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ORIGINAL ARTICLE



Where is the consumer centre? A case of St. Petersburg

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Abstract

In an urban economy, the distribution of people and real estate prices depends on the location of the central business district of a city. As distance from the city centre increases, both prices and population density diminish, for travel costs increase in terms of time and money. As manufacturing gradually leaves the cities, the importance of consumer amenities as attractors of population to the urban areas increases. The role of a business centre is being replaced by the consumer centre. In this paper, we identify the location of the consumer centre of St. Petersburg - the second largest city in Russia and its former capital. For this purpose using the data from open sources in the Internet regarding the location of many different types of urban amenities, the indices of their spatial density are computed. Using the weights based on coefficients of spatial variation and surveybased weights, the individual indices are aggregated to two general centrality indices. Their unique maxima correspond to the city centre of St. Petersburg, which is located on Nevsky prospekt, between Fontanka river and Liteinyi prospekt.

KEYWORDS

St. Petersburg, urban amenities, consumer city centre, 2D kernel density estimation

JEL CLASSIFICATION R14; R15; C43

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1 | INTRODUCTION

In the urban economy, the distribution of people and real estate prices depends on the location of the central business district of a city (Alonso, 1964; Mills, 1967; Muth, 1969). As distance from the city centre increases, prices and population density diminish, reflecting the increasing travel costs in terms of time and money.

Glaeser, Kolko, and Saiz (2001) show that as manufacturing gradually leaves the cities, the importance of consumer amenities as an attractor of population to the urban areas increases. The role of a business centre is being replaced by the consumer centre. While cities once relied on jobs to attract people, urban amenities (restaurants, shops, education opportunities, museums, etc.) are becoming critical. Using a model in which the natural and urban amenities play a central role, Brueckner, Thisse, and Zenou (1999) explain the spatial distribution of different social classes across the surface of the city. If the city centre has plenty of these amenities, then *ceteris paribus* the rich will be concentrated in the centre, while poor will live in the periphery. Otherwise, the central part of the city will be populated by the low-income families, whereas the high-income households will live in the suburbs. Moreover, as Clark (2003) establishes, different types of amenities attract different groups of the population, whose differences are more nuanced than simply income level. For example, college graduates tend to live in the settlements with less natural and more urban amenities, while seniors favour more the natural amenities. Inventors are more likely to live in the places where both natural and urban amenities are in abundance (Clark, 2003).

In the applied literature, the proximity to different natural and urban amenities is considered to be a factor determining the real estate values: Luttik (2000) (green areas, water, and open spaces); Bourassa, Hoesli, and Sun (2004) (view); Rietveld, Debrezion, and Pels (2007) and Brandt and Maennig (2012) (railway stations); Ahlfeldt and Maennig (2010) (stadiums).

Relatively few studies apply the hedonic approach to Russian data. Most of them focus on the case of Moscow. Magnus and Peresetskiy (2010) analyse the determinants of the asking housing prices in Moscow. Two spatial variables are used: travel time to the next subway station and distance from the nearest subway station to the city centre. The authors set the centre of Moscow to be Red Square, based on the circular shape of the Russian capital city. Krasilnikov and Scherbakova (2011a) estimate hedonic model using data on the asking prices of dwellings in St. Petersburg. This study uses the same two spatial variables. The co-ordinates of the city centre are computed by averaging the co-ordinates of all dwellings in their sample. The estimated city centre is located in the Peter and Paul Fortress. Krasilnikov and Scherbakova (2011b) employ similar methodology in order to identify city centres in their study on four Russian metropolises (Moscow, Novosibirsk, St. Petersburg, and Yekaterinburg). Similarly, Katyshev and Khakimova (2012) use in their analysis of housing prices in Moscow the two variables of proximity to the centre and to the closest subway station. Interestingly, as the centre of Moscow they take the subway station Okhotnyi ryad, which is about 0.5 km from Red Square. In addition, since the focus of their study is on the environmental quality, they also consider the distance to the nearest factory. Tchugunov (2013) uses a much wider list of amenities to assess their impact on the housing prices in Moscow: (i) distance to the nearest subway station; (ii) distance to the secondary schools and their quality (measured by the performance of the pupils); (iii) number of parks; (iv) number of sports facilities; (v) number of health care institutions per 10,000 persons; and (vi) number of municipal police units per 10,000 persons. By contrast, this study does not employ any measure of proximity to the city centre, capturing the spatial heterogeneity of prices by the district dummies. Nosov and Tsypin (2015) investigate the determinants of asking prices for one-room apartments in a medium-size Russian city Orenburg. In order to capture spatial factors they take advantage of spatial clusters obtained by the k-means clustering technique and of the distance to the city centre, which is defined as the central post office of the city. In Russia, post offices are typically used as departure points to measure the distances. Kholodilin and Ulbricht (2015), who estimate hedonic regressions for 48 large European cities, including seven Russian cities (Kazan, Moscow, Nizniy Novgorod, Rostov on Don, Samara, St. Petersburg, and Yekaterinburg), capture spatial effects only by district dummies.

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As the amount and variety of information published on the Internet increase, the possibilities of exploiting it to measure the natural and urban amenities at the microlevel (individual parks, shops, restaurants, etc.) expand extraordinarily. For example, Ahlfeldt and Wendland (2016) suggest a method of computing the so-called potential spaces taking in account the geographical distribution of different natural and urban amenities objects.

The aim of this paper is to develop a simple and easily applicable method of delineating the consumer city centre. As an example, it is used to identify the exact coordinates of the consumer centre of St. Petersburg, Russia, that is, the point with the highest density of consumer urban amenities in the whole city. This information can be used for different purposes. For example, it can be employed in the hedonic analysis of the housing prices and rents, where both the detailed evaluation of the impact of different urban amenities and a compact representation of all the relevant amenities by a single index are desirable. Moreover, when assessing accessibility, it is critically important to know where the city centre is located. In this case, the centre of St. Petersburg identified in this paper can be used to construct the isochrones (equal travel time curves, see, e.g., Kholodilin, 2016), which require choosing the co-ordinates of the city centre. Finally, the estimation of population density gradient requires an exact knowledge of the central business district location. If the centre co-ordinates are misspecified, then, as Alperovich and Deutsch (1992) demonstrated, this can lead to an underestimation of the gradient.

In this study, we treat the city centre as a point instead of an area. This is, of course, an overly simplification because the centre of the city cannot be reduced to just one point. This simplification, however, can be very useful in practical applications. First, it is much easier to compute distances or travel times to a single point than to an area. In the case of area, one has to make an uneasy choice whether to compute accessibility with respect to the centroid of the area or to its boundaries. Second, the definition of a central area can be much more involved, for we would need to impose some rather *ad hoc* thresholds that will separate the central area from the area surrounding it. Third, treating city centre as a point fits well in the existing literature on hedonic models, where the price gradient is estimated.

St. Petersburg is the second largest city in Russia and its former capital. During the twentieth century, it underwent many dramatic changes related to wars and revolutions. In 1918, after having served as the capital of the vast Russian Empire for two centuries, it became a regionally important city. Since then, three times St. Petersburg has had its population drastically decrease: it lost more than half of its population during both the Russian Civil War of 1918–1920 and the Second World War. Later, during the 1990s, as a result of radical socio-economic and political transformations, St. Petersburg lost 500,000 citizens, ending the decade with 4.5 million residents. It is only during the early 2000s that the city managed to recover in terms of population, exceeding 5.2 million in 2016. Moreover, in the 1930s, there was a plan to displace the political centre of the city from the neighbourhood of the Winter Palace,¹ to the south by about 11 km, in the direction of Moscow. However, the entry of Russia into the Second World War made this plan obsolete. Overall, the central planning system that was in place in Russia between 1917 and 1990 tried to spatially distribute amenities in a planned manner in accordance with its non-market principles. Despite all these changes, the city kept many of the cultural values accumulated over the years in form of palaces, museums, and theatres. Its historic centre is a UNESCO World Heritage Site. Moreover, the transition to a market economy that started in the early 1990s led to a rapid increase in amenities, especially shops and restaurants.

The paper has following structure. Section 2 reviews the literature on delineating city centres. Section 3 introduces the method of finding location of city centre used in this paper and describes the underlying data. In section 4, the estimated co-ordinates of the consumer city centre are contrasted against alternative estimates, which are based on different techniques and data. Finally, section 5 draws conclusions.



2 | APPROACHES TO DELINEATING THE CITY CENTRE

Despite the importance of the notion of central business districts (CBD) in urban and housing research, as a rule, in the literature, its location is arbitrarily chosen. Typically, the choice of its co-ordinates is not justified.

At the same time, there is an extensive literature devoted to determining the city centre; see Table 1 for a concise overview. It can be divided in two unequal groups: a couple of studies by urban economists and many works by economic geographers.

2.1 | Urban economics

One of the first urban economists addressing this issue is Alperovich (1982). He uses the population density gradient model in order to identify the location of the CBD of Tel-Aviv-Jaffa. Departing from the hypothesis of diminishing population density as the distance to the centre becomes larger and using different functional forms modelling this relationship, he undertakes a grid search and chooses from all the candidates the point, for which the adjusted R^2 is maximized. He uses the data on population at the level of census tracts that produce a quite detailed picture of the geographical distribution of population density. However, such information is not always available. Moreover, the census tract boundaries are predetermined and do not reflect actual local housing market areas.

Paper	Data	Method	Number of cities (country)
Murphy and Vance (1954)	land use by blocks	indices of intensity and nature of land use	9 (USA)
Alperovich (1982)	population by census tracts	density gradient model, OLS	1 (Israel)
Alperovich and Deutsch (1994)	population by census tracts	density gradient model, exponential and Box-Cox	1 (Israel)
Thurstain-Goodwin and Unwin (2000)	sectoral employment by postal code districtsfrom official statistics	2-d kernel density estimation and aggregation of the empirical density functions using arbitrary weights	1 (UK)
Montello et al. (2003)	street survey	drawing of city centre by the respondents	1 (USA)
Borruso and Porceddu (2009)	urban amenities objects from Yellow pages	2-d kernel density estimation for all amenities simultaneously	2 (Italy)
Hollenstein and Purves (2010)	geocoded and tagged pictures from Flickr	2-d kernel density estimation	1 (Switzerland), 2 (UK), 2 (USA), and 1 (Australia)
Lüscher and Weibel (2013)	urban amenities objects from official statistics	2-d kernel density estimation and aggregation using survey-based weights	10 (UK)
Taubenböck et al. (2013)	building footprints and street networks from the OpenStreetMap as well as 2- and 3-d satellite pictures	3-d city model and blockwise classification using fuzzy logic	1 (France)
Sun et al. (2016)	check-ins in social network Gowalla	cluster analysis and Voronoi polygons	3 (Germany)

TABLE 1 Approaches to delineating the city centre

Alperovich and Deutsch (1994) suggest an approach that estimates the co-ordinates of the CBD by including them as unknown parameters in the econometric model and applying the maximum likelihood method. This allows determining not only the region, to which the CBD belong, but also the CBD's precise point co-ordinates. In addition, it is possible to test various hypotheses about the location of the centre. For example, one can test whether the CBD is shifting in space due to the changing structure of the city. This approach permits to flexibly model the potential non-linearities using the Box–Cox transformations.

2.2 | Economic geography

Economic geographers represent an independent and a very different strand of the literature. One of the first studies to address the question of delineating a city centre is Murphy and Vance (1954), which employs land use data. In particular, two indicators are used: (i) the total space to ground floor ratio; and (ii) the "central business use" space to ground floor area at the block level. For many decades, the approach of Murphy and Vance (1954) dominated economic geography. After nearly 60 years, it was modified by Taubenböck et al. (2013), who use detailed data on the intensity of the land use taken from both open sources and satellite pictures, then applying morphological 3D modelling of the land use at the level of blocks with the object of delimiting the CBD of Paris. This method, with its objectivity and flexibility, is very data demanding and computation intensive. Furthermore, its applicability depends to large extent on the country and regional differences in the heights of buildings, which are determined, for instance, by the ground or by legal height restrictions. Buildings within the historical centre of St. Petersburg are subject to legal restrictions respecting height, among other conditions.

Thurstain-Goodwin and Unwin (2000) suggest an innovative approach that subjects sectoral employment data attached to the centroids of the postal code districts to spatial smoothing using 2D kernel density estimation (KDE). Subsequently, the resulting empirical functions of spatial density are aggregated into a single index by computing their weighted average. It should be noted that the weights are determined arbitrarily, a weakness of the approach. This method is improved by Borruso and Porceddu (2009) and Lüscher and Weibel (2013) in terms of both the input data and the weighting scheme. Borruso and Porceddu (2009) collect microlevel data on different activities (clothing, arts and culture, banks and insurance companies, retail, etc.) from the Yellow pages and georeference each establishment. Then, a kernel density estimation of all these features taken together is done. Based on the resulting isolines the city centre is delineated using three standard deviations as a threshold. We find, however, that mixing together different urban amenities is difficult to justify. Various amenities have different frequencies: for instance, there many more shops than theatres. At the same time, some amenities are more typical of a centre than others. When mixed in a single data set, then the amenities that are less typical of a centre, but occurring more frequently, can have a larger impact on the estimated location of the city centre, thus biasing the resulting coordinates. Lüscher and Weibel (2013) use point-of-interest data, that is, microlevel information on commercial establishments (accommodation; eating and drinking; attractions; etc.) supplied by official UK bodies. The authors conduct an internet survey to identify whether features should be considered as typical or atypical for a city centre. Based on the results, they determine weights for each feature. For each feature a 2D KDE is carried out. The resulting smoothed spatial distributions are aggregated using the survey-based weights. Finally, the boundaries of city centres are determined as an area, for which the computed city centre typicality exceeds 0.5. The computed centres are compared to the "comparative centres" based on alternative representations (tourist maps, Wikipedia, and Flickr).

Apart from the density of urban amenities, other density indicators drew attention of the researchers. Hollenstein and Purves (2010) take advantage of the tagged and georeferenced images from the photography website Flickr.com. The city centre boundaries are obtained through KDE of the locations of the pictures tagged as referring to the inner city (downtown, cbd, central, innercity, city centre). Sun et al. (2016) use location-based social networking (LBSN) data. They take advantage of the fact that georeferenced and time-stamped "check-ins" (sometimes referred to as a type of volunteered geographic information) represent the displacements of the LBSN users and tend to be clustered in space, especially where commercial facilities (shops, restaurants, cinemas, etc.) abound. Therefore, these LBSN mobility data can serve as an indicator of the LBSN users' mobility. The data are collected from Gowalla, a LBSN. Clusters of point data are constructed and the boundaries of city centre are defined as the boundaries of the Voronoi polygons around the points belonging to the largest cluster.

A very unusual approach employed by Montello, Goodchild, Gottsegen, and Fohl (2003) asked people on the street to draw the boundaries delimiting, on a paper map, where they are 50% and 100% confident downtown is located. The intersection of the hand-drawn maps can be considered as a conventionally defined city centre.

2.3 | Monocentricity vs. policentricity

Here, we depart from the assumption that St. Petersburg has a unique centre. It corresponds to the standard Alonso–Muth–Mills urban economic model. However, there is a large literature on polycentric cities, which implies that a city can have a main centre together with several subcentres; see an overview in Kholodilin and Limonov (2018). Two other works should be mentioned here, which are not included in that overview. First, Osland and Thorsen (2008) examine several labour-market accessibility measures that approximate the employment subcentres, which compete with the CBD. These measures take into account both the number of job opportunities offered by each employment subcentre and the distance to it. Second, Gibb, Osland, and Pryce (2014) estimate the monetary value of access welfare obtained from the multiple employment nodes. The authors use the gravity-based access variable and maximum likelihood method to estimate the appropriate functional form that captures the non-monotonic effects of proximity: being too close to an employment node means more noise and congestion, while living too far from it implies higher commuting costs.

Kholodilin and Limonov (2018) test and reject the hypothesis of polycentricity for St. Petersburg using the spatial distribution of eating establishments as a proxy for the location of the city centre. Therefore, we can safely confine this study to exploring only a monocentric case.

3 | AN INDEX OF URBAN AMENITIES

3.1 | Data

In order to identify the consumer centre of St. Petersburg, Russia, it is necessary to identify the locations of each type of urban amenities. With these data at hand, it is possible to compute the spatial density indices for each type. The indices can be interpreted as an accessibility measure to different amenities at any point within the city.

The sources of data, the number of observations of each type of amenities, and more general categories of amenities are reported in Table 2. Overall, 18 types of urban amenities are considered: banks, cinemas, fitness clubs, food stores, healthcare establishments (polyclinics, hospitals, dental clinics, women's consultation clinics, early treatment centres, etc.), hairdressers, kindergartens, lawyers, museums, notaries, pharmacies, schools, shops (shoes, cloths, jewelry, etc.), restaurants, shopping malls, temples, and theatres. The largest number of observations is available for the shops (7,139), while the smallest number is for the cinemas (90). The data were collected from various websites containing information (name, type of establishment, its geographical co-ordinates, and sometimes its price range as well as the rating based on the client votes) about different specialized individual establishments.

There are several caveats related to the data. First, we cannot be sure that they are complete. Second, it cannot also be guaranteed that the data are up-to-date. For example, the lists of each amenity can contain the establishments that are no longer functioning, since it implies an additional and not rewarded effort to remove them from the list. We claim, however, that these are the best data that can be found. First of all, no official complete and up-to-date lists of amenities are available for St. Petersburg as well as for many other cities. There is

TABLE 2 Data sources

Amenity	Number of observations	Website	Category
Banks	874	www.banki.ru	Offices, notaries, banks
Cinemas	90	www.afisha.ru	Culture
Fitness clubs	224	https://sportgyms.ru/	Fitness, pools
Food stores	1655	www.yp.ru	Food stores
Hairdressers	1994	www.yp.ru	Beauty, hairdressers
Health care	2082	www.spbmed.info	Health care
Kindergartens	1028	https://detsadi-spb.ru	Education
Lawyers	425	www.yp.ru	Offices, notaries, banks
Museums	221	www.afisha.ru	Culture
Notaries	314	sanktpeterburg.tradeis.ru	Offices, notaries, banks
Open spaces	6975	https://data.nextgis.com/	Green spaces
Pharmacies	1026	www.spbmed.info	Health care
Restaurants	3138	www.restoclub.ru	Restaurants
Schools	635	https://apeterburg.com	Education
Shopping malls	176	https://peterburg2.ru	Shopping malls
Shops	7139	www.shopping-spb.su	Cloth and shoe stores
Temples	351	https://temples.ru/	Temples
Theaters	349	www.afisha.ru	Culture

no information on how many establishments are active in each type of amenities. Therefore, we tried to use the websites that list the largest number of establishments compared to other similar websites. Second, the websites, which we use as a source of data here, are customer-oriented with information being supplied by the owners of the establishments. The owners are interested in being visible and, thus, will rarely miss the opportunity to place information about their establishments online. Third, although the data can be incomplete or not always updated, there is no reason to assume that this incompleteness or lack of updating follow any systematic spatial pattern. Thus, we can more or less safely assume that our data approximate quite accurately the spatial distribution of amenities.

3.2 | Spatial densities of urban amenities

In accordance with the literature, in order to estimate the spatial density of each amenity, we took advantage of the two-dimensional kernel density estimation method.² Following the advice of Borruso and Porceddu (2009), we split the city into square cells with a size of approximately 200 m per side of the square and obtained a grid with 127,500 cells (375×340). The window size, *BW*, was determined separately for each co-ordinate using the following rule of thumb (See Venables & Ripley, 2002):

$$BW = 4 \times 1.06 \times \min\{\sigma_x, h\} \times N^{-\frac{1}{5}}$$

$$\tag{1}$$

where σ_x is the standard deviation of the variable *x* (in this case, the variable is either longitude or latitude of individual objects); *N* is the number of observations of variable *x*:

$$h = \frac{Q_3 - Q_1}{1.34},\tag{2}$$

where Q_1 and Q_3 are the first and third quartiles of the variable x, respectively.

The smoothed spatial distribution of selected urban amenities considered here is depicted in Figures 1 and 2. The darker shading corresponds to a higher density. In accordance with Christaller (1980), who distinguishes between the higher and lower order central goods, each amenity has a different degree of centrality. The former figure shows the four most decentralized amenities (schools, kindergartens, pharmacies, and hairdressers), while the latter displays the four most centralized amenities (museums, notaries, restaurants, and theatres). For example, while the schools are widely scattered over the territory of the city, the museums are mainly concentrated in the historical



FIGURE 1 Amenities with lowest spatial concentration

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FIGURE 2 Amenities with highest spatial concentration

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districts of the city (Admiralteiskiy, Vasileostrovskiy, Petrogradskiy, and Tsentral'nyi) and have a clear cut centre. Such differences are easy to understand when the nature of the services provided by, for example, the pharmacies and the theatres is taken into account. The former satisfy more basic needs and, hence, must be located close to the customers, while the latter are aimed at satisfying higher order requirements of a much more limited group of customers. Moreover, the geographical distribution of many theatres is determined by their history: prior to the October 1917 revolution, it was mainly higher income individuals attending theatre performances; consequently these were built close to the neighbourhoods where such persons lived. At that time, most nobles had their palaces close to the imperial palace.

Figure 3 shows the centres of the smoothed spatial distribution of individual urban amenities. Most of them are clustered together in Tsentral'ny district. Three, education, sports, and food stores, are located more to the west, in Admiralteiskiy district.

The location of the consumer centre of St. Petersburg is identified using a composite index of spatial density of the urban amenities, which is obtained by aggregating the smoothed spatial densities of individual amenities. The composite index is calculated as follows:



FIGURE 3 Centres of spatial distribution of individual amenities

$$\mathsf{ADI}_{ij} = \sum_{k=1}^{K} \widetilde{\mathsf{AD}}_{ij}^{k} \mathsf{w}_{k},\tag{3}$$

where

$$\widetilde{AD}_{ij}^{k} = \frac{AD_{ij}^{k} - \mu_{k}}{\sigma_{k}},$$

 AD_{ij}^k is the spatial density of the k-th type of amenity in the cell *ij*; μ_k is the mean of smoothed spatial distribution of k-th amenity; σ_k is the standard error of amenity k; and w_k is the weight of this type. The weights are normalized in such a way that they sum to 1.

3.2.1 | Variation-based weights

One way to determine the weights is to base them on the coefficient of variation of the smoothed spatial density. Indeed, the amenities that have clearly identified peaks are characterized by higher spatial density variance and, thus, higher coefficient of variation. By contrast, when amenities are evenly distributed across the surface of the city, then the coefficient of variation should be equal zero. Hence, the weights are computed as follows:

$$w_k = \frac{\frac{\sigma_k}{\mu_k}}{\sum_{k=1}^{K} \frac{\sigma_k}{\mu_k}},\tag{4}$$

where σ_k is the standard deviation of the spatial density of amenity k and μ_k is the mean of the spatial density of the amenity.

Table 3 reports coefficients of variation of individual amenities and corresponding weights. The amenities are arranged in the order of increasing spatial variation. The higher the variation coefficient the more spatially concentrated the corresponding amenity. Thus, the amenities placed in the upper part of the table are the most spatially dispersed.

The composite index of the spatial density of the urban amenities is shown in Figure 4. The darker shading corresponds to a higher spatial density. The maximum of the index is attained at Nevsky prospekt, between Liteynyi and Ligovskii prospekts. This is the place where the highest concentration of all amenities is attained.

3.2.2 | Survey-based weights

The second way to compute the weights is that of Lüscher and Weibel (2013). In order to obtain user defined weights, we conducted a survey in January-March 2017 in St. Petersburg. The survey consists of 10 questions,

Amenity	Variation coefficient	Weight
Schools	2.421	0.034
Kindergartens	2.524	0.035
Pharmacies	2.573	0.036
Hairdressers	2.678	0.037
Temples	2.699	0.037
Cinemas	2.759	0.038
Food stores	2.832	0.039
Shopping malls	2.878	0.040
Fitness clubs	2.986	0.041
Health care	3.475	0.048
Lawyers	4.550	0.063
Banks	4.990	0.069
Shops	5.540	0.077
Museums	6.421	0.089
Notaries	6.430	0.089
Restaurants	7.774	0.108
Theaters	8.532	0.118

TABLE 3 Variation-based weights of individual amenities





falling into two broad categories: (i) individual characteristics of the respondents (age, gender, educational level, size of the settlement of origin, and their nearest crossroads); and (ii) characteristics of the city centre (what do the respondents associate with the city centre as well as which amenities they find typical for the city centre and which are not).

The survey was conducted online using Google Forms. The invitations were sent to the friends of the authors and to the friends' friends. Therefore, it is difficult to judge the response rate, since we do not know how many persons received invitations but did not respond. Thus, our survey design is very similar to that of Lüscher and Weibel (2013), who to a large extent draw their information on amenities weight from British academics and their students.

We received 140 correctly filled questionnaires. Very few filled questionnaires were discarded, mainly on the basis of missing information. Given that survey respondents were mostly the students of the National Research University - Higher School of Economics St. Petersburg, the share of young persons (aged between 18 and 24) exceeds 74%. In addition, females make up two-thirds of the respondents. Over 46% of respondents are university graduates. Finally, 35% of respondents come from St. Petersburg, almost 14% are from other cities with population exceeding 1 million, about 47% are from smaller cities, and slightly more than 4% are from the countryside. This implies that the survey participants are not representative of the permanent population of St. Petersburg. For example, in 2018, the females made up 54%, while the 20-24 years old persons accounted for just 4.5% of the total population of the city (Petrostat, 2019). This can introduce certain bias in the weighting scheme. However, the weights we obtained are qualitatively to those of Lüscher and Weibel (2013). Of course, in both surveys, the main respondents are academics and students. But the fact that responses of British and Russian participants concord is somewhat comforting. This does not, however, mean that we should forget about the potential bias. For instance, academics and students can put too much weight on cultural and educational amenities, while the youth can be more geared toward entertainment. To some extent, though, this bias is alleviated by the fact that we have 12 amenity groups, so that the weight of a single group is relatively small. Moreover, locations of amenity-specific centres are relatively close to each other implying that their weighted averages based on different weighting schemes should not differ a lot.

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Figure 5 shows the survey-based weights of 12 amenity categories. Cultural amenities and restaurants are perceived by the survey participants as the most typical for the city centre, while the sports and health care amenities are thought to be the most atypical ones. Thus, the former are assigned large positive values, while the latter larger in absolute terms negative values.

The general amenities index with survey-based weights is computed as:

$$\mathsf{ADI}_{ij}^{\mathsf{S}} = c_m \times \sum_{k=1}^{K} \mathsf{AD}_{ij}^k \mathbf{w}_k^{\mathsf{S}} + c_a, \tag{5}$$

where

$$c_m = \frac{1}{\sum_{k=1}^{K} |w_k^S|} \text{ and } c_a = c_m \times \sum_{k=1}^{K^-} |w_k^S|, \tag{6}$$

are normalization constants ensuring that $0 \le ADI_{ij}^{S} \le 1$; while $k = 1, 2, ..., K^{-}$ are the indices of the negative surveybased weights.

In cases when a category includes more than one individual amenity type, these types are aggregated to the category index using simple averaging. The correspondence between amenity types and categories is shown in Table 2.

Similar to Lüscher and Weibel (2013), the area-like amenities (open green spaces) are transformed into spatial densities by computing the share of the land devoted to the green areas within a circular window of 240 m radius around the centre of each raster cell.

The resulting general amenities index is displayed in Figure 6. Again, darker shaded areas correspond to the higher spatial density of all amenities. Interestingly, three amenity-poor areas appeared: two in the north and one in the south. Apparently, they fall into industrial zones of the city. The distance between the variation- and survey-





based estimates of consumer city centre is 1.1 km. The survey-based centre is located more to the north than the variation-based centre; see black and green dots in Figure 7. In addition, four other estimates of city centre are shown there: two employment- and two population-based estimates obtained using the methodology of Alperovich and Deutsch (1994); see Section 4. Moreover, the map displays as an orange area the contours of the historic centre of St. Petersburg as defined by the UNESCO. It can be seen that the highest concentration of amenities falls into the historic centre with its rich cultural heritage.

4 | ROBUSTNESS CHECK

In order to check the robustness of our results we use several alternative methods of finding the city centre location and delineating the city centre as a region. If alternative estimates of the consumer city centre, based on different data sources and methodologies, agree and corroborate the results obtained using our preferred method, then it implies three things. First, the consumer city centre is something measurable and its location can be identified relatively precisely. Second, the alternative techniques are interchangeable. Third, our preferred method is reliable and can be safely used in case other information is missing.

4.1 | Gradient method

First, we use the approach suggested in Alperovich and Deutsch (1994). For this purpose the following two regressions were estimated using the method of the maximum likelihood:

Exponential regression:

(7)

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FIGURE 7 Alternative point estimates of city centre

where p_i is the population or employment density in the *i*th municipal district (MD); α is a parameter measuring the population or employment density in the CBD; γ is the so-called density gradient that describes the diminishing population or employment density as the distance from the CBD increases; $d((\theta_1, \theta_2), (c_{i1}, c_{i2}))$ is the distance in km between the CBD and the centroid of the district *i* (θ_1 and θ_2 are the longitude and latitude of the CBD, while c_{i1} and c_{i2} are the coordinates of the centroid of the *i*-th MD); ε_i is the error term.

Box-Cox regression:

$$\frac{p_i^{\lambda} - 1}{\lambda} = \alpha + \gamma d((\theta_1, \theta_2), (c_{i1}, c_{i2})) + \varepsilon_i,$$
(8)

where λ is a non-linearity parameter determining the functional form of the regression. When $\lambda \rightarrow 0$, the model tends to the exponential form, while when $\lambda = 1$ it takes the linear form.

The data on the area, population, and employment in all 111 municipal districts of St. Petersburg, as of 2015, are taken from the database of the municipal district indicators of the St. Petersburg's statistical office Petrostat (http:// petrostat.gks.ru/wps/wcm/connect/rosstat_ts/petrostat/ru/statistics/Sant_Petersburg/db/). The distribution of population and employment density by municipal districts is shown in the upper panels of Figure 8. This graph displays the population and employment density by the municipal districts of St. Petersburg. The darker the shading, the higher the density. The highest employment density is observed in the historical centre of the city and gradually declines toward the city periphery. For the population, the picture is not that clear cut, for there are some MDs with high population density that are relatively far from the city centre.

The results of estimation of models (7) and (8) for the population and employment are reported in Table 4. In all cases, the density gradient is negative and statistically significant, which implies that the population and employment





(a) population by subdistricts

(b) employment by subdistricts



FIGURE 8 Popu lation and employment density and density gradients

densities decay as the distance from the CBD increases. The gradient varies between -0.12 and -0.19. The estimated non-linearity parameter λ is 0.190 for the population and 0.105 for the employment. This means that in the former case, the Box-Cox transformation model is more different from the exponential specification than in the latter case; see Figure 8. The figure depicts the dependence between population density (panel (c)) and employment density (panel (d)), on the one hand, and distance to the CBD, on the other. Both functions (exponential and Box-Cox) differ in their middle part. As the distance to the CBD increases from 0 to 10 km, the population density diminishes from over 200 to 60 persons/ha for exponential specification and from 160 to 110 persons/ha for the Box-Cox one. At the same time, employment density decreases from over 60 to 10 persons/ha for the exponential and from 50 to 25 persons/ha for the Box-Cox specification.

The parameters θ_1 and θ_2 are the longitude and latitude of the CBD, respectively. The CBDs identified using the Alperovich and Deutsch (1994) method are shown together with the variation- and survey-based consumer centres in Figure 7. All these centre estimates lie in Tsentral'nyi (Central) district. Moreover, all fall within the boundaries of the UNESCO World Heritage Site that makes up the historic centre of St. Petersburg. The distance between the variation-based consumer centre and CBDs is; (i) approximately 0.4 and 0.8 km (exponential and Box-Cox specifications, correspondingly) for the population, and (ii) about 1.2–1.4 for employment. The distance between the survey-based consumer centre and CBDs is: (iii) approximately 1.3 and 1.9 km (exponential and Box-Cox specifications, correspondingly) for the population; and (ii) around 1.8 for employment, similarly for both specifications.

Thus, the centres of St. Petersburg determined using different techniques are relatively close to each other. The differences between them are related, first, to the fact that the CBD reflects concentration of the productive activities, while consumer centre characterizes the consumption opportunities. Second, they are based on different information (population/employment vs. urban amenities) at different aggregation levels (municipal districts vs. individual amenity objects). It should be noted that the variation-based consumer centre has the shortest average distance to all other centre estimates, unlike the survey-based one.

	Dependent variable:				
	population density		employment density		
	Specification:				
Coefficient	exponential (1)	Box-Cox (2)	exponential (3)	Box-Cox (4)	
α	5.280***	8.531***	4.045***	4.879***	
	(0.154)	(1.391)	(0.189)	(0.35)	
γ	-0.115***	-0.191***	-0.140***	-0.163***	
	(0.008)	(0.036)	(0.01)	(0.014)	
σ	1.051***	1.991***	1.278***	1.491***	
	(0.071)	(0.449)	(0.086)	(0.136)	
θ_1	30.348***	30.352* * *	30.324***	30.321***	
	(0.029)	(0.031)	(0.016)	(0.016)	
θ_2	59.926***	59.933* * *	59.934***	59.935***	
	(0.013)	(0.014)	(0.008)	(0.008)	
λ		0.190***		0.105***	
		(0.059)		(0.029)	
Observations	111				

TABLE 4 Employment and population density estimation results

Notes. p < 0.1; p < 0.05; p < 0.05; p < 0.01; Numbers in parentheses are standard errors of the estimated parameters.



FIGURE 9 The crossroads based city centre region

4.2 | Place of living method

Our second alternative approach is based on the survey that we conducted in St. Petersburg in January–March 2017. We asked the respondents to judge whether they live in the city centre, between the centre and the periphery, or in the periphery. Moreover, they had to name the closest crossroads to their place of living. The purpose of this question was to determine, more or less, the respondent's home co-ordinates without making the respondents reveal potentially sensitive information regarding their personal address. Figure 9 shows the corresponding crossroads classified in the three categories according to the proximity to the city centre. The city centre category denoted by red letter *C* represents the union of individual estimates of the centre and, thus, the largest estimate of central area.

4.3 | Drawing method

The third approach follows that of Montello et al. (2003). During the above mentioned survey, the same respondents were asked to draw on the map they were provided with two regions delineating what is in their opinion the city centre with probability of 100% and 50%. The rest of the map was coded as having the zero probability of being the city centre. The survey respondents supplied 51 maps with two central regions. The individual maps were geocoded³, rasterized using a 1000×1000 grid, and averaged. As a result we obtain a

consensus region that most of survey participants who drew the map perceive as being the St. Petersburg city centre with the highest probability; see Figure 10. It is surrounded by areas with gradually declining probability of centrality. Both estimates of consumer centre belong to the region with the highest probability of being central. The point with maximum probability of being city centre assigned by the survey participants is located between both consumer centre estimates, a bit to the west. Consumer centre estimates do not belong to the area of the highest probability of being central, but are located very close to it.

4.4 | User-generated content method

The fourth centre delineation method we use follows Hollenstein and Purves (2010). Here, we take advantage of the geocoded and tagged pictures from Instagram, the most widely used photography website in Russia.



FIGURE 10 The averaged manually drawn city centre region



FIGURE 11 Spatially smoothed distribution of Instagram photographs

From the over 8 million photographs taken by persons whose city of origin is denoted as St. Petersburg we selected those having geographical co-ordinates and such tags as "center," "centre," or "ETH" (which is "city centre" in Russian). It should be noted that over two-thirds of the persons who posted their photos are females and 81% of those whose age is known are younger than 30.⁴ The smoothed spatial distribution of these photographs is shown Figure 11. It is very concentrated along the historical avenue of the city, Nevsky prospekt. The peak of the distribution is located at the subway station "Kanal Griboyedova." It is, thus, located about 1 km to the west of the variation-based consumer centre. However, the latter belongs to a local peak of the spatial distribution of Instagram centre-related pictures.

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⁴The demographic characteristics of the Instagram users are obtained from their VK account linked to their Instagram account. VK, or VKontakte, is the largest Russian social network, an analog of Facebook; https://vk.com.

5 | CONCLUSION

In this study, using microdata about various objects of urban consumer amenities collected on the Internet, we constructed individual indices of the spatial density of urban amenities in St. Petersburg, Russia. These indices are aggregated to two alternative composite indices of centrality depending on the way the weights are computed. Given that the centrality index with variation-based weights is, on average, the closest to the alternative centre estimates, we took it as a proxy for the location of the consumer centre of St. Petersburg. This consumer centre is located on Nevsky prospekt, between Fontanka river and Liteinyi prospekt.

The variation-based method has also valuable practical advantages. While survey-based weights are more difficult to obtain and to guarantee the representativeness of the survey, the variation-based weights are much easier to compute. They also rest on an intuitive assumption that amenities with higher spatial concentration should contribute more to the delineation of the city centre. In the Big Data era, all the necessary components are thus readily available to estimate the location of the consumer city centre. For example, huge amounts of spatial information are collected by the participants of the OpenStreetMaps community and can be readily downloaded by researchers. It is, therefore, relatively easy to obtain and to process such data for many cities using the approach proposed in this study.

The results of the amenities-based approach were cross-checked using four alternative techniques: population/employment density gradients, place of living approach, map drawing method, and user-generated content method. All in all, the method employed in this paper produces plausible results that are confirmed by other approaches using different techniques and different data.

The findings of this study can be useful for various purposes. First, the estimate of the city centre can be employed in hedonic regressions of housing prices and rents as well as in the analysis of the determinants of the spatial distribution of employment and economic activities in St. Petersburg. Second, the methodology proposed here can help the city planners to identify the areas that are undersupplied with amenities, the extreme case being the purely residential or purely office neighbourhoods. Such "dispirited grey areas" can be a source of insecurity and, eventually, urban degradation due to their monotonous dullness (Jacobs, 2016). Third, it is also applicable for an historical analysis of the urban economy in general and housing market; see, for example, (Kholodilin and Limonov, 2018; Kholodilin et al., 2020). By investigating the potential displacements of the city centre it is possible to obtain insights in the factors behind such changes and uncover potential challenges. Finally, the approach suggested in this study can be helpful as a guidance for tourists, since it can identify the areas that are the most interesting to visit due to their richness in terms of consumer and cultural amenities.

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Resumen. En una economía urbana, la distribución de las personas y de los precios de los bienes inmuebles depende de la ubicación del distrito financiero central de una ciudad. A medida que aumenta la distancia al centro de la ciudad, tanto los precios como la densidad de población disminuyen, mientras que los costos de viaje aumentan en términos de tiempo y dinero. A medida que el sector de manufacturas abandona gradualmente las ciudades, la importancia de los servicios de consumo aumenta como un factor de atracción de la población a las zonas urbanas. El papel de un centro financiero está siendo reemplazado por el de un centro de consumo. En este artículo se identifica la ubicación del centro de consumo de San Petersburgo, la segunda ciudad más grande de Rusia y su antigua capital. Para ello se calcularon los índices de la densidad espacial de muchos tipos diferentes de servicios urbanos, utilizando datos sobre su ubicación de fuentes de Internet abiertas al público. Se utilizaron ponderaciones basadas en los coeficientes de variación espacial y ponderaciones basadas en un muestreo para poder agregar los índices individuales a dos índices generales de centralidad. Su máxima corresponde al centro de la ciudad de San Petersburgo, que se encuentra en la Avenida Nevsky, entre el río Fontanka y la Avenida Liteinyi.

抄録:都市経済では、人口分布及び土地価格はその都市の中心業務地区の立地に依存する。都市中心部からの距離が増加するにつれて、物価と人口密度は低下し、移動にかかる時間と交通費は増加する。製造業が徐々に都市部から離れるにつれて、都市地域への人口の誘因としての消費者アメニティの重要性が増している。経済の中心地としての役割は消費者センターに取って代わられようとしている。本稿では、ロシア第二の大都市であり、かっての首都であるサンクトペテルブルクの消費者センターの立地を検討する。この目的のために、インターネット上のオープンソースから得られる、様々なタイプの都市アメニティの立地に関するデータを用いて、アメニティの空間密度の指標を計算する。空間変動係数に基づく重みと調査に基づく重みを用いて、個々の指標を一般的な2つの中心性指標に集約した。サンクトペテルブルクの中心部に対応するユニークな極大値は、ネフスキー大通りの、フォンタンカ川とリチェイニ大通りに挟まれたところに位置する。

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