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EXPLORING ASSOCIATIONS BETWEEN PARKING OCCUPANCY RATE AT RESIDENTIAL ESTATES AND SPATIAL CHARACTERISTICS. THE CASE OF YEKATERINBURG

Financial losses due to low demand for parking spaces in garages at residential estates is a key motivation for this research. The purpose of this paper in particular is to statistically explore the relationship between parking occupancy rates and various factors on transport supply, characteristics of location and the building. The occupancy rate of parking was measured as the ratio of actual number of cars to total number of parking spaces. The fieldwork on counting occupied parking spaces was conducted 2 times per day during a week on a sample of 13 locations in different areas of a 1.4-million Yekaterinburg city in Russia. 4700 observed parking spaces give sample size of 173 records. Statistical analysis shows that the crow-fly distance to the city center as well as the number of public transport stops are strongly associated with occupancy rate for parking. Also, occupancy rate is much more affected by the type of parking ownership. Private owning means purchase of a parking space or renting it while public ownership suggests free access. So private parking means a 45% decline in occupancy compared to the public parking regime. Research provides empirical results and some theoretical underpinnings are also highlighted.

JEL Classification: R42.

Keywords: parking garages, parking occupancy rate, parking performance, Russia.

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Introduction

According to local regulations in Russia all residential estates must have a specific number of parking spaces. Such parking requirements may vary from one region to another. However, there is one common feature for any of these requirements – they encourage oversupply of parking spaces. This course of action results in the paradox of prices. The price for parking space purchase in residential garage is sometimes more than a price for resident's car. As far as parking spaces sell separately from flats there is a common problem of shortage in profits for developers due to low demand for parking garages.

In order to reduce financial losses some Russian developers try to avoid parking requirement using different methods. One of these can be explained in terms of evidence-based approach to demonstrate excessive capacity of garages that satisfied parking requirement. This idea was primary for a developer in Yekaterinburg city where local officials require one parking space for each 80 square meters of living area. The developer proposed to finance a survey on a low occupancy rate issue. Nonetheless the developer manages the residential estates after people moved in, there are no observations on parking performance due to the absence of automated control for parking garages (apart from a video control). As far as the developer is going to build up a new residential estate in a city center they try to use survey results in their negotiations with the city government on lowering minimum parking requirements for this project. The research question is as follows: Does spatial characteristics influence the occupancy rate for parking at residential estates? The survey suggests a statistical analysis and fieldwork. During a one week fieldwork empirical data of parking performance for 13 locations were collected. Thirteen characteristics of urban milieu such as environmental attributes, transport supply and building characteristics were also gathered for each location.

The paper is organized as follows. Section 2 describes literature review. The methodological approach and the data used in the analysis are shown in section 3. Section 4 presents the results. Finally, the discussion and conclusion section discuss the findings, the limitations, and general considerations for future research are presented in the discussion section.

Literature review

The issue of parking requirements was considered by Donald Shoup (1999) who pointed out that US "urban planners set the minimum parking requirements for every land use to satisfy the peak demand for free parking" (Shoup, 1999: 549). Later he developed the idea and put that issue into the broad framework of negative impacts of car use such as air pollution, urban design, costs of housing and maintenance expenses (Shoup, 2011). These side effects became a core for legal framework analysis of parking requirement issues in numerous studies from China (Wang and Yuan, 2013), Latin America (Alberto et.al., 2013), Asia (ADB, 2011), Europe (Kordansky and Herman, 2011). Such works often deal with the analysis of a legal framework and take into account some data thematically related to the agenda of transport and urban planning. The analytics and recommendations are made up guided by foreign achievements, predominantly of European and American kind. A step forward was made by Li and Guo (2014) who studied consequences of deregulating the minimum parking requirement. After documents analysis they found that the abolishment of parking requirement led to 49% reduction of parking supply in new residential estates in London. In other words a lot of sources on parking requirement issue focus on legal framework primarily while empirical evidence is absent. Some studies used secondary data with particular focus on the parking issue. Such papers deal with the impact that parking supply has on traffic and explore the relationship between the abundant supply of parking spaces and car usage. For instance, Weinberger, et al. (2009) examined income, car ownership, urban density, access to public transport stops, travel time and a number of off-street parking spaces for two districts of New York city. They found that "households with on-site, off-street parking are inclined to drive more than their neighbors are" (Ibid.: 29). Another research for New York city made the connection between the increasing amount of parking spaces and cars (Guo, 2013). The statistical analysis showed that the capacity of a parking lot (the total number of parking spaces) is more important than the income or other socio-demographic resident characteristics who own a car. Data from the 1998 regional travel behavior survey on various household and land use attributes (e.g. number of households for particular district, car ownership, household size and income, number of driver licenses, etc.) and the analysis of Google street view service were the source for that study (Guo, 2013). Swedish researchers came to similar conclusions after analyzing the data of a driver's travel behavior related to workplace parking. In particular, they outlined that limited access to

parking is the single most effective way of reducing car use in work trips (Christiansen, et al., 2017). In other words some statistical correlations on parking availability and car use are highlighted in numerous studies based on secondary sources data with weak attention to parking requirement issue.

There are also several examples of research concerning the elasticity of paid parking demand (Guo, McDonnel, 2013; Piccioni, et al., 2018). On-street parking occupancy in Stockholm was studied by analyzing data from parking meters and ticket machines (Cats et al., 2016). Spanish researches dealt with methods of GIS analysis and statistical data on specific parking garages in Barcelona to estimate "the impact of garage fare and curbside regulation characteristics (fare and type of dedicated spaces) on garage parking demand" (Gragera, Albalate, 2016: 161). Regarding methodological issue of studied papers it is preferred to gather data using automated approach for gathering data rather than fieldwork per se.

A step forward was made in 2011 in the study of parking requirement compliance in New York. McDonnel, Madar and Been (2011) used a lot-level data and GIS datasets to analyze sensitivity between developer response on parking requirement and proximity to public transport stations. "Our results indicate that the per-unit parking requirement in New York is, on average, lower in areas near rail transit stations, but the required number of spaces per square foot of lot area is higher, on average, in transit accessible areas. We also find that by and large, developers tend to build only the bare minimum of parking required by zoning, suggesting that the minimum parking requirements are binding for developers, as argued by critics, and that developers do not simply build parking out of perceived marked need" (Ibid.: 21).

So there are a number of approaches to study parking issue. Firstly, it is a normative analysis on parking requirements that do not fit best practice and therefore should be transformed. Other studies deal with automobile-based travel behavior aspects in their connections with available parking. Third group of researches focus on elasticity and pricing issues related to parking usage. Almost all of them use automated gathered data or secondary sources while fieldwork is missed. It is also hard to say that parking requirements and theoretical underpinnings on contemporary approach to parking policy are popular issues in academic literature nowadays. In other words, there are a lot of different applied techniques to study parking while little attention is paid to parking requirements and fieldwork.

In order to fill the gap on Russian experience in the field of parking requirements empirical dynamics of occupancy rate for residential parking facilities was considered. Also some spatial conditions of urban milieu were included into analysis in order to find statistical connection between them and parking occupancy rate (calculated as a ratio of occupied spaces to the nominal capacity of parking).

Method

The key idea of the approach was to gather empirical data on parking occupancy rate and to combine it with some attributes of urban milieu in their location. The method of fieldwork suggested a manual counting of the number of occupied and free parking spaces as well as parking violations. Off-street parking facilities including on-ground, underground and aboveground parking garages were observed as well as on-street parking around residential estates. Spatial attributes of urban milieu were collected from secondary sources, either visually or using simple manual operations with GIS services.

The schedule of fieldwork suggested 4 visits to each location during weekdays and 2 visits during weekend. The idea was to capture the peak occupancy period when people are hypothetically at their homes and non-peak occupancy period. After interviewing 10 citizens of the city the peak time for parking was set in the early morning till 8:00 and late evening after 21:00. The off-peak parking time was set between 11:00 and 17:00 in connection with traffic situation in a city. The weekend has the same temporal framework for the fieldwork as a weekday. Fieldwork took one week from April, 21 till April, 28.

4700 parking spaces were observed in total which give 173 records. As it was mentioned above, the sponsor of the survey is going to build up a huge residential district in the city center. This fact explains the prevalence of "central" locations (Table 1). Also two parking spots near business centers ("Pr" and "Is")[2] were observed due to their proximity to the developed site. During the week 13 locations were observed six times each. Clearly all of them have different number of parking spaces and spatial characteristics. To trace statistical correlations a multiple linear regression model was

[2] This research was financed by a local commercial company so parking locations have specific code due to contract obligations.

used by the method of least squares using the forced inclusion of independent variables. Dependent variable was the occupancy rate of parking measured as the ratio of the actual number of cars to the nominal parking capacity.

Regarding attributes for statistical analysis some specific features of the environment, transport supply and the characteristics of the building itself were included. In our case tying to administrative borders is meaningless due to the aspects of administrative divisions. In accordance with it, we accepted a simplified scheme “Center - Semi-periphery – Periphery”, based on the distance to the city center and the existence of natural and artificial barriers. The reference point for the city center was the municipal government building. Crow-fly distance for “central” residential estates is between 1 and 5 km, 6-12 kilometers and more than 13 kilometers are relevant for “semi-periphery” and “periphery” buildings respectively. Table 1 shows the sample of selected locations.

Tab. 1. The sample of the survey.

Name of the location	On-street parking	Off-street parking		Underground parking garage	Aboveground parking garage
		free*	limited		
Center					
Kr		X		X	
Bj	X	X	X	X	
13			X		
Mw	X	X	X	X**	
Pr			X	X**	
Is			X		
Gc		X	X		
Semi-periphery					
Fa			X	X**	

Mc	X	X		X
		Periphery		
Nv	X	X	X	
Ky	X	X	X	
Sk		X		
Sy	X	X		

Note 1: * Free off-street parking means that there are no obstacles to enter the parking lot located outside the road network such as barrier gates.

Note 2: ** Items marked with an asterisk are locations which could not be visited due to the limited access.

Selected attributes provided the opportunity to collect spatial variables from secondary sources and by using GIS resources in scarce timing.

Tab. 2. Attributes used in the analysis.

The group of attributes	Variable	Measurement
Environment	Center - Semi-periphery - Periphery	A tool from Yandex.maps service
	Field - Individual housing construction - 3-5 floors - 6-9 floors - 10-16 floors - above 17 floors	Visually
Location	Distance towards the center in a straight line	A tool from Yandex.maps service
	Distance towards the center by car	
Building	Number of apartments	Official data provided

		by developer
	Minimum and maximum number of floors	Description from cian.ru
Transport service	Types of land transport	Yandex.map service
	Number of land transport routes	Manual count via Yandex.map service
	Number of halting points of land transport within a radius of 0.8 km	
	Availability of stations of main transport within a radius of 0.8 km*	
	Walking distance towards metro station or commuter rail	
Cost	The minimum cost of a parking space	Advertisements from cian.ru, avito.ru
	The maximum cost of a parking space	

Note 1: According to numerous studies the impact area of public transport for residential properties is 800 meters (Ratner and Goetz, 2013; Hurst and West, 2014; Bhattachajee and Goetz, 2016).

The data from cian.ru website on housing supply and official documents from websites of developers were used as a source for estimation of the number of apartments and total number of parking spaces. “Location” and “Transport service” attributes were calculated manually with the help of Yandex.Maps web-service. The prices for parking spaces are available via advertisements on web resources such as www.avito.ru and www.cian.ru (Table 3). The minimum price for a parking space in “Ky” site was taken from the advertisement which was posted on the wall at the exit from the parking garage (which is below market average).

Tab.3. Minimum and maximum prices of parking spaces in parking garages (RUB).

Residential estate name	Nv	Ky	Mc	Bj	Kr
Minimum	750000	250000	350000	600000	950000
Maximum	780000	1000000	480000	999000	1100000

After coding the database contains 173 cases.

4. Results

4.1. Field research results

The prevalence of parking spaces in parking garages (39%) reflects the focus of the survey (Table 4).

Tab. 4. Types of parking spaces in the sample.

Title	Number	
	n	%
Parking garages	1847	39
On-street parking	574	12
Off-street free parking	1313	28
Off-street limited access parking	966	21
Total	4700	100

The occupancy rate was calculated as a ratio of occupied spaces to the nominal capacity of parking (Table 5).

Tab.5. The occupancy rate for parking garages at residential estates (%).

Title	Nv	Ky	Mc	Bj	Kr
Average	55	51	41	36	40
Minimum	35	49	24	22	25
Maximum	73	67	58	58	52

Among the surveyed locations “Nv” site is characterized by the best maximum occupancy rate of parking garages among others (73%). At the same time, this residential estate has the least ratio of the number of apartments to the number of parking spaces being equal to 3,6 (Table 6). “Kr” site has the highest provision of parking spaces, which is equal to 1,6 parking spaces per apartment. At the same time, the maximum occupancy of parking in this residential estate is the smallest among all locations and is slightly more than a half (52%).

Tab. 6. The ratio of the number of apartments to parking spaces in garages.

Residential estate title	Nv	Ky	Mc	Bj	Kr
Parking spaces (S)	162	491	257	676	261
Apartments (A)	588	919	864	2301	419
Apartments to parking spaces (A/S)	3,6	1,9	3,4	3,4	1,6

It should also be mentioned that “Mc” parking garage is commissioned only partly. According to the website of the developer, it is planned to increase the capacity of the parking garage by 2 times. Actually 3 out of 5 residential buildings were inhabited during the survey while others were under construction.

The comparison of collected data on the occupancy and the available reports from the sponsor of the survey on the sales of parking spaces highlights some inconsistencies. For example, there were 94% of parking spaces sold in “Nv”, which is higher than observed maximum occupancy of 73%. In “Ky” the situation is the opposite: only 59% of parking spaces were sold while 67% were actually occupied at night time. Such inconsistencies might be caused by plenty of factors. For example, unintentional talks with security personnel exposed specific aspects of parking performance. It was noted that one of the car owners bought the parking space however used it once a month. Another time, during the morning visit to a parking garage, security personnel stated that more than 10 cars had left until 8 am on Saturday. He noted that April is the beginning for the summer cottage season (a.k.a. “dacha”), which also explains why some cars had not returned to the underground parking on Friday evening. Another example is that the parking space can be used to place or store the equipment as was noticed for fast food restaurant in “Ky” site. All above, a more accurate explanation of such inconsistencies requires research carried out with other instruments.

Table 7

The occupancy of on-street parking (%).

Residential estate title	Nv	Ky	Mc	Bj	Sy	Mw
Average	78	87	94	99	83	107
Minimum	39	69	89	93	63	93
Maximum	105	104	101	105	108	122

The exceeding of 100% means that cars are placed with traffic violations or they are parked outside of the marked parking spaces, for example, on sidewalks (Table 8). According to Donald Shoup (2011) this effect is described as a spillover parking.

Tab. 8. Factors influenced the exceeding of 100% occupancy.

Violations and parking outside marked spots	%
Outside painted parking spaces	64
On sidewalks	18
Blocking the free drive of an already parked car	16
Closer than 5 meters to a pedestrian crossing or intersection	2

Similarly, off-street parking with free access during the inter-peak hours was often full (Table 9). In some cases, different points of interest were located nearby especially in the city central locations.

Tab. 9. The occupancy of free off-street parking (%).

Residential estate title	Nv	Ky	Mc	By	Kr	Sy	Sk	13	Mw	Gc
Average	94	97	108	90	87	86	81	73	89	89
Minimum	69	77	101	80	78	63	49	42	75	78
Maximum	126	121	120	102	100	100	101	106	104	103

On the other hand, at “Sy” site, the number of parked cars on off-street parking, which is the nearest to the main street, was noticeably higher than the one on the opposite side of the residential estate. A similar situation is observed in “Bj” along one of the streets. Same observations are valid for off-street parking with limited access at “Is” business site (Table 10), where the occupancy of parking spaces in proximity to

related building was significantly higher than at the distance of 500 meters (in other words on the opposite side of parking site). It also should be mentioned that some drivers at “Is” business site parked their cars outside marked spaces or with other rule violations despite the availability of free parking spaces nearby.

Besides, maximum occupancy rates for off-street parking with free access were observed in the inter-peak hours for “central” residential estates. Such places did not only have housing but also several points of interest such as shops, business-related activities, etc. The only exception is the “13” site, which has variables similar to those that are observed at the peripheral locations.

Tab. 10. The off-street parking occupancy rate with limited access (%).

Residential estate title	13	Is	By (inside)*	By	Pr	Pr (doubled limited access)**	Mw	Gc	Fa
Average	63	32	52	82	38	31	99	55	76
Minimum	35	0	9	76	10	9	91	17	32
Maximum	78	93	88	91	85	74	102	100	116

Note 1: * “Inside” means off-street parking within a gated courtyard.

Note 2: Double limited access means that parking entrance suggests barrier gates inside already restricted parking area. In other words a car should drive through two barrier gates to park here.

The maximum occupancy rate was higher than 100% for residential estates at night due to the parking of cars outside marked spaces and on the sidewalks. In other cases, access barriers at residential estates led to the availability of parking spots during the inter-peak hours, but the average values were quite low. For non-residential facilities, the maximum occupancy increased on the inter-peak time, while at night it fallen to 0%, which means the absence of cars.

On-street parking during the inter-peak time had an occupancy rate of more than 100% due to traffic violations, while at the same time the occupancy rate of the parking garages declined to 22%. The reverse dynamics of occupancy rates at business facilities in the area of the business district was also noticeable. So there is clear evidence of inefficient usage of parking in central locations due to ownership issues. While public parking suffers from a spillover effect, nearby parking garages and off-street facilities offer plenty of free parking spaces.

4.2. Statistical analysis results

Several hypotheses were previously formulated to identify significant factors in each group of attributes such as "environment", "location", "building" and "transport service" (as presented in Table 2). In all cases the dependent variable was occupancy rate (the chosen scale type is quantitative and measured in fractions), which was calculated as the ratio of the actual number of cars to the nominal parking capacity.

To test each of the four hypotheses, we built multiple linear regression model by the method of least squares using the forced inclusion of independent variables by using SPSS (Statistical Package for Social Sciences) software (Version 17). The environmental characteristics alone do not have a statistically significant impact on the occupancy of parking. The same applies to the data which characterize the transport supply within locations of sampling. Numerous attempts show that not all of explanatory variables show statistical significant coefficients. For further calculations, we kept only the significant predictors.

Independent variables:

- The number of public transport stops (scale type – quantitative, measured in units).
- The type of ownership that means the difference between the need to buy a parking space in the parking garage and free parking (scale type – nominal; 1 = private, 0 = public).
- The distance to the city center by car (scale type – quantitative, km).

The regression coefficient was $R^2 = 0,3$. Occupancy rate during the weekdays is much more affected by the type of ownership. The equation of the model is as follows:

Y=0,53+0,006"the number of public transport stops" - 0,42"the type of ownership" + 0,026"the distance to the center by car".

The equation of the model in case of private parking is as follows:

Y=0.11+0.006"the number of public transport stops" + 0.026"the distance to the center by car".

The equation of the model in case of public parking is as follows:

Y=0.53+0.006"the number of public transport stops" + 0.026"the distance to the center by car".

In other words, the further the location is from the city center and the fewer public transport stops are within a radius of 0.8 km, the higher is the occupancy rate for parking. In the case of public parking the occupancy rate increases by 42%. However, this conclusion is applicable to 30% of cases during weekdays.

Table 11

The model data on weekdays.

Variable	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95,0% Confidence Interval for B		Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
(Constant)	0,53	0,09		5,866	0	0,351	0,709		
Amount of public transport stops	0,006	0,002	0,301	2,936	0,004	0,002	0,01	0,588	1,702

Mode of payment	-0,422	0,063	-0,538	-6,699	0	-0,547	-0,297	0,958	1,044
Distance to the city center by car	0,026	0,008	0,324	3,16	0,002	0,01	0,042	0,587	1,703

The verification of the model for the autocorrelation of the residuals:

- The Durbin-Watson statistic shows that the autocorrelation of the residuals is weak, which allows to conclude that the built model is adequate.

- The residuals are normally distributed, the requirement of heteroscedasticity of the residuals is completed.

The quality of the model has significantly improved when only weekends were taken into account. R^2 coefficient has increased, while the autocorrelation of residuals wasn't found out. Initially, all variables specified in last hypothesis were included in the model. The regression coefficient was R^2= 0,48. Similar to the case of weekdays, the occupancy rate for weekends is much more affected by the type of ownership. The equation of the model is as follows:

Y=0,47+0,006"the number of public transport stops" - 0,44"the type of ownership"+ 0,035"the distance to the center by car".

The equation of the model in case of private parking is as follows:

Y=0,03+0,006"the number of public transport stops" + 0,035"the distance to the center by car».

The equation of the model in case of free parking is as follows:

Y=0,47+0,006"the number of public transport stops" + 0,035"the distance to the center by car".

Table 12

Model data for weekends.

Variable	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B		Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
(Constant)	0,474	0,1		4,731	0	0,273	0,675		
Amount of public transport stops	0,006	0,002	0,412	3,082	0,003	0,002	0,011	0,558	1,792
Mode of payment	-0,44	0,068	-0,659	-6,437	0	-0,577	-0,303	0,951	1,052
Distance to the city center by car	0,035	0,009	0,515	3,848	0	0,017	0,053	0,558	1,793

The conclusion is similar to the one made based on the model built for weekdays. The difference is that the type of ownership affects the occupancy rate of 44%, while the quality of the model allows to explain 48% of cases on weekends.

As a result, it is appropriate to make the following conclusion: the further the location is from the city center and the smaller is the number of public transport stops within a radius of 0.8 km – the higher is the occupancy rate of parking. At the same

time, purchasing a parking space at the parking garage means a 45% decline in occupancy rate compared to the public free parking.

5. Concluding remarks

The analysis allows us to conclude that various spatial characteristics and parking occupancy rate are interrelated. Regression shows that the crow-fly distance to the city center as well as the number of public transport stops have influenced occupancy rate for parking at residential estates. At the same time, the type of ownership for parking space in garages means a 45% decline in occupancy in case of private owning compared to free parking regime. On the other hand almost all parking garages during off-peak hours show less than 50% occupancy rate. Also for central locations off-peak time suggests spillover effect for on-street and off-street parking facilities with open access. Such sort of observations shows inefficient usage of parking facilities due to ownership issue.

Hypothetically the total supply of parking spaces nowadays does actually satisfy the demand. This is a caution outcome that can be elaborated in further researches. Nonetheless this idea seems a worthwhile implication for decision-makers while the usage of existed parking requirement is questionable strategy.

Literature review shows that market-driven approach is a solution for the parking requirements problem (e.g. Shoup, 2011). In that case a developer should be free in his ability to set appropriate amount on parking spaces due to forecasts on parking demand. However a reasonable approach to calculate that number of parking spaces is not obvious. How is it possible to predict the number of purchases for parking spaces? Spatial conditions of urban milieu are just a part of that vision. Issues of this kind bring the problematic to a different level, requiring us to consider a broader range of aspects, such as the characteristics of car usage, travel behavior, parking policy in general, etc. The methodology of forecasting therefore becomes the main issue in the problem of parking supply. However, as some research shows, an accuracy of such methodology could be low (e.g. Pickrell, 1990; Goodwin, 1997; Flyvbjerg, et.al., 2005).

The presented analysis, in its turn, illustrates the empirical situation and highlights methodological limitations for possible approach of forecasting. Representative sample seems like a crucial one. Locations listed are not representative due to the absence of the sampling frame and the procedure of probability selection. At the same time, a sampling frame can be made if only a parking census had been conducted, which requires vast resources.

The ability of the model to adequately point out the efficiency in 44% cases means its incapability to explain the rest of 56%. The chosen subject is also a complicated one. The research shows consequences of the problems related to survey instruments such as the absence of representative sampling, regular observations during the year, incorrect or insufficient variables, etc. Under such circumstances, it is reasonable to raise the question on the adequacy of the methodology for the stated problem which might bring the problem on a different level in analysis for possible further researches.

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