	Before	After	Diff.	Before	After	Diff.	Before	After	Diff.
High Increase	2.87	0.82	-72%	4.00	3.55	-11%	183.74	116.36	-37%
Low Increase	11.82	4.92	-58%	0.56	1.19	112%	21.11	53.13	152%
Unchanged	7.72	7.67	-1%	2.44	2.62	8%	112.49	115.44	3%

6. DISCUSSION AND CONCLUSION

A parking pricing scheme is evaluated in this study based on a before-after comparison of parking utilization measures. We presented a method to systematically measure and analyse on-street parking. The results confirm that the policy fulfilled its objective to increase the ease of finding a vacant parking place in the central areas and hence reduce searching time and traffic caused by searching for a curbside parking. The on-street parking search process could be simplified by considering a sequence of independent Bernoulli trials with the failure rate corresponding to the average parking occupancy in a given area. This implies that the probability that a certain number of blocks is traversed before finding a vacant on-street parking spot could be approximated based on the Geometric distribution. For example, the average number of blocks that need to be traversed in the central business district before finding an available parking place decreased from 6.67 to 2.38 following the introduction of the new parking scheme. This suggests yielding a substantial decrease in the contribution of cruising traffic to overall traffic flows.

At the same time, the current pricing scheme is found inadequate for obtaining the 85% occupancy level objective. Prices need to be fine-tuned as follows: in the central business district the price need to be set between the 2013 level and the current level; for the commercial centre fringes and the main arterials the occupancy level was in fact lower than desired already in 2013 and decreased further due to the price increase. Parking prices on these streets should be reduced below their 2013 levels. It is believed that this error in the scheme design could have been avoided by relying on the methodology presented in this paper rather than on a manual parking survey; in contrast, prices on the remaining streets where prices have not changed should increase in order to relieve them for the current occupancy level. Note that the latter group includes streets with different price levels.

Calculating price elasticity confirms the conclusions made by a TCRP report and other authors on their dependency on specific circumstance to the point that they risk becoming deceptive. The 58% price increase in this area resulted with a 32% decrease in occupancy level reflecting a price elasticity of -0.55. However this figure is arguably meaningless without considering the temporal variations. Moreover, average parking duration was affected dramatically. The average decrease of 8.6 parking vehicle-hours per day (average parking duration multiplied by throughput) corresponds to a price elasticity of -1.29. The corresponding aggregate price elasticity of total parking time on the 'Low increase' class is a mere -0.16. The higher percentage price increase on these streets (73%) resulted with a less significant decrease in parking utilization (18%) reflecting a price elasticity of -0.25. These differences stem from differences in the original pricing levels as well as the different functions that the respective streets play in the urban environment.

The problems associated with interpreting various parking price elasticity and their transferability question the excessive focus on price elasticity. Instead, it is recommended to consider multiple measures of parking utilization when carrying out a policy evaluation. This need is further strengthened by the interaction between parking occupancy, duration and throughput which in this case study led to contradictory effects of price increase on throughput as well as turnover. This is especially important when policy objectives include a more efficient parking supply management through a greater circulation of inflow and outflow (e.g. to encourage visitors over commuters).

Further studies are needed to gain better understanding on various dimensions of parking decisions. In particular, assessing the overall demand for parking and the generation and substitution effects of parking pricing changes for different user groups. This includes the joint effect of congestion and parking policies which was considered in analytical models but could be supported by empirical findings from cities where they coexist such as in Stockholm [*26*]. Such an analysis will also shed light on the behavioural response to pricing and the adaptation measures taken by travellers and the similarities and differences between responses to parking and congestion pricing. Furthermore, this case study demonstrated that a price increase may counterintuitively result with a greater number of parking cars throughout the day. The adjustment to the price increase manifests itself in shortening the parking duration and hence lower parking fee per car. These results suggest that users are highly adaptive to changes in parking regulations. A spatial analysis of on- and off-street parking alternatives and their respective walking distances and prices can potentially shed light on the space syntax of parking decisions.

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