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# HOW DOES SUBWAY AND GROUND TRANSIT PROXIMITY AFFECT RENTAL PRICES?

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# How does subway and ground transit proximity affect rental prices?☆

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**Abstract**

This study focuses on the ground transportation system and its impact on the rents in 30 of Russia's largest cities. It also compares the effect with subway transit networks. The data set includes rent information from an all-Russia online advertisement website Avito and various measures of proximity to the public transit network stops (including subways for cities with them). The analysis is conducted using linear hedonic models. The results show that the ground transportation proximity is important for housing rent formation in both cities with and without subways, although the effect for subway stations is greater in comparison. Nevertheless, the benefits of a denser ground transportation system are high and stable, whereas the distance to the closest bus stop and the number within the walking distance are important solely for cities with a subway system and without it, respectively.

**Keywords**: housing rent; public transit; subway; hedonic analysis; largest Russian cities.
**JEL codes**: C43, O18, R38.

## 1. Introduction

The impact of various amenities on housing price formation is covered in a large number of studies. The influence of public transport, on which this study is concentrated, has been also a subject of analysis in the past. It is one of the most important determinants of housing prices because it affects accessibility to workplaces and other natural and urban amenities (Grebennikov et al., 2012). The earliest studies in this area consider the city as a system of concentric rings in which transportation allows access to the central business district (CBD) from residential areas (e.g., Hochman and Pines, 1971). As real cities may not follow such assumptions, these are made less strict in recent empirical studies (Gutiérrez-i-Puigarnau et al., 2016), which find a significant link between housing prices and transportation accessibility.

Typically, the impact of public transit is investigated for large cities and megapolises,[1] where a key determinant of housing prices is walking distance to a subway station. However, in the case of Russia, the vast majority of its more than a 1000 cities have no subway system. In 2010, 163 out of all 1100 Russia's cities had the population of more than 100,000.[2] As many as 15 of them are considered as megapolises, while only seven of these possess a subway system. In other words, only half of Russian megapolises have a subway. This is a low value compared to advanced economies. For example, in the USA, ten out of the total of 30,000 cities are megapolises, while subway systems are functioning in eleven cities. In Germany, only 5% of cities having a population exceeding 100,000, are megapolises, but more than 20% of cities of over 100,000 people have a subway system. A similar proportion is observed in France, where 15% of cities have a subway, while only one city can be considered a megapolis and four cities as large cities.[3]

By contrast, the subway availability in Russia is typical for emerging economies. In particular, among the BRICS[4] countries, Russia is fourth in terms of both the total and the urban population. Nevertheless, it occupies the third place in terms of the number of cities with a subway and in terms of the overall number of stations. South Africa does not possess a subway

[1] In this study, the word "megapolis" is used to denote a city with a population exceeding 1 million.
[2] According to the All-Russian National Population Census: http://www.gks.ru.
[3] See http://www.statdata.ru.
[4] Brazil, Russia, India, China, and South Africa.

network. Brazil has the same number of cities with subways as Russia, but there are fewer stations. However, subways in Brazilian cities have much more extensive networks, with the minimum of 19 stations; while in Russia all cities, except for St. Petersburg and Moscow, have less than 15 stations. The subways in India and China are more developed than in Russia and are rapidly expanding. Currently, there are eleven cities in India and 35 cities in China having subway systems. Thus, it is likely that the evidence found for Russia can be to some extent extrapolated to the other emerging economies.

In addition, Russian subway systems are relatively small, only Moscow's and St. Petersburg's subway networks have passenger traffic that exceeds 100 billion persons per year.[5] The reason for that is the small coverage area and the small number of lines and stations. All in all, for Russia, a traditional subway-oriented approach would be applicable to a limited number of cities, while this study examines not only megapolises but also urban areas with a population over 500,000 people. These cities receive less attention, despite the fact that public transit and its influence on housing rents is also an important issue there.

In Russia, there are four main types of the intracity ground public transit: bus, trolleybus, tram, and minibuses.[6] The most widespread of them are the buses. In 2014, in the whole of Russia, the bus passenger traffic was equal to 11,551 billion people per year out of 19,526 billion people carried by all three types of the ground transit, which is around 59%.[7] Only 86 of the total of 1114 cities in Russia have a tram system and approximately 93 have a trolleybus system.[8] Their networks are also much less developed than the bus systems. Nevertheless, tram and trolleybus stops are typically located very close to or shared with bus stops. The same holds for minibuses, which often have similar routes and official stops as the buses. Therefore, for the purposes of the study, as we do not investigate routes or types of transportation but only stop locations, it is possible to focus only on official bus stops.

Accessibility plays an important role for the owners and renters of housing units. For that reason rental prices are expected to depend on it. Based on the previous statistics, intracity

[5]See `http://k-metro.ru/stats/ussr-stats-2017/`.

[6]In Russian, the latter are called *marshrutki*. These stop on request, but typically follow the routes of their larger counterparts.

[7]See `http://www.gks.ru/free_doc/doc_2015/rusfig/rus-15.pdf`.

[8]See `http://ymtram.mashke.org/russia/`.

travel in Russia is conducted more often using ground transit networks even when a subway exists, as the nearest subway station might not be accessible on foot. For that reason, in Russia, it is very important to take ground transit into consideration. In particular, it is worth investigating whether it has more or less impact on the housing prices than subways, as this issue is poorly researched. This problem also is critical for understanding of how rental prices are formed in large Russian cities, which could lead developers and city managers to take into an account extra accessibility factors and to make cities more efficient.

This study examines the impact of the public ground transit on housing rents in Russian cities with a population of 100,000 or more. The study considers both the positive and negative effects of public transit on rents for apartments, which are incorporated into several transport-related variables. The convenience and accessibility of transportation services exert a positive impact. To be more precise, it is expected that the spatial density of public transit stops will be positively related to rents. However, the noise and pollution resulting from the ground transport are expected to exert a negative impact on rents.

In addition, the study compares cities with and without subways in terms of the differences in their influence on the ground transportation system. It is expected that these distinctions will exist, given the mutual impact of ground and subway transit systems. However, neither the size nor the sign of this difference are easy to predict. On the one hand, the availability of such an alternative as a subway can reduce the impact of the ground transit. On the other hand, it can raise the demand for it, for the ground transit complements the subway by bringing in people living in the peripheral areas without subway stations.

The paper is organized as follows: section 2 presents the literature review, focused on transportation accessibility in cities. Section 3 covers the data and methodology of the study. Section 4 reports the empirical results and discusses them. Finally, section 5 concludes with the final outcomes and possible policy implications.

## 2. Public transit and the housing prices

The famous Alonso (1964)-Mills (1972)-Muth (1975) urban model that tries to explain the internal structure of cities represents a city as a system of rings. A stylized city consists of a central area called the CBD, in which most employees work and business activities take place, and an outer residential ring. Transportation is assumed to play a key role in this theoretical framework as it delivers employees to the CBD. Proximity to a workplace determines the price of housing units through both money and the non-pecuniary costs of transportation (Guerrieri et al., 2013). With household income as an important factor determining the location of housing (Gutiérrez-i-Puigarnau et al., 2016), the housing units in the city center are expected to have higher prices, whereas those located in the residential ring should have lower prices. Voith (1991) presents empirical evidence for this theory using US data and finds a 6.4% premium for apartments in the zone closer to the CBD.

Buyers and renters make their choice on the location of a housing unit based on their preferences among which closeness to their workplace as well as to cultural, medical, and other amenities plays an important role (Grebennikov et al., 2012). For instance, Rouwendal and Meijer (2001) demonstrate, using Dutch data, that people dislike commuting to work and connective networks of streets are also preferable, as they make commuting easier (Song et al., 2003). Tolpegina and Uchinina (2014) in their study of the middle-sized Russian city of Penza, note that rental prices are higher in the center of the city due to such factors as a denser transport system and better social infrastructure.

The design of the transportation system plays an important role in accessibility within a city (Gibbons and Machin, 2008). Ryan (1999) indicates two ways of measuring transport accessibility: by distance and by time. The author stresses that time-related measures exert a significant influence on housing prices, while the results for distance measures are mixed. Nevertheless, Sharov (2018), when studying the Russian city of Irkutsk, comes to the conclusion that geographical distance from the city center is negatively associated with transport accessibility and, hence, with the purchase cost per square meter of residential units. Similar results are obtained for Warsaw (Niedzielski and Śleszyński, 2008).

Several measures of transport accessibility using different destinations (job, cultural, medical destinations) are summarized by Grebennikov et al. (2012), who also note that in Russia only job-residence accessibility is taken into account when planning a city. According to Bartholomew and Ewing (2011), the design of a city strongly affects real estate prices.

Many countries adopted various job-housing balance policies to optimize the ratios of people living and commuting to a district versus the ones working in it (Sultana, 2002). Although the job-housing imbalance is connected to a longer commuting time (Sultana, 2002), solving it is not always effective for traffic-related problems (Giuliano, 1991).

There is an extensive empirical evidence for the importance of transport systems for housing markets in different countries. New commuting routes influence the prices of nearby housing units, according to Bajic (1983) and Henneberry (1998). Bajic (1983) points out that a new subway line in Toronto shifted prices upward in the local housing market. Olayiwola et al. (2005) present empirical results on Nigerian data concluding that there is a highly significant positive connection between improvements in the transportation network and housing prices. Similar results are obtained by Damm et al. (1980) for Washington. Nevertheless, Henneberry (1998) presents more controversial results, stating that, although before and immediately after the opening of a new transport route in the UK the distance to it was an important factor for price formation, in the later years its significance had almost vanished.

Most of the studies concentrate on railway or subway accessibility. The analysis of the Hamburg public transit system carried out by Brandt and Maennig (2012) shows a statistically significant connection between the proximity to the S-Bahn stations of apartments (a premium of up to 4.6%). The same results are presented by Du and Mulley (2007), who conclude that closeness to the subway and to schools can be more important for the housing prices of a particular dwelling than proximity to a workplace. These findings are similar to those of Gibbons and Machin (2008).

In addition to location preferences, when choosing a housing unit, renters and buyers consider the negative externalities of transportation system as well as its positive impact on commuting time (Giuliano, 1991). For example, Harrison and Rubinfeld (1978) stress the negative influence of air pollution on the rental market. Similarly, traffic noise reduces real estate and rental prices, according to Brandt and Maennig (2011) and Andersson et al. (2015).

## 3. Data and methodology

### *3.1. Data*

The data used in the study are obtained from the Russian advertisement website Avito,[9] which has a real estate section with more than 6 million ads on long-term residential renting (see Figure 1). The data set, kindly provided to us by Avito, encompasses the period between January 1, 2016 and October 2, 2017 for 30 cities. The big advantage of this site is that it covers the whole country, unlike most similar websites in Russia, which focus mainly on specific regions (e.g., `https://www.bn.ru/` for St. Petersburg and `www.farpost.ru` for Vladivostok). The unit of observation is a dwelling in an apartment block — the most widespread type of accommodation in large Russian cities.

The descriptive statistics for the data are displayed in Table 1. The observations with missing values are excluded from the initial data. The outliers by city for the key variable are detected using the multivariate Cook-distance approach. They are treated with the capping/flooring technique: observations with values greater than 95% of the variable distribution are replaced with a borderline 95%-level value. Values that are smaller than 5% are replaced by 5%-level estimate in the same manner. After that, 617,344 observations remain.

The initial data set is then divided into two samples: cities with a subway and buses (group A) versus cities only with ground transportation (group B). In Table 1, the variable *subway* allocates cities and towns to one of these groups. The apartment offers are distributed nearly equally among cities with and without subways. The rationale for the division are the possible differences between the cities of groups A and B, which could not be accounted for by the *city* variable and which stems from the different compositions of their transit networks. The modelling on separate samples allows us to see distinctions in coefficients and also to include subway variables as they are an important factor for megapolises.

The dependent variable is the logarithm of the monthly asking rent in rubles per square meter, $\log(Rent)$. The city-specific distribution of this variable is shown in Figure 2. Each boxplot's width represents the number advertisements published for each particular city or town. Expectedly, the most expensive cities are Moscow and St. Petersburg, which also

[9] `https://www.avito.ru`.

account for a most of the observations. The least expensive towns are Tolyatti and Voronezh. The gap between the most expensive and the least expensive cities is almost four times.

There are three sets of explanatory variables: structural, locational, and city/neighborhood characteristics.

*Structural characteristics.* These are the physical characteristics of the apartment itself and of the building: $floor$, $floor\_ratio$, *buildingtype*, and *rooms*. The variable $floor$ is a storey on which the apartment is located. $floor\_ratio$ is computed as a ratio of the $floor$ to the overall number of floors in the building ($floors$). All three variables are not used because of multicollinearity problems, but $floor\_ratio$ has better predictive power than floor number. Categories of floor (first, middle, and top) perform worse than $floor\_ratio$. The use of both types of variables again yields high variance-inflation factor (VIF) results. *buildingtype* is a vector variable, which reflects material used to construct the building. *rooms* is the number of rooms in the apartment.

*Locational characteristics.* The second set of variables describes the transportation system. In the model for cities without a subway, only four are used. Bus stops used in the analysis are assumed to have equal weight. The routes and types of transportation passing through the stop are not taken into account. *bus_closest* is the distance from the apartment to the nearest bus stop. $bus1000$ reflects the number of the bus stops in a radius of 1000 meters. Other distance thresholds were tested too. However, 1000 meters turned out to be the best one, as 500 meter yields lower values of ($R^2$) and RMSE. In addition, 1000 meter distance is equivalent to a 10–15 minutes walk, given that the walking speed is about 4 km/hour. The variable *density_buses* is a representation of the 2-dimensional kernel density for bus network, which is calculated in the following way:

1. Construction of bus stops density plot;
2. Calculation of the probability for a particular flat to be in 50th (1st category), 30th (2nd category), and 10th (3rd category) percentiles of that density;
3. Classification of the flat into a categories by said probability;
4. Calculation of the final variable by summation of binary outcomes from the previous step.

The variable *density* is constructed in a similar way and stands for the spatial density of apartments. This indicator can serve as a proxy for population density. The correlation between apartment and the bus density is weak-to-moderately positive (0.37) over the whole dataset. However, this correlation differs substantially across cities from a weakly negative to a strongly positive relationship (see Table 2). The correlation between these densities accounts for the overlap between the bus network and the population density for which the density of the apartments-for-rent ads is used as a proxy. In general, the larger the correlation, the better the accessibility in the area. For example, in St. Petersburg, where many neighborhoods are not covered by bus routes or covered insufficiently (Amosov and Safina, 2015), the correlation is -0.178.

*City and neighborhood characteristics.* Two additional variables indicate in which city and in which district of the city the advertised apartment is located: *city* and *city_district*. They reflect the city- and the neighborhood-specific characteristics of a particular apartment. Using the longitude and latitude reported in the advertisements we verified whether the apartment is really located in the city indicated in the ad. The reason is that in some cases the apartments are located far away from the city indicated in the advertisement. The ads where the real location does not coincide with the indicated one are removed. Again, using the geographical coordinates, the apartments are allocated to the administrative districts of the corresponding city in order to control for differences in rents related to a neighborhood.

### *3.2. Methodology*

In order to assess the impact of ground and subway transport accessibility we take advantage of the traditional hedonic methodology. The model to be estimated is formulated as follows:

$$\log(Rent_i) = \alpha' X_i + \beta' L_i + \gamma_{city} + \delta_{district} + \epsilon_i \tag{1}$$

where $Rent_i$ is the asking rent per square meter for the $i$-th apartment; $X_i$ is a vector of structural features of the apartment (such as the floor, floor ratio, type of building, and number of rooms); $L_i$ is a vector of the locational features of the apartment (the distance to the nearest bus stop, the number of bus stops within 1000 meters, the density of spatial distribution of bus stops, the distance to the nearest subway station, and the number of subway stations within

1000 and 3000 meters); $\alpha_{city}$ is the city fixed effect; $\theta_{district}$ is the city district fixed effect; and $\epsilon_i$ is the random term.

The models are estimated using the ordinary least square approach with robust standard errors. A robust regression is necessary in order to account for the possible heteroscedasticity of the residuals and the presence of outliers. We have no reason to exclude these observations from consideration and, thus, with robust regression a compromise is reached.

In order to check for multicollinearity, VIF are calculated (see Table 3). VIF not exceeding 10 indicate no serious multicollenearity problems in the model.

The Shapiro-Wilk and the closely related Shapiro-Francia normality tests are applied for each subsample of cities. The null hypothesis stating that the data fit the normal distribution is rejected for all of them. Nevertheless, for large samples[10] the normality tests tend to overreject the null hypothesis even for close-to-normally distributed data, as they are valid up to 2000 and 5000 observations, respectively.

We also test for heteroscedasticity using the Breusch-Pagan test, whose null hypothesis implies constant variance. With a $p$-value close to 0, this hypothesis is rejected for all four regressions (Table 4). For that reason, the robust regressions are used.

## 4. Results

The estimation results for our hedonic model are presented in Table 4. The first column shows the results obtained for the whole sample of 30 cities. The second and the third columns present outcomes for the separate models including cities with and without subways, respectively. The fourth column reports the results for the model covering the cities with subways and including the variables related to subway station proximity.

The coefficients for city fixed effects from the first model are reported in the last column of Table 2 with respect to Barnaul as a base. The highest coefficients are found for Moscow and St. Petersburg, which have the largest population as well as the largest bus and subway networks. Among all the cities, Tolyatti is the cheapest. This confirms the distribution of rents displayed in Figure 2. Samara and Rostov-on-Don have city fixed effects that are similar to

[10]The minimum number of observations per city equals 1750 for Vladivostok; see Table 2.

that of Barnaul, as their coefficients are not statistically significant. The fixed effects reflecting the districts within cities are not reported here in order to save space.

The floor on which the apartment is located exerts different effects in the cities with and without subways. For those with subways, the coefficients of both floor-related variables are statistically significant, while the upward movement of the apartment by one additional floor increases the rent by approximately 0.25% and simultaneously reduces it by 1.40% in relation the floor ratio. The picture is different for the cities without subway. There, the floor of the flat is not significant, while the relative position of the apartment in the building is. With each additional unit increase in the floor ratio, the rental price increases by 1.88%. One explanation could be the differences in the height composition of the housing in the cities with and without subways. Cities with subways are larger and have more high-rise residential buildings than those without subways.

The number of rooms and the building type have similar effects for all city types. The highest rent per square meter is asked for studios, i.e., one-room apartments without separate kitchen. The more rooms, the lower the rent per square meter, albeit the rate of decrease declines as the number of rooms increases. The readiest explanation is that, given the relatively low incomes of the majority of the Russian population, smaller dwellings, being the most affordable, are more popular among Russian renters. Among the five building types, the lowest rents are asked for apartments in wooden houses, while the highest ones are requested for the apartments in the monolithic buildings. This can be explained by the level of comfort: apart from being more durable, the monolithic buildings are more likely to have the full range of conveniences such as central heating, WC, and bathroom, which can well be absent in wooden houses.

Based on the results in Table 4, we can conclude that proximity to a bus stop does not significantly affect the rental price in the cities without a subway, while the impact of the number of bus stops within a 1000 meter radius is a positive and statistically significant increase of 0.15%. In the cities with subways, the situation is similar (Table 4, column 3). The effect of the number of bus stops is significant but accounts only for a 0.05% change.

The inclusion of subway proximity measures changes the significance of the bus proximity variables (Table 4, column 4). The presence of a bus stop nearby slightly increases the rental price. A larger number of bus stops in the neighborhood does not influence the rent. The stronger effect of the closeness to the bus can be related to the overall higher length of commute in larger cities, which makes the closeness to transport more important. The insignificance of the number of bus stops in the area can also be a result of the higher pollution levels that overcompensate the benefits of a better accessibility. This factor is less important in smaller cities, where pollution levels from transport are lower as traffic load is less intensive Bobrov (2011). Nevertheless, the effect of proximity to the nearest bus stop vanishes for the whole sample, while the number of bus stops within walking distance stays significant and is 0.06% per bus stop.

The density of bus stops (*density_buses*) is the most influential variable among transport network regressors. Its increase by one unit, which is equivalent to transferring the dwelling to a higher bus density ring of the city, leads to a 3.00% increase of the rent price per $m^2$ for the overall sample. A similar increase in the apartment density measure brings about a 0.98% change for the whole sample.

The effect of the bus density on rental prices is stable across cities with and without subway systems. Although the coefficient for the density of the bus network is statistically significant in both cases, it is larger for the cities with subways: 2.57% versus 3.22%. For the density of advertised apartments, a similar pattern is observed: 0.80% and 3.22%, respectively. The results for the model of cities with subways, which accounts for the proximity to subway stations (Table 4, column 4), display the same property, as the density measure coefficients are higher than in the cities with only ground transportation. The bus density accounts for 2.83% increase of the rental price, while apartment density leads to a 1.10% change. A possible explanation for this is that in larger cities, a transport network offering extra alternative routes is more preferable than that having shorter distances to stops but fewer routes.

The fourth model also demonstrates the importance of subway proximity for rental prices. A larger distance from a subway station reduces the rental price. The number of bus stops affects housing prices non-linearly as each additional stop within the radius of 1 km decreases the rent by 0.47%, whereas a subway station within a radius of 3 km raises the rent by 0.36%. A possible explanation for that is the presence of higher negative externalities in the immediate neighborhood of subway stations. Many stations located too close to the dwelling exert a negative impact, since they are associated with more noise. At the same time, having more stations within the 3 km radius is beneficial due to lower externalities and better accessibility (Brandt and Maennig, 2011; Andersson et al., 2015).

These results imply that the bus network and bus accessibility make a substantial contribution to housing rents. $R^2$ in the model for cities without a subway is much lower than in other models. In other words, in smaller cities without a subway system, factors other than transport accessibility contribute to a greater extent to housing rents. In the megapolises with subways, the transport system accounts for a higher proportion of variance.

These results are in agreement with the conclusion by Ryan (1999) who states that a proximity measure by distance is not a stable predictor of housing prices. The closeness to a bus stop is insignificant for models, which do not control for subways. The significance in that case can be attributed to longer commute times by bus and subway combined.

The proximity to the nearest subway station is statistically significant and accounts for $-0.0008\%$ change in the rental price per meter. These results differ from those of Brandt and Maennig (2012), who investigate purchase prices and not rents and use a non-linear specification of proximity. They find that a maximum price premium of $+4.6\%$ is attained at the 250–750 meter distance from the closest station. In our case, the effect of proximity to the nearest subway station is estimated in a linear way and is relatively small: at the distance of 750 meters, the rent decreases by 0.57%. The reason for that, apart from differences in data and methodology, is the low density of subway stations in Russian megapolises in comparison to the bus density (see Figure 3) and to the subway density in cities analyzed from other countries. For example, the Hamburg subway has 91 stations, such that each station on average covers an area of 8.3 $km^2$.[11] In addition, if we take into account that Hamburg has 48 S-Bahn stations, then one station (subway or S-Bahn) serves an area of just 4.7 km$^2$. The lowest value in Russia is observed in Moscow, where one subway station serves an area of 11.9 $km^2$. In other Russian cities, the subway coverage is worse. For instance, in St. Petersburg, one subway station covers an area of about 20.0 km$^2$.

The number of bus and subway stations in the neighborhood of a dwelling exerts a statistically significant impact on its rent. For buses, having more stops within 1000 meters, is

[11] See http://mapa-metro.com/en/Germany/Hamburg/Hamburg-U-Bahn-map.htm.

preferable due to better accessibility. In contrast, extra subway stations within the same radius lead to more traffic and noise pollution, which is in agreement with a study by Harrison and Rubinfeld (1978), while the availability of many stations within 3 km is still a convenient situation, for it provides relatively good accessibility without negative externalities. Thus, this variable has a positive effect on rents.

High premia for the density of the bus network are in accordance with a study by Voith (1991) who found a premium of 6.4% for zones closer to the CBD. That denser areas belong to the CBD is in agreement with Sharov (2018). Our estimate of the premium is 3%, which is the largest value among the coefficients of transport-related variables. The denseness of the transport network directly relates to the rental prices due to better accessibility and connective networks (Song et al., 2003).

## 5. Conclusion

Transport accessibility is a crucial factor when renting a housing unit. The research on the question is substantial, but rarely includes empirical results for smaller cities, especially in a cross-city analysis. Most studies concentrate on subway accessibility when investigating public transit, whereas in Russia and other emerging economies ground transportation is more widespread.

This paper sheds light on the effects ground public transit systems exert on housing rents in two types of cities: those having both subway and ground networks and those possessing only ground transportation. The data used in this paper cover rental prices for apartments in apartment buildings in the 30 largest cities of Russia.

The primary finding of this study is that the density of the transportation system plays an important role in the formation of rent for apartments. The density of bus stops in the area affects the rent in both types of cities, but in the cities with a subway system the rental prices benefit more from a denser network. The proximity to bus stops plays a smaller role in terms of the housing value and persists only in cities with subway systems. In the cities without a subway, a larger number of bus stops within walking distance is valued higher. A denser network with many possible routes from different bus stops results in better accessibility, which raises the value of the housing unit. For large cities, the last factor is less important, whereas the closeness to a bus stop is more important. This effect can be explained by the longer commuting times in larger cities. Commuters tend to prefer shortened commute times (Rouwendal and Meijer, 2001) and agree to suffer from negative externalities (noise, pollution, and congestion) in their area to reduce them.

We also discovered that only a small percentage of the variance of the dependent variable can be attributed to the transport system in the cities without a subway. In larger cities with a subway, the rents depend to a larger extent on transportation: transport explains a larger proportion of the variance and the coefficients related to it have larger absolute values. For that reason, further investigation of cities without subways would give a better understanding of the process, as it seems to be distinct from that in large cities.

These results are useful for the purposes of the city planning in Russia and other emerging economies. As mentioned, in Russia, only the accessibility of work places is taken into consideration in city design. However, based on the results of this study, the density of the bus network in the area has to be taken into account as well. More bus stops and better accessibility in the area will lead to higher residential prices, which is beneficial for developers. Previous research also shows the importance of access to schools and other infrastructure, which are not currently considered in city planning in Russia.

In addition, the outcomes of the study can be used as a basis for a pricing model for housing units and as an instrument for transport subsidy analysis. Public transit is heavily subsidized in Russia. The subsidies compensate for around 52–90% of the losses incurred by the carriers, as reported by Bessonov (2005). However, when discussing the costs of public transit its benefits have to be taken into account. In particular, this study demonstrates that the proximity to public transit raises residential rents and, hence, the revenues of landlords, which brings about larger income tax revenues for the government. Moreover, higher rents resulting from locations near bus stops or subway stations can also imply higher housing prices. This can lead to higher revenues from stamp duty and property taxes. Thus, the subsidies must be corrected for these tax revenues generated by the proximity of public transit in order to arrive at the net costs of the public transit.

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**Appendix**

Table 1: Descriptive statistics

| Statistic | Mean | St. Dev. | Min | Median | Max |
|---|---|---|---|---|---|
| log(Rent) | 6.040 | 0.477 | 4.576 | 5.983 | 7.014 |
| city | | | | | |
| city_district | | | | | |
| lon | 49.997 | 20.826 | 29.454 | 39.745 | 135.189 |
| lat | 54.337 | 4.186 | 42.889 | 55.658 | 60.213 |
| floor | 5.800 | 4.327 | 1.000 | 5.000 | 99.000 |
| floors | 10.670 | 5.871 | 1.000 | 9.000 | 99.000 |
| floor_ratio | 0.562 | 0.268 | 0.011 | 0.560 | 1.000 |
| buildingtype | | | | | |
| rooms | | | | | |
| subway | 0.506 | 0.500 | 0 | 1 | 1 |
| subway_closest | 2,114.3 | 3,042.5 | 0.000 | 1,108.0 | 48,606.9 |
| subway1000 | 0.724 | 1.149 | 0.000 | 0.000 | 13.000 |
| subway3000 | 4.807 | 6.656 | 0.000 | 3.000 | 50.000 |
| bus_closest | 217.718 | 290.614 | 0.416 | 168.538 | 80,736.060 |
| bus1000 | 29.425 | 18.687 | 0 | 25 | 126 |
| density | 0.964 | 1.417 | 0 | 0 | 6 |
| density_buses | 2.415 | 2.055 | 0 | 2 | 6 |

Table 2: Cities characteristics

| City | Number of rent ads | Population 1000 persons | Number of bus stops | Number of subway stations | Flat/bus densities correlation | Price in relation to Barnaul |
|---|---|---|---|---|---|---|
| Moscow | 143,110 | 11,514.3 | 10,820 | 215 | 0.401 | 0.866 |
| Saint Petersburg | 81,821 | 4,848.7 | 9,280 | 68 | −0.178 | 0.779 |
| Novosibirsk | 14,362 | 1,473.7 | 1,601 | 13 | 0.704 | 0.327 |
| Yekaterinburg | 15,636 | 1,350.1 | 1,078 | 10 | 0.480 | 0.166 |
| Nizhniy Novgorod | 15,498 | 1,250.6 | 1,037 | 15 | 0.401 | −0.092 |
| Samara | 20,536 | 1,164.9 | 1,053 | 10 | 0.499 | 0.000 |
| Omsk | 12,807 | 1,154.0 | 1,493 | 0 | 0.380 | −0.287 |
| Kazan | 21,163 | 1,143.6 | 1,189 | 10 | 0.401 | 0.191 |
| Chelyabinsk | 15,362 | 1,130.3 | 967 | 0 | 0.467 | −0.232 |
| Rostov-on-Don | 24,615 | 1,089.9 | 1,012 | 0 | 0.333 | 0.00 |
| Ufa | 24,742 | 1,062.3 | 871 | 0 | 0.588 | 0.042 |
| Volgograd | 15,611 | 1,021.2 | 1,273 | 0 | 0.485 | −0.119 |
| Perm | 12,817 | 991.5 | 1,040 | 0 | 0.708 | −0.064 |
| Krasnoyarsk | 15,173 | 973.9 | 1,081 | 0 | 0.380 | 0.044 |
| Voronezh | 21,037 | 890.0 | 854 | 0 | 0.575 | −0.292 |
| Saratov | 10,120 | 837.8 | 1,083 | 0 | 0.457 | −0.290 |
| Krasnodar | 42,088 | 744.9 | 1,139 | 0 | −0.159 | 0.175 |
| Tolyatti | 5,554 | 719.5 | 782 | 0 | 0.489 | −0.327 |
| Izhevsk | 6,644 | 628.1 | 666 | 0 | 0.461 | −0.189 |
| Ulyanovsk | 6,582 | 613.8 | 825 | 0 | 0.605 | −0.247 |
| Barnaul | 8,852 | 612.1 | 852 | 0 | −0.110 | 0.00 |
| Vladivostok | 1,750 | 592.1 | 785 | 0 | 0.425 | 0.323 |
| Yaroslavl | 11,701 | 591.5 | 592 | 0 | 0.204 | −0.228 |
| Irkutsk | 14,245 | 587.2 | 572 | 0 | −0.142 | 0.151 |
| Tyumen | 17,794 | 581.8 | 1,032 | 0 | 0.038 | −0.029 |
| Makhachkala | 7,343 | 578.0 | 811 | 0 | 0.108 | −0.137 |
| Khabarovsk | 8,532 | 577.7 | 587 | 0 | −0.142 | 0.358 |
| Novokuznetsk | 4,554 | 547.9 | 760 | 0 | 0.764 | −0.320 |
| Orenburg | 10,112 | 547.0 | 295 | 0 | 0.635 | −0.202 |
| Kemerovo | 7,183 | 532.9 | 910 | 0 | 0.269 | −0.255 |

Table 3: VIF for public transit accessibility transport variables

| Variable | VIF | 1/VIF |
|---|---|---|
| bus_closest | 2.04 | 0.490469 |
| bus1000 | 2.40 | 0.417085 |
| density | 2.19 | 0.457179 |
| density_bus | 2.56 | 0.391069 |
| subway_closest | 2.61 | 0.382697 |
| subway1000 | 2.82 | 0.354040 |
| subway3000 | 5.26 | 0.190067 |

Table 4: Estimation results

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | Dependent variable: log(Rent) | | | |
| Intercept | 5.418*** | 5.556*** | 5.378*** | 5.411*** |
| | (0.0870) | (0.146) | (0.106) | (0.106) |
| floor / 100 | 0.151*** | 0.023 | 0.249*** | 0.253*** |
| | (0.012) | (0.019) | (0.015) | (0.015) |
| floor_ratio / 100 | 0.285 | 1.864*** | -1.405*** | -1.477*** |
| | (0.161) | (0.225) | (0.228) | (0.228) |
| bus_closest / $10^6$ | -0.484 | 2.813 | -1.418 | 5.648* |
| | (1.567) | (1.550) | (2.378) | (2.351) |
| bus1000 / 1000 | 0.627*** | 1.503*** | 0.463*** | -0.002 |
| | (0.025) | (0.066) | (0.027) | (0.030) |
| density_buses / 10 | 0.296*** | 0.254*** | 0.317*** | 0.279*** |
| | (0.002) | (0.004) | (0.003) | (0.003) |
| density / 100 | 0.977*** | 0.796*** | 1.160*** | 1.097*** |
| | (0.034) | (0.045) | (0.054) | (0.054) |
| subway_closest / $10^5$ | | | | -0.787*** |
| | | | | (0.024) |
| subway1000 / 100 | | | | -0.469*** |
| | | | | (0.061) |
| subway3000 / 100 | | | | 0.356*** |
| | | | | (0.014) |
| buildingtype | + | + | + | + |
| rooms | + | + | + | + |
| city | + | + | + | + |
| city_district | + | + | + | + |
| $N$ | 617338 | 305217 | 312121 | 312121 |
| adj. $R^2$ | 0.761 | 0.431 | 0.699 | 0.701 |

Robust standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 1: Map of the cities in our sample

Figure 2: The distribution of the square meter rents in big Russian cities

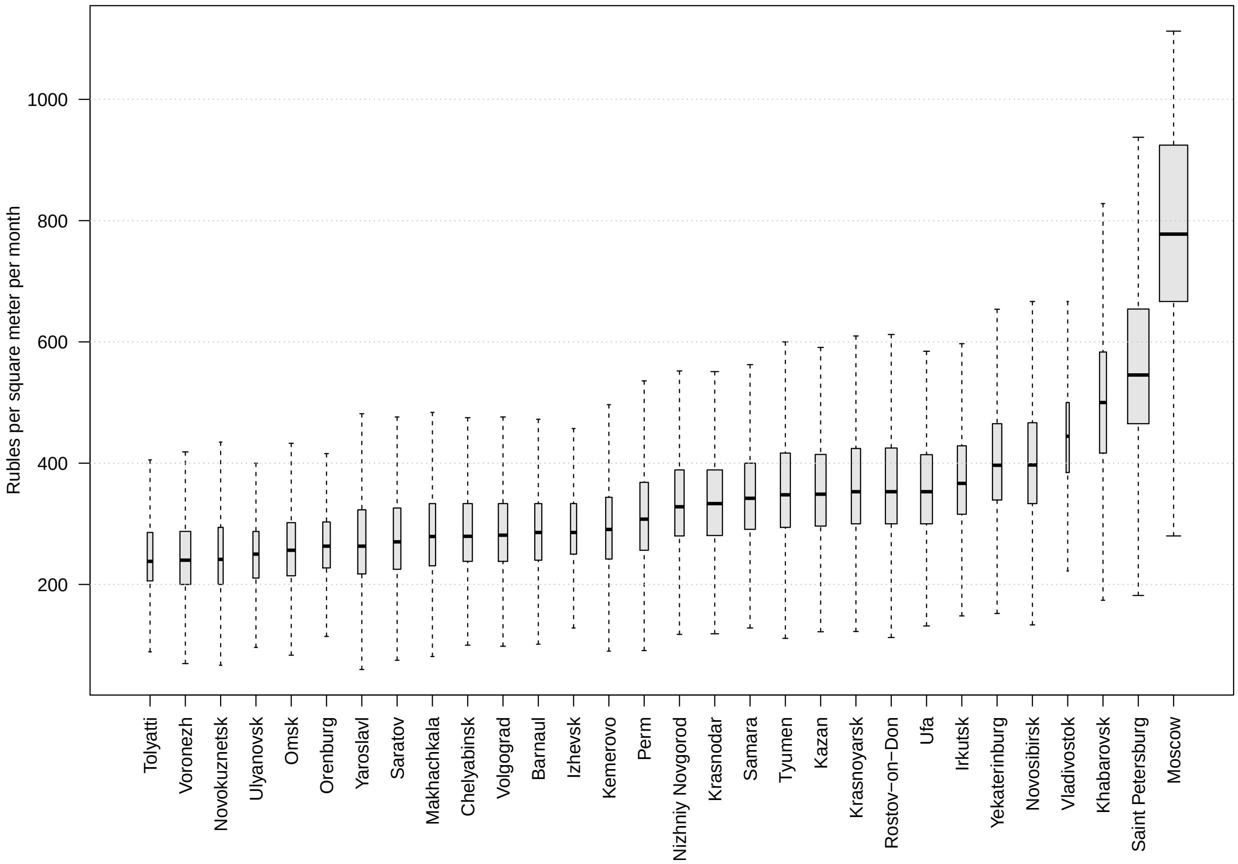

Figure 3: Average area served by one bus stop or one subway station by city