Spatial and temporal patterns of economic segregation in Sweden's metropolitan areas: a mobility approach

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Abstract

The statistical resources at hand for segregation research are usually almost exclusively confined to annual or decennial records where the only available spatial information is the individual's place of residence. This coarse temporal periodicity and spatial resolution provides a very limited account of people's diurnal lives. Incorporating mobility and temporal dimensions in segregation analysis is advocated within a growing body of research but there has rarely been sufficient data to make this possible. In this paper, we employ a fine-grained mobile phone dataset outlining the daily mobility of a substantial sample of the residents of Sweden's metropolitan areas. Combining spatial trajectory data with detailed socioeconomic residential statistics, we are able to study how everyday spatial mobility in cities shapes the segregation experiences of people and changes the segregation levels of places. Results indicate that while mobility alleviates segregation for some individuals, the population of a large number of areas remain highly segregated even when daily mobility is taken into account. Individuals residing or spending time in central urban areas are more exposed to individuals from other areas because of daily moves to these central places. Daytime movement to central areas also reduces segregation significantly for people from places remote from city centres but with high average levels of mobility whilst daytime segregation levels remain close to their original night-time levels in low-mobility areas in the outskirts of the cities.

Keywords: Segregation, mobility, mobile phones, time geography, Big Data, co-presence

1. Introduction

The lion's share of segregation research has traditionally focused on the area of residence. However, a growing body of literature argues that segregation needs to be treated as a process occurring also outside the location of one's home, the argument being that individual experiences of segregation are not only a result of the conditions of the home neighbourhood, but also daily mobility in and through other places (Wong & Shaw 2011; Kwan 2013; Krivo et al 2013; Heringa et al 2014; Matthews 2014). This literature acknowledges that areas outside the residential neighbourhood may have a significant role in determining personal experiences of segregation, and accordingly, individuals residing in the same area may be exposed to very different social and economic contexts depending on the nature of their daily mobility. For example, if segregation is strongly pronounced at the residential level while other domains of daily life are characterised by greater diversity, daily mobility may facilitate encounters and interactions between members of groups unlikely to take place if a person was spatially restricted to their residential neighbourhood.

Since data on daily spatial trajectories are rarely available in the censuses and administrative data sources most commonly used for research, the majority of studies offer limited insights into the impacts of daily mobility. However, the growing availability of large-scale mobility data from a variety of digital sources including personal communication devices, social media and location-based services is greatly improving the prospects for mobility-oriented research (Arribas-Bel, 2014; Batty, 2012). These kinds of data open up new research directions that were not possible before. Due to the low collection costs and their wide population coverage, these new kinds of data sources have been employed in a number of recent papers (see for instance: Steenbruggen et al. 2015; Blondel et al 2015; Zook et al 2015).

In this paper, we make use of data from mobile phones to address how daily mobility impacts upon residential segregation by income level in Sweden's metropolitan areas. Employing a time-geographical framework, where the mobility of phones during the course of a regular working day is tracked, we study the degree of co-presence between individuals residing in areas with different shares of residents in wealth and poverty. Since these data are void of any information on the users, we make use of each phone's estimated home neighbourhood to assign it aggregated statistics from the PLACE database depicting the proportion of rich and poor individuals in the neighbourhood defined following an accepted EU definition[1].

This approach allows us to compare to what extent patterns of residential segregation across cities translate into actual physical separation in time and space and to what extent individuals from rich and poor places mix as part of their daily routine as contrasted with their night-time residential location. The focus on economic segregation is for two reasons. First, economic segregation is easy to compare between locations and over time making it preferable for use in a between-metropolitan area comparative framework because of the availability of consistent data. Second, economic segregation has increased significantly in the Nordic countries over time making it an interesting field of study for both academic and political reasons (Wessel 2015; Östh et al 2014).

While the goal of this paper is to investigate if daily mobility can reduce the spatial separation which originates from segregated residential patterns, it needs to be emphasized that we do not suggest that increased levels of spatial proximity would necessarily reduce or abolish the negative and discriminatory practices commonly associated with residential segregation. Neither does our analysis allow us to say anything about the actual nature of co-presence, since we are only able to define co-presence as a binary condition. We cannot tell if co-presence is necessarily of a meaningful (or positive) nature or if it is negative; we only have information on whether phones were in close proximity. However, it is well known that segregation in its most extreme state ultimately leads to the complete spatial separation of people and groups and that a prerequisite for greater integration is that members of different groups, in at least some areas of daily life, share the same spaces (e.g. Dixon et al 2005). It is therefore of interest to study to what extent this is happening outside the residential neighbourhood in Swedish cities where segregation by place of residence is strongly pronounced.

[1] Relative poverty is defined as having 60% of the median national income or less. Relative wealth is defined as having 140% of the median income or more.

1.1 Segregation across multiple spatial domains

A substantial amount of research has dealt with the question of how far being co-present with others in the same space matters for experiences of segregation. According to Amin (2002), sharing the same space and visually encountering others is on its own rarely sufficient for meaningful interactions to take place, however, these are likely to occur in “micropublics”, public spaces where individuals “break out” of their own realms to interact with others. Nevertheless, while such interactions may initially appear as trivial, they can be important for facilitating the understanding of other people’s lives (Legeby, 2013). A similar view is put forward by Valentine (2008), building on research undertaken in a socio-economically diverse neighbourhood in London where findings from interviews with residents indicated that spatial proximity did not by default translate into lower levels of prejudice but in some circumstances it might.

While the relative importance of co-presence for any individual is difficult to measure due to variations in, for instance, the urban landscape, climate and individual preferences; these variations remain equally important also if we assume that individuals are stationary at the residential location. This means that co-presence through mobility is unlikely to introduce error terms that are not already present when conducting a traditional residential-level analysis of segregation. If we assume that certain groups of residents living in the same city rarely or never encounter one another, negative consequences may ensue as the prospects for understanding others are reduced. A number of studies have pointed to how such extreme forms of social seclusion are becoming more frequent in many urban settings, for example illustrated by the upper and upper-middle classes never encountering people living lives different from their own during almost any of their daily activities (e.g. Atkinson & Flint 2004; Rodenstedt 2014; Boterman & Musterd 2016).

The underlying theoretical basis for research on segregation outside the residential context is that if a person is exposed to a different level of segregation in other contexts where they spend time, this might have an impact on their personal experiences of segregation. Studies addressing segregation in schools (Burgess et al. 2005; Reardon et al 2000; Andersson et al 2012; Östh et al. 2013) all indicate that ethnical segregation is more accentuated in schools compared to residential neighbourhoods. The two Swedish studies (Andersson et al. 2012 & Östh et al. 2013) also indicate that school segregation tends to increase over time. Studies on workplace related segregation suggests the opposite relationship between work and home. Ellis et al (2004) found that for male Mexican immigrants and native-born whites in Los Angeles, segregation at the workplace was lower than in the area of residence, whereas this was not true for women due to gender differences in labour market participation. Åslund and Skans (2014) found that workplace segregation is lower than corresponding residential segregation. Strömgren et al. (2014) finds similar results as well as results that suggest that intermarriages between natives and immigrants lower workplace segregation significantly for men but not for women. Blumen & Zamir (2001) finds in a study of workplace segregation in Tel-Aviv that most residents were found to be spending their working hours in more mixed social environments compared to their residential neighbourhoods. Apart from fixed places such as home, school and workplace several other studies target a wide range of different activities that may lead to increasing or decreasing levels of segregation. Lucas' (2012) study and summarization of earlier research on transport and social exclusion, for example, suggests that a wide range of parameters ranging from planning, physical, economical factors etc. affects exclusion and segregation from mobility. Other studies have shown that access to recreational and amenity rich surroundings or access to healthy food markets or to fast-food restaurants reinforces segregation (see for instance Hutchinson 1987; Kwate 2007). Social or cultural bonds within groups may lead to self-segregating behaviour that depending on socio-economic status and contexts may be positive. Edin et al (2003), showed that ethnic clustering increased employment rates among immigrants and Östh (2017) found that mortality risks among immigrant groups dropped in areas of greater concentrations of peers.

Another body of research is comprised of studies covering segregation across the whole range of daily life, focusing on the entire socio-spatial trajectory rather than a specific activity or area. Quantitative studies of this kind generally involve a multitude of methodological and computational challenges and different methods and measurements have been proposed (Wong & Shaw 2011; Palmer 2013; Farber et al 2013, 2015). In a paper where travel-diary data from residents in southeast Florida was used, Wong & Shaw (2011), for example, demonstrated how measures of exposure for different racial groups, following the index proposed by Lieberson (1981), could be computed in order to illustrate the importance of daily travel patterns for interethnic contact.

Along similar lines, Farber et al (2013, 2015) devised the social interaction potential (SIP) metric for measuring the feasibility of contact and interaction between residents living in different parts of the same metropolitan region. Experimenting with a variety of methods for studying mobility segregation using samples collected from GPS trajectories, Palmer (2013) found that in many cases even relatively small samples of individual trajectories could be sufficient for depicting segregation also in larger metropolitan areas.

In terms of scale, the most extensive empirical studies have been the ones addressing the segregation between the Estonian majority and the Russian-speaking minority in Estonia, employing data from mobile phones to study the degree of co-presence between the two groups in urban spaces (Järv et al 2015; Silm & Ahas 2014; Toomet et al 2015). The findings indicated that daily mobility decreases residential segregation depicted in census records based on place of residence, although there is considerable variation between different time frames as well as between different types of residential areas.

Furthermore, an instructive finding from numerous studies is that there seems to be a strong correlation between the characteristics of the residential neighbourhood and the areas visited during daily and other reoccurring activities (Wang et al 2012; Krivo et al 2013; Wang & Li 2016). In the study by Krivo et al (2013) on social isolation in the Los Angeles area, multi-level analysis revealed that the use of urban space during out of home-activities was strongly tied to the area of residence, indicating that most people spent their time in areas with characteristics akin to the home neighbourhood. Similar results were obtained by Wang et al (2012), who found that there were major differences between residents in Beijing's affluent and non-affluent neighbourhoods in terms of their time use and travel habits, with this also extending to which areas they regularly visited and spent their time in.

1.2 Urban segregation in Sweden

Apart from a few scientific reports on segregation on workplaces and in schools (see previous section) the vast majority of Swedish segregation literature is focused on residential segregation in larger metropolitan areas. Central to the Swedish segregation debate has been the identification of neighbourhoods on the edges of cities as concentrations of economic disadvantage, social stress, and ethnic minorities (see for instance, Molina 1997, Musterd and Andersson, 2005). Moreover, recent findings suggest that segregation levels have increased over recent decades in the main metropolitan areas (Östh et al. 2014a; Andersson & Kährik 2016).

Our study is therefore focused on segregation in the three largest metropolitan areas in Sweden, Stockholm (population ca. 2,000,000), Göteborg (population ca. 1,000,000) and Malmö (population ca 700,000).

2. Materials and methods

2.1 Mobility and Socioeconomic data

For our analysis, we construct two datasets making use of two kinds of data, **mobility data** and **socioeconomic residential statistics**. The **mobility data** are drawn from data provided by a major telecommunications company covering a 24-hour ordinary weekday (Tuesday) in the early summer of 2014[2]. Data is limited to one day because of the large volume of data observations (several hundreds of millions observations per 24h), making it technically challenging to follow phones for more than 24 hours. Tuesday was chosen since it represents a *typical* weekday and may as such function as a proxy for everyday mobility. Almost 250 million events generated by approximately 1.2 million unique Swedish phones are included (only phones holding a Swedish phone number are used in this study), meaning that the data covers approximately 15% of the Swedish population. The use of phones belonging to the company is geographically balanced in the studied areas, meaning that the shares of users are relatively similar throughout the study areas. Since mobile phone penetration in Sweden is among the highest in the world, mobile phone use is not restricted to certain demographic or social groups. The observed patterns of mobility can therefore be viewed as a representative sample of the mobility of Swedes on this particular day[3]. Individual phones were tracked through an anonymized identification number which allowed the mobility of all phones to be followed but which, for privacy reasons, lacked all information related to the owner. The spatial resolution is defined by the spatial extent of the phone mast catchment areas which serve the phones. Mast catchment areas can crudely be defined as the area being closest to a mobile-phone mast. Masts are more placed more densely in urban areas and this for two reasons; increased demand for service due to population density requires more masts to provide the service and the physical complexity of the urban landscape with buildings that block connectivity requires denser placement.

The phone mobility data is network-driven (Calabrese et al 2015), meaning that the positions of phones are recorded as long as they remain switched on regardless of if the phone is actively used.

[2]The data are stored in the MIND database at Uppsala University.

[3]According to World Bank statistics, there were 128 Mobile cellular subscriptions per 100 people in 2014 in Sweden.

While events are recorded in the case of phone-to-mast communication, phones also report their position to the closest mast every five minutes when switched on, which means that we are able to follow the mobility of each phone using this temporal definition regardless of whether they send/receive texts or calls. Especially during the night hours, some phones are silent (no connection between mast and phone is observed during a five-minute interval). However, since all mast-handovers (transfer of service from one mast to the next mast) are recorded, silent phones can be assumed to stay under the service of mast j at time t since the last event for that phone was logged for the same mast (as long as the phone is not turned off). Since silent phones are stationary unless turned off (probably due to night rest), the risk of associating phones to the wrong locations is likely to be relatively small. A phone that is in use for a full 24 hours is consequently assigned 288 five-minute time-slots, whose records progressively are filled with the last known location.

Since no information about the phone user is gathered, the location where each phone rests for the longest duration between 00:00 and 07:20 is assumed to be the probable location of home or temporary night rest, although it should be acknowledged that an unknown fraction of phones may be assigned to locations where they usually do not spend their night rest (being at a hotel, sleeping over at friends, or similar). In the studied population, the coordinates at any time between 00:00 and 07:20 were identical to the designated home coordinates in 85% of the time. This means that the assigned home location was a location of rest for most phones but that some phones were used by individuals who were active during the night or came to rest at a late hour or left early in the morning. If we treat the studied 24-hour day as a snapshot in time we assume that the share of hotel dwellers, night-time workers and the large majority of individuals who rest in their homes are no different from the distribution of people at any other time.

In larger urban areas, mast areas are relatively small because there are more masts to service a denser population, and so mast areas can consequently be described in terms of neighbourhoods. In rural and remote areas, the catchment areas of masts are bigger in size making it difficult to describe areas in terms of neighbourhoods. Hence we concentrate on the more densely-populated urban areas of Stockholm, Göteborg and Malmö for practical reasons as well as for the other reasons outlined above. Spatially the three areas each roughly cover 7,500 km^2 including all central to suburban areas as well as the sprawling 'urban-close rural' areas beyond the city (rural areas surrounding the three metropolitan areas where almost all of the commuting is directed towards the major urban core-areas). The delineation of study areas was made specifically for this study with the sole purpose of including as much of the urban areas as possible whilst making sure that the catchment areas are small enough to pick up mobility. Most of the spatial extents of the studied metropolitan areas are depicted in Figure 1 (less populated to rural areas in the urban outskirts are not shown). Letters represent residential suburbs known to have strong concentrations of residential poverty; stars represent city centre-areas known to be more affluent. In the Stockholm map, letters 'R' represents Risne, 'B' represents Botkyrka, 'H' stands for Husby and 'RT' represents Rinkeby/Tensta. In Göteborg 'B' represents Biskopsgården, 'H 'Hammarkullen and 'G' Gårdsten. In Malmö 'S' represents Södra Sofielund and 'R' represents Rosengård.

Figure 1 approximately here

Figure The three metropolitan study areas. From left: Stockholm and the suburbs Risne (R), Botkyrka (B), Rinkeby/Tensta (RT) and Husby (H); Göteborg with suburbs Biskopsgården (B), Hammarkullen (H) and Gårdsten (G); Malmö with suburbs Södra Sofielund (S) and Rosengård (R). Stars represent central parts of each metropolitan area.

The number of phones connected to a telephone mast varies considerably at different times, not least because many of the less night-active masts are associated with day activities such as work rather than residential activities. This means that describing the socioeconomic status of the residents of some night-rest areas using traditional area-based measures, where the characteristics of the local population (the ones residing within the realms of the area) are assumed to be the same as the night-rest population, is problematic if the number of total residents is small. There are also problems associated with the ecological fallacy where the characteristics of an individual cannot be reliably inferred from their spatial neighbourhood. There is no conclusive answer to these problems but their danger is minimised in this case by the use of the PLACE database geo-referenced to 100m and the use of EquiPop software to construct small bespoke neighbourhoods since small areas are more likely to be socially homogenous than larger units given the scale of spatial variation of phenomena such as wealth and poverty – see for example Lloyd (2015).

In order to cater for these population variations and issues, the data depicting the socioeconomic characteristics in the neighbourhood surrounding each mast are therefore defined using a *k*-nearest approach using the EquiPop software (Östh 2014; Östh et al. 2014; Östh et al. 2015). Using data drawn from the PLACE database, a Statistics Sweden (SCB) compiled research database located at Uppsala University containing a longitudinal register describing demographics, socioeconomics and geography of all Swedish residents, characteristics of observed residents from the year 2010 are used to describe the average socioeconomic characteristics of the 800 nearest neighbours from the location of each mast. The count of 800 was chosen since it lay close to the median count of phones connected to each mast in the three metropolitan regions[4]. As socioeconomic characteristics, we look for the share of poor and wealthy individuals around each mast (in other words the share poor or rich among the 800 nearest neighbours from any mast). The definition of poverty and wealth follows the commonly used EU definition of relative poverty (equalling or having an income lower than 60% of the median income in the country) and inverse for wealth (having at least 140% of the median income).

2.2 Methodological approach

These approaches described below necessarily make a number of assumptions and it is well to be explicit about these (Kwan 2016). By combining the different kinds of data described above, we can construct two datasets that can be compared in further analysis, a **time-geographical (TG) dataset** and a **home dataset.** Both datasets are designed to be equal to each other with the only difference being that one assumes that the population is stationary over a 24-hour period (Home) whilst the other assumes that the population is mobile according to the observed phone mobility patterns (TG).

The TG dataset is constructed by assigning each phone initial socioeconomic characteristics derived from where the phone spent the longest time between 00:00 and 07:00 during the studied day (designated night-rest-location in terms of mast-service area), an approach which can be described as *dipping* the phone in the local socioeconomic context of its residential neighbourhood (contextual mast values calculated as described in section 2.1.). It is assumed that the night-rest location is that of home. All phones that are sharing night-rest-locations thus share the socioeconomic statuses, statuses they bring to each place they visit during the day. As phone-holders move during the course of the day, the exposure to phones with different initial socioeconomic statuses will cause each phone to pick up *influences* from co-present phone-holders.

[4]Due to agreement between the telephone service company and the research team, the exact count of phones and masts may not be revealed.

Thus, mobility is conceptualised in a time-geographical fashion where socioeconomic characteristics are shared between phones that are co-present in a telephone mast area (area serviced by a specific mast) at the same time. As phone-owners move around in space-time where phone users with different characteristics are co-present, the phone user is assumed to be exposed to other phone-holders who may be more or less similar in terms of socio-economic characteristics. Over a day, the different trajectories of the phone-holders will lead to different patterns of socio-economic exposure for different phone-holders. It should be noted that the co-presence areas cannot be seen as full representations of real-life neighbourhoods since co-presence only captures physical co-presence in time and space, and that these assumed interactions may be ranging in quality from actual meetings to sitting in two different vehicles with no interaction. Having that said, we assume that co-presence often accommodates similarities between peers that more or less explains modes of transport, and motivations for being in the location. Over the course of the day, these similarities between peers will be more common and more important for the formation of the full-day statistics than erroneous encounters produced as a result of technical mast settings including being assigned to different masts for service or bandwidth reasons. In addition, the size of the mast-areas is generally small enough to depict the economic composition of most areas also in cases where phones for technical reason hop between masts. This because the density of masts is much finer than the spatial sorting of economic activity and socio-economic groups which means that the observed phone trajectories can be assumed to be good enough for segregation analysis but not for a detailed analysis of the path-trajectory of each phone.

Mobility time is partitioned into five-minute slots (the finest temporal unit available in the MIND database) meaning that the maximum exposure to other phone-users a phone-user can experience is 24 hours * 12 five-minute-slots = 288 five-minute units. However, since phones may be turned off or located outside of the range of a mast, not all phones are exposed to the full 288-unit period.

The computed exposure to wealth and to poverty for any phone-user is a product of the average exposure at all times during the 24-hour window. In equations 1 and 2, the computations are formulated (with poverty as an example) as follows:

$$Poverty_{jt} = \frac{\sum_{jt} NightRestPoverty_i}{CoPresenceCounts_{jt}} \qquad \text{equation 1.}$$

In equation 1, the place-specific and time-specific (co-presence) poverty value is specified, where j represents mast-area, t represents temporal unit and i represents the values attributable to the individual phones. The computed value is shared among all co-present phone-users. $NightRestPoverty_i$ represents the share of poor individuals surrounding the mast recognized as the night-rest-location. $CoPresenceCounts_{jt}$ represents the number of co-present phone-holders at a specific place at a specific time.

$$PovertyTG_i = \frac{\sum_i Poverty_{jt}}{TimeUnitsObserved_i} \qquad \text{equation 2.}$$

In equation 2, $Poverty_{jt}$ values are aggregated on an individual level, summarizing the poverty exposure of each phone during the active time-units of the 24-hour period. The computed $PovertyTG_i$ value represents the average exposure to poverty experienced by the phone-user, and is the value that is used to compare TG values to home values. The variable $TimeUnitsObserved_i$ represents the total number of five-minute intervals recorded for each phone during the 24-hour window.

The **home dataset** is in all essential similar to the TG population with the exception that the population is assumed to be stationary throughout the day. This means that the values representing shares of poor and wealthy individuals are identical to the populations and values used to create the $NightRestPoverty_i$ and $NightRestWealth_i$ variables, holding the share of poor and wealthy night-rest individuals surrounding each mast.

2.3 Methods for comparison

To measure the impact of mobility on segregation, we employ a series of tests which fall into two categories; global statistical measures and local statistical measures. The selected global measure looks at the variability of populations at the regional level of metropolitan areas whilst the local measures consider local spatial patterns of exposure to wealth and poverty. This means that the global measure can be used to communicate the overall effect whilst the local measure can be used to trace local deviations from general patterns and averages. The Gini index is employed as a global measure and can be used to look at the total exposure to wealth or poverty in each population and expresses how much of the exposure that deviates from a *utopian* state where all phones have equal shares of exposure. The Gini coefficient renders a value that is equal to zero if the utopian state is observed and one in case of complete inequality. By comparing Gini coefficients between urban areas and datasets (home and TG), the unequal distribution of exposure of wealth and poverty can be compared.

For testing local patterns in the deviation of exposure we make use of maps to depict the deviation between populations. For each mast area, we divide the local average TG value by the home value. By mapping the rendered values for all mast areas, the distribution of areas more or less affected by mobility can be shown.

3. Results

The paper's main question is whether spatial mobility reduces or increases segregation when compared with a derived night-time residential population. A variety of methods are used to answer this question and in this section we present the results from these approaches in two main sections, the first of which focuses on the global pattern by metropolitan area, the second of which considers variations within metropolitan areas.

3.1 Global statistics

Our analysis begins in Table 1 which presents simple descriptive statistics such as the mean, median, standard deviation and minimum and maximum values across the three metropolitan areas for poverty and wealth. Values representing the TG populations are presented as aggregated full day values (and not for each five-minute time slot). This means that both the TG and home populations contain equivalent number of *phones*. The means should be the same in both the TG and the non-TG populations and only in the case of wealth in Stockholm can differences in the means can be observed. This is a direct result of some phones being turned off or out of reach at some times. The differences in standard deviation, maximum and minimum indicate that mobility tends to reduce overall differences between areas and phones by lowering deviations and reducing the range between minimum and maximum. This makes sense if we take into account that most mobility from a high-poverty or high-wealth area is likely directed towards areas with lower concentrations of both wealth and poverty, simply because these are much more numerous (Shuttleworth et al. 2015). In other words, the greater the rate of population mobility, the greater the reduction in areal differences between places. In line with what is known from previous research on residential segregation in the three metropolitan areas, poverty levels are most pronounced in the urban area of Malmö but relatively similar in magnitude in Göteborg and Stockholm. The effect of mobility also seems to be relatively similar in all three regions.

Table 1. Descriptive statistics for the concentration of poor and wealthy individuals in each metropolitan region before and after daily mobility.

		Poverty				
		Mean	Median	SD	Min	Max
Stockholm	Home	0,13	0,11	0,08	0,01	0,70
	TG	0,13	0,12	0,05	0,03	0,64
Göteborg	Home	0,13	0,12	0,07	0,03	0,51
	TG	0,13	0,12	0,05	0,05	0,40
Malmö	Home	0,19	0,17	0,09	0,04	0,59
	TG	0,19	0,18	0,07	0,06	0,45

		Wealth				
		Mean	Median	SD	Min	Max
Stockholm	Home	0,30	0,29	0,11	0,03	0,60
	TG	0,29	0,29	0,08	0,05	0,54
Göteborg	Home	0,26	0,26	0,09	0,01	0,52
	TG	0,26	0,26	0,06	0,05	0,43
Malmö	Home	0,22	0,23	0,09	0,00	0,47
	TG	0,22	0,23	0,06	0,02	0,43

A well-known method for the estimation of the distribution of inequality is the use of Gini statistics. Traditionally Gini coefficients express the deviation between an equal distribution of wealth and an observed distribution of wealth. Here, the perfect distribution is represented by an equal distribution of exposure to wealth and poverty and the so called Lorenz curves represent the observed distributions of exposure to wealth and poverty. As in traditional Gini indices, greater values indicate greater inequalities. The Gini coefficients in table 2 indicate that mobility (TG) reduces the inequality for both wealth and poverty. The reduction is around 1/3 for all areas in the in terms of wealth but with regard to poverty the reduction is smaller and varies more between regions, with the least reduction in the Malmö area. These patterns confirm those revealed in Table 1.

Table 2. Gini-coefficients before and after daily mobility.

	Wealth	
	Home	TG
Stockholm	0,21	0,14
Göteborg	0,18	0,12
Malmö	0,23	0,15

	Poverty	
	Home	TG
Stockholm	0,28	0,19
Göteborg	0,26	0,18
Malmö	0,26	0,19

3.2 Local statistics

The global statistics shows that mobility clearly helps to reduce the differences in exposure to both wealth and poverty throughout the metropolitan areas. The global statistics cannot, however, tell us about the changes in exposure locally. In order to tell what type of areas that are affected differently, we map how exposure to wealthy and poor peers change as mobility is taken into account.

In Figure 1, exposure to poverty and wealth is illustrated side by side for Stockholm (equivalent figures for Göteborg and Malmö are available in the Appendix as figures A1 and A2). The maps are constructed to enhance statistics rather than the underlying landscape, which makes the identification of particular areas in each metropolitan area difficult.

The top row of maps shows the spatial distribution of poverty (left) and wealth (right) for the home population (i.e. residential distribution). Red colours indicate strong concentrations (of poverty and wealth) while blue colours indicate the opposite. Map colouration is based on ½ standard deviations for all three metropolitan areas which mean that the mapped results can be compared between maps. The bottom row of maps shows the ratio of TG over Home ($\frac{TG}{Home}$). In locations where the TG value is greater than that of Home, the ratio is greater than 1. In cases where the TG value is smaller than 1, the ratio is below 1. Also here the colouration expresses ½ standard deviations of the ratio distribution of the entire studied population, however the colours are different. Blue colours indicate that the ratio is greater than 1 which means that mobility (TG) has strengthened the exposure of the studied group (poor or wealthy). Brown colours, on the other hand, indicate that mobility has weakened the exposure.

The top row maps indicate a concentration of wealth in the more central parts of the city and in coastal areas (high amenity areas), while poverty tends to be more concentrated in specific locations, especially in suburbs that were built (predominately) during the 1960 as multi-floor buildings to meet the need for housing from rural areas and international work migration (known as *Million Program* housing). The bottom row of maps depicts a more fragmented pattern compared to the top row maps (especially the poverty map). This is expected since the poorest and wealthiest areas can only become less concentrated due to mobility because of basement and ceiling effects which mean that their spatial patterns will be more fragmented (see also Shuttleworth et al. 2015). Having said that, there are relatively many areas in close proximity to poor neighbourhoods that become dark blue in the poverty map; i.e. already-poor areas are becoming poorer due to the inflow of people from other poor areas. The reasons for this pattern are may be varied (and unproven) but are likely to include mobility to sub-urban centres where schools and retail facilities are located. The bottom row (TG over home) wealth-map indicates that wealth tends to concentrate in the central areas of the city. This may be attributable to the spatial distribution of jobs where higher-wage jobs tend to be more clustered to the central parts of the urban area in Swedish cities (Gould, 2007).

Figure 2 Approximately here

Figure 1. Top row show maps over the distribution of residential (Home) poverty (left map) and wealth (right map) where strong concentrations are depicted red and the opposite blue. Lower row shows TG over Home calculations for poverty (left) and wealth (right) where blue values indicates concentration effects due to mobility and brown indicates a reduction due to mobility.

4. Conclusions

Employing a unique dataset describing the flow of mobile phone users in the three major metropolitan regions in Sweden during a 24-hour period in the early summer of 2014, this study aimed to address whether observed patterns of economic segregation at the residential level in Swedish metropolitan areas remain intact when controlling for daily mobility. Using two datasets contrasting stationary and mobile populations, the overall results confirm that mobility appears to reduce segregation. The results also indicate that the effect of mobility is more profound for exposure to wealth and less so for poverty, especially in Malmö. The underlying reason for the regional disparities in the effect of mobility for segregation is not analysed in this study, but it is likely that urban structure, including accessibility to jobs and service, residential planning and infrastructure may play important roles.

The areas where mobility has the greatest impact appear to be the central parts of each metropolitan area where residents to a greater extent than others are exposed to visitors from areas with opposite economic structures, normalizing segregation towards the regional averages. In suburban areas with strong concentrations of either poverty or wealth and low shares of external visitors, the results indicate that segregation still decreases when mobility comes into play. This is likely largely a result of the physical and economical urban structures where the locations of urban opportunities are strongly concentrated to the inner city. Consequently, residents from equally poor and wealthy areas converge in the inner city to such a magnitude that the extreme patterns of segregation present at the residential level are being reduced.

Whereas levels of daily segregation in many neighbourhoods appear to decrease due to mobility, it is difficult to measure to what extent increased levels of co-presence have a direct impact on individual experiences of segregation, and it remains a question which should be further examined using other methods. However, the observed effect of mobility say something about how patterns of residential segregation correspond to the daily socio-spatial trajectory – in other words, that the residential neighbourhood cannot be regarded as the sole determinant of economic segregation.

Ethics

The use of our mobile phone data in research has been approved by a regional ethics board in Sweden (Regionala etikprövningsnämnden i Uppsala [Regional Board of Ethics in Uppsala] with reference code 2017-205B).

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Appendix

A1 approximately here

A1 Top row show maps over the distribution of residential (Home) poverty (left map) and wealth (right map) where strong concentrations are depicted red and the opposite blue. Lower row shows TG over Home calculations for poverty (left) and wealth (right) where blue values indicates concentration effects due to mobility and brown indicates a reduction due to mobility.

A2 Approximately here

A2 Top row show maps over the distribution of residential (Home) poverty (left map) and wealth (right map) where strong concentrations are depicted red and the opposite blue. Lower row shows TG over Home calculations for poverty (left) and wealth (right) where blue values indicates concentration effects due to mobility and brown indicates a reduction due to mobility.