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Transit-induced socioeconomic ascent and new metro stations in Helsinki Metropolitan Area: Distinct effects on renters, homeowners, and pre-existing housing dwellers

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ABSTRACT

In recent years, transit-oriented developments have been studied from different angles in different countries. Question has been raised whether public investments in transportation trigger the areas nearby to gentrify or even cause the affordability paradox for the low-income households if they cannot afford to live in the accessibility improved areas. This article contributes to the literature of transit-induced neighbourhood change by estimating the short-term causal effect of accessibility improvements on neighbourhoods' household income, share of highly educated individuals, and share of low-income households, separating between renters and residents in the existing and new housing stock. We are using a quasi-experimental study design with propensity score matching and difference-in-differences regression setup to analyse the socioeconomic changes in the areas close to the newly built metro stations. Overall, we identify a positive effect on the share of residents with higher educations, but don't see effects on median household income or share of low-income households. However, on closer examination, we find short-term transit-induced changes for residents in old housing stock, and to some extent for homeowners, but for the renters we don't find significant results. The findings of this article show that short-term transit-induced neighbourhood change occurs in areas where accessibility has improved.

1. Introduction

Transit-oriented developments (TOD) promote “investments to transit” and mixed land-use around stations to achieve a densely built environment, where private car use is replaced by sustainable transportation modes. Investments in transportation infrastructure are seen as a prerequisite for sustainable urban growth and are often paired with urban renewal or urban infill. In addition to sustainable urban development, the investments in local transportation infrastructure have direct and indirect economic benefits (e.g. Glaeser et al., 2008; Mayer and Trevien, 2017). Public transportation can be seen as an amenity that affects the neighbourhoods' desirability and people's willingness to locate accessible areas (e.g. Bardaka et al., 2018; Bowes and Ihlanfeldt, 2001; Deka, 2017; Gibbons and Machin, 2005; Harjunen, 2018; Heilmann, 2018).

However, areas' increased desirability among educated medium- and high-income households, can trigger or cause out-move of the low- and middle-income households (Delmelle and Nilsson, 2020; Dong, 2017). The socioeconomic ascent of the areas is then a sum of the potential effects the investment has on the extant population and the changes occurring due to households moving in and out of these areas. Sometimes, transit-oriented development has been associated with the affordability paradox, where investments made to improve low-income neighbourhoods, lead to low-income households not being able to afford to live in the improved areas. The mix of both public investment in transportation and public and private investments in housing and other

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amenities nearby can cause gentrification, resulting in lower amount of affordable homes near transit stations. This highlights the need to understand the role of public investments on socioeconomic ascent and get a deeper understanding of the investments' effects on the neighbourhoods' socioeconomic changes and future development. Indeed, there is increasing discussion on these processes and triggers behind them in North America, Asia and Western Europe (e.g. Anguelovski et al., 2018; Bardaka et al., 2018; Deka, 2017; Delmelle et al., 2021; Delmelle and Nilsson, 2020; Ellen et al., 2019; Grube-Cavers and Patterson, 2015; Heilmann, 2018; Kim and Wu, 2022; Pathak et al., 2017; Rigolon and Németh, 2020; Zheng and Kahn, 2013; Zuk et al., 2018). The case of Helsinki Metropolitan area (HMA) provides interesting insights to this literature because of Finland's low levels of residential segregation and wealth inequality even in the Nordic context (Pfeffer and Waitkus, 2021; Skifter Andersen et al., 2016). Hence, any effects found can be expected to be stronger in more unequal social and institutional contexts. Previous literature has mainly focused on the US context where there is less housing regulation, and the housing benefits are much lower compared to the Finnish context. Our results thus expand the literature to context more comparable to some of the housing regimes in e.g., European, and Scandinavian contexts.

This article contributes to the literature of transit-induced neighbourhood change by estimating the short-term causal effect of accessibility improvements, namely opening of new metro stations, on neighbourhoods' socioeconomic structure in the capital region of Finland distinguishing effects in different subgroups of residents. Our analysis is conducted on very detailed geographic units (250 m × 250 m grids), which is novel compared to most of the existing studies that typically analyse census tracts or other wide geographical units. Our precise and unique data allows us to separately study the effects of transit-induced developments on renters, homeowners and people living in the pre-existing housing stock. The analysis of these separate groups has not been possible in the previous studies although they are theoretically very relevant to truly understand the processes driving the overall demographic change of the affected neighbourhoods. We use propensity score matching (PSM) and difference-in-differences (DID) methods to analyse the neighbourhoods in Helsinki Metropolitan Area (HMA) in Finland before and after the public transportation investments to the Metro rail network. Transit-induced socioeconomic ascent or displacement has been studied separately with PSM (e.g. Dong, 2017) and DID methods (e.g. Bardaka et al., 2018), and combining these methods (Delmelle et al., 2021), as we are doing, to get the average treatment effect of the transit-oriented development compared to control areas that resembled the treated areas before the treatment. Neighbourhoods' socioeconomic ascent is typically studied over longer time periods, since neighbourhoods' socioeconomic change takes time, but neighbourhoods' short-term changes can give indications of long-term developments. Thus, our results offer multiple important contributions to the literature of neighbourhoods' short-term socioeconomic change (e.g. Bardaka et al., 2018; Dong, 2017; Kim and Wu, 2022).

2. Transit investments and socioeconomic ascent

Neighbourhood ascent broadly refers to increases in a neighbourhood's socioeconomic standing over time based on housing values and residents' income and education levels (Owens, 2012). Often, but not always, the ascent is closely related to gentrification that refers to the process of a previously low-income neighbourhood attracting educated middle- and high-income residents. While ascent can be driven by the growth of the economic area (e.g. Guerrieri et al., 2013), it has been argued that sometimes the process is triggered by policies aimed at improving the area, such as developing green spaces (Anguelovski et al., 2018; Kim and Wu, 2022; Rigolon and Németh, 2020), reducing crime (Ellen et al., 2019) or financing public investments (Heilmann, 2018; Hess, 2020; Immergluck, 2009; Zheng and Kahn, 2013).

The impacts of traffic investments on neighbourhood change are often referred to as state-led or transit-induced gentrification, especially in the literature from the US context. TOD is urban development in the transportation system and land close to public transportation. It contains both public and private investments, since transportation investments are mostly funded by public money, while housing development as well as other amenities nearby are often financed by private investments (Dorsey and Mulder, 2013; Zheng and Kahn, 2013). TOD renews the urban area by promoting highly accessible dense areas to increase sustainability by reducing car-use. Together with sustainable urban development, TOD also has positive economic effects for the individuals and municipalities, since improved rail transit access can increase the economic activity of the municipality (Mayer and Trevien, 2017).

In addition to municipality-level effects mentioned above, improved public transportation can trigger different socioeconomic developments within a city by increasing housing prices and widening income distribution (Heilmann, 2018). Accessibility capitalises on housing prices and rents, and it affects the location choice of the residents who are willing-to-pay for it (e.g. Bardaka et al., 2018; Bowes and Ihlanfeldt, 2001; Deka, 2017; Gibbons and Machin, 2005; Harjunen, 2018). In highly accessible areas, housing prices tend to be higher attracting high-income households (Barton and Gibbons, 2017). In the long-term, housing stock and tenure will affect the area's socioeconomic development, and TOD can lead to a high share of multi-family housing and renter-occupied apartments near the densely built transit stations. High-share of multi-family housing and renter-occupied apartments can attract educated people who have few children (Nilsson and Delmelle, 2018: 168). If the population density increases together with the share of renters, it might negatively affect the neighbourhood's median income (Barton and Gibbons, 2017: 548, 550).

The ongoing discussion regarding the impact of large transit-oriented investments on gentrification and socioeconomic ascent has led to varying conclusions. Delmelle and Nilsson (2020: 137) argue, that the impact of transit on neighbourhoods' socioeconomic structure is highly context dependent. This can be seen from the survival study from Grube-Cavers and Patterson (2015) who studied gentrification as an event, and looked at the probability of an area to gentrify when they were located near transit. Gentrification was measured by average rent, average household income, share of highly educated residents, share of homeowners, and share of residents working in professional occupation. They found a connection between transportation and gentrification in Montreal and Toronto, but not in Vancouver. Similarly, Bardaka et al. (2018) studied the average treatment effect of Denver light rail on gentrification and found that household income and housing prices increased with the transportation investment. However, they did not find any causal effect for the increase of highly educated residents or residents working in managerial occupations. Bardaka et al. (2018) acknowledged that data limitations prevented them from determining whether the demand for housing in the area or housing tenure affected the gentrification process.

Our study contributes to the literature on transit-induced socioeconomic ascent by estimating the short-term causal effect of accessibility improvements on neighbourhoods' socioeconomic structure for different subgroups of residents. As housing stock, housing tenure or location can trigger or cause socioeconomic ascent, we discuss the effect of socioeconomic ascent and its intensity separately on owner- or renter-occupied housing and pre-existing buildings i.e., buildings that have been built prior the decision to build the transportation investment was made. With the full population panel register data we achieve greater detail compared to the previous studies based on surveys or restricted samples.

3. Empirical approach

3.1. Empirical methodology

Our empirical strategy aims at identifying the short-term causal relationship between improved accessibility and the socioeconomic changes in areas close to the newly built West Metro stations, which are an extension to the existing metro rail network. The analysis is performed using a statistical grid of 250 m × 250 m, which is based on the identification of Statistical Finland (Statistics Finland, 2023). To identify the average treatment effect of newly opened metro stations on the socioeconomic changes in the area, we analyse panel data spanning from 2008 to 2020, employing a difference-in-differences (DID) strategy. Our DID model is:

$$y_{it} = \alpha + \delta_i + \beta_1 * post_t + \beta_2 * treat_i + \beta_3 * post_t * treat_i + \gamma * controls_{it} + \varepsilon_{it} \quad (1)$$

y_{it} is our dependent variable measuring gentrification. Following the existing literature, we use three outcome variables to measure gentrifying development in the neighbourhood: *Household's income, share of highly educated residents and share of low-income households*. Our measure of gentrification represents the respective variable in area *i* in year *t*. For the identification of causal relationship, grids that are at least 50% inside the 800 m catchment area of the new metro stations are selected and assigned as treatment group, and for these grid cells, the indicator variable $treat_i$ equals 1. For all other grid cells, the variable $treat_i$ equals 0. We set the catchment area to 800 m as appreciation of the stations is usually found to be the highest within 800 m (Bardaka et al., 2018: 29; Harjunen, 2018; Kauria, 2021), and according to Heilmann (2018), transit planners often use 800 m catchment area to indicate the maximum distance people are willing to walk to the nearest public transportation stop. $Post_t$ gets a value of 1, if year is between 2018 and 2020, which present post-treatment years being three years after the opening of the metro line. For the pre-treatment period, spanning from 2008 to 2017, the variable gets a value of 0. The decision to build the West Metro was made in 2009 and the construction process began the year after. Then, the first stage of West Metro started to operate in the middle of November 2017. The coefficient for interaction term $post_t * treat_i$ can be interpreted as causal, measuring the average treatment effect of the improved accessibility on neighbourhood change within 800 m of the newly built metro stations.

We control for neighbourhood's socioeconomic and location related factors that could be correlated with our variables of interest. Our control variables are *share of young adults, small households, detached houses, new residential buildings, population density and distance to CBD* (Central business district of Helsinki). *Share of young adults, and small households* are included as controls as they describe the socioeconomic structure of the area and might be related to the income and education. *Share of detached houses* and *new residential buildings* can make the area more desirable and affect the location decisions of the medium- and high-income households. Location related controls, *population density* and *distance to CBD*, are related to both location of the new stations, since new stations are built in highly populated areas further away from the city centre, and household income and education of the area, since close distance to city centre is typically correlated with higher income households.

One potential problem in relation to the model specification is the possible endogeneity between our dependent and independent variables, which is good to keep in mind when interpreting the results. In terms of multicollinearity, neither variance inflation factor values nor the correlations between the included variables revealed any concerns. Finally, α is the constant variable and δ_i represents neighbourhood fixed effects at zip-code level. The error term ε_{it} is clustered at zip-code[1] level to account for potential spatial autocorrelation as recommended by Abadie et al. (2022).

Investments in the transportation system, particularly the locations of the new stations and stops, are not random since they are a combination of strategic and political decision-making. Due to this lack of randomness in our study setting, we use quasi-experimental DID approach to identify the causal effect of the treatment. Our main interest is the average treatment effect of the newly built metro stations, and we want to see how improved accessibility affects the socioeconomic change. When constructing the control group, it is important that accessibility to old metro or train stations does not affect the control area's socioeconomic development and that the control areas are not affected by the treatment itself or other policy interventions. Extant literature shows that significant housing price appreciation can be found within 1600 m of the stations (Bardaka et al., 2018; Harjunen, 2018). Hence, to ensure that the parallel trend assumption is not violated due to effects spreading wider than our catchment area and simultaneous policy decisions, we exclude grids located within 1600 m of future stations of the second stage of West Metro, extensions to stations of the community rail transit (the Ring Rail) and future stops of Jokeri Light Rail from our set of control grids. These major public transportation investments were ongoing or started during our study period, and our interest is in the so-called first stage of West Metro that is an extension of the existing metro network to western Espoo.

One fundamental condition for gentrification is that the social status of the area is below average (Hammel and Wyly, 1996; Freeman, 2005). Thus, in our case, we use the terminology of social ascent throughout the paper, as the areas we study are not particularly disadvantaged to start with when it comes to for example median income, as is presented in the following Table 1.

After excluding the grids located within 1600 m of the old metro and train stations and the grids located between 800 and 1600 m of the new (treated) metro stations, we employ PSM for our two subsamples. Our matching procedure is similar to Delmelle et al. (2021) and Pathak et al. (2017) who also used PSM to construct a control group that resembles the treatment group before the intervention. For matching, we use data from 2008 that is our first pre-treatment year and construct the control group with the nearest neighbour algorithm. In the PSM regression, our dependent variable is the 800 m distance to the nearest newly built metro station. Akin to previous literature, we used grid-specified explanatory variables in the matching procedure. Those include share of young adults, share of small households, share of detached houses, share of new residential buildings, population density and distance to CDB. In our PSM regression, the outcome variables (household income, education, share of low-income households) are excluded. Detailed information on variables used for PSM for different sub-samples and the standardized mean difference plots can be found in the supplementary material. After treatment and control groups are constructed through PSM procedure, the DID regression is employed to isolate the average treatment effect of the newly built metro stations.

In addition to the visual inspection of parallel trends (Fig. 1), we also performed a more formal test to estimate if the year fixed effects of control and treatment groups are statistically significantly different in the pre-intervention period spanning from 2002 to 2016. The test indicates that the pre-intervention parallel trend assumption is only violated in the owner-occupied subsample for household income and low-income households' variables. For the full sample and other subsamples, the parallel trend assumption holds for all the variables of interest. The results of these tests are reported in the supplementary

Table 1
Descriptive statistics for Helsinki Metropolitan region (HMA), treatment, and control areas.

	Household median income in 2008	Share of low-income households in 2008	Share of highly educated residents in 2008
HMA	32,330	0.40	0.28
Treatment	32,080	0.30	0.41
Control	30,480	0.36	0.30

[1] In Finland cities are divided by postal areas, ZIP's. In HMA there is 172 postal areas, and on average one postal area includes 80 grids. Sizes of postal area's vary, and typically the postal areas are smaller in densely populated areas, and wider further away from city centrums.

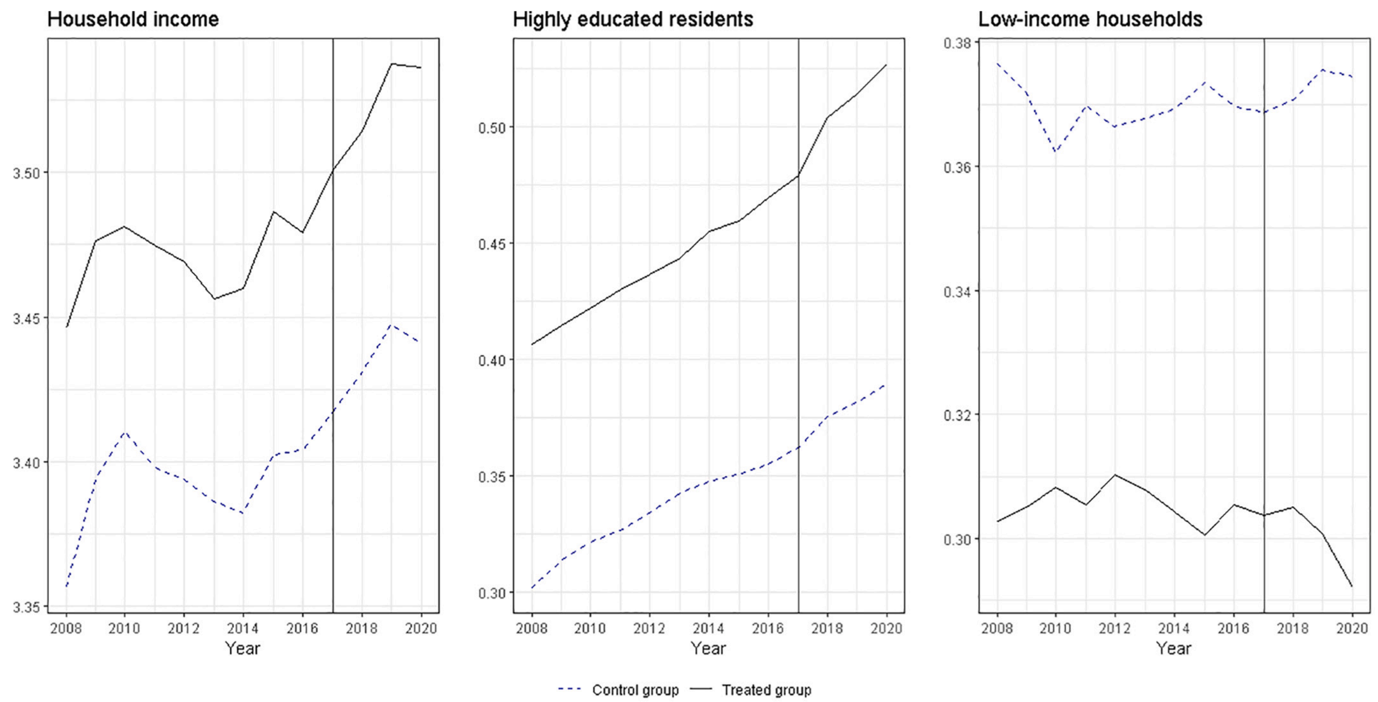

Fig. 1. Parallel trends for gentrification measures for treatment and control group for the full data after PSM. Treatment group covers locations within 800 m of the new metro stations. Control group is matched using the nearest neighbour method.

material.

3.2. Data

Our main data comes from Statistics Finland, who provides geo-coded microdata containing information on the whole population who have lived in the HMA during our study period (Statistics Finland, 2023). Data has information on income, education, age, and housing related factors on individual and household levels. As we are analysing neighbourhood level changes, we aggregate this data to 250 m × 250 m grid level. Observations that do not include income or locational information are removed from the analysis.

Our first year of analysis is 2008, a year before the decision to build the West Metro was made and our last year of analysis is 2020, three years after the first stage of West Metro started to operate. As we are interested in the effect of improved accessibility on gentrification, we exclude the grids that had less than 20 residents in year 2008 or 2020. In the beginning of analysis, we have 1528 grids located in the HMA. The number of observations by grid vary from the minimum of 20 to 1700. On average, there are 250 observations in a grid.

Full list of our grid-level aggregated variables as well as their definitions are presented in Table 2. *Household income, share of highly educated residents,* and *share of low-income households* are our main outcome variables to measure socioeconomic ascent in a grid level. We do not have information on the housing prices, which is also a popular measure in gentrification studies. For example, a recent study by Bardaka et al. (2018) showed that results were statistically equally as significant when gentrification was measured either by studying the changes in household income or housing prices. Our control variables include the *share of young adults, share of small households, share of detached houses, share of new residential buildings, population density* and *distance to CBD.* Only renters living in the free market occupied housing units are included. If gentrification occurs, it should not be seen in the subsidized rental housing units, since the change in accessibility or other amenities does not affect the subsidized rental market.

Locational information on transportation network, stations and stops are provided by Helsinki Regional Transport Authority (HSL, 2023) and

Table 2
Variable names and definitions.

Name	Definition
Household income (log)	Median household income (adjusted to 2020 value, in 1000 euros) in logs.[a]
Highly educated residents (%)	Proportion of highly educated residents who are over 25 years old and have at least a bachelor's degree.
Low-income households (%)	Proportion of people whose household income is in the two lowest income quintiles.
Young adults (%)	Proportion of population between the age of 25 and 39.
Small households (%)	Proportion of households with 1–2 people.
Detached houses (%)	Proportion of single-family detached houses of area's building stock.
New residential buildings (%)	Proportion of buildings built during the study period (2008–2020).
Population density	Population density per square kilometre.
Distance to CBD (log)	Logarithmic distance between grid's centroid and the Helsinki central business district in kilometres.

[a] The disposable household income contains households all income and deducts paid transfers (Statistics Finland, 2022).

City of Helsinki Urban Environment Division (City of Helsinki, 2023). Our study area, the treated and control groups before matching, as well as the potentially confounding transportation projects can be seen in Fig. 2.

Table 3 present the descriptive statistics of our data before and after PSM. Before PSM, we have 15 159 grid cells, that are divided into treatment group (1306 grid cells) and control group (13 853 grid cells). After matching, we have 1319 grid cells in the control group after matching.

Looking at the control variables, our matched control group resembles the treated group in pre-treatment years well. Our variables of interest have all increased more among the treated group compared to the matched control group. During our study period, the median household income has increased by 6.2% in the treated group when it has increased by 5.1% in (matched) control group. Share of highly educated residents has increased by 7 percentage points in treated group, when the increase has been 5 percentage points in the (matched)

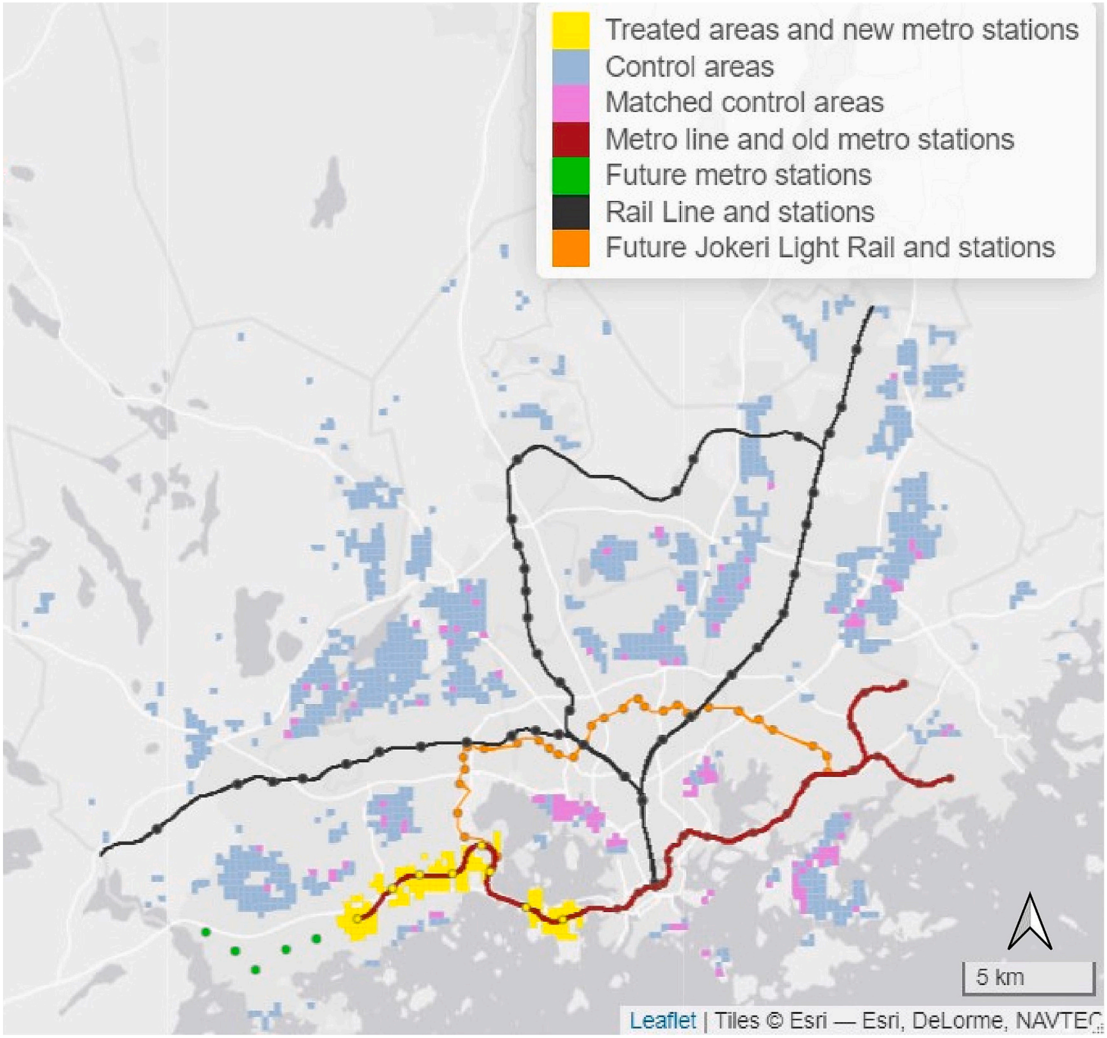

Fig. 2. The map of study area showing existing railway lines, treated neighbourhoods around the new metro stations, control areas, and matched control areas. Data for the figure is from three different sources. Grid information is based on Statistics Finland (Statistics Finland, 2023). Transportation network, stations and stops is provided by HSL, and open data is available on https://www.hsl.fi/en/hsl/open-data (© HSL, 2023). Open data for Jokeri light rail and stations is provided by the city of Helsinki Urban Environment division, and available on (City of Helsinki, 2023).

control group. Share of low-income households reduced 1 percentage point in treated group and increased 1 percentage point in (matched) control group.

4. Results

4.1. The effect of change in accessibility on socioeconomic ascent

Our results show significant treatment effects for the full data sample for the shares of highly educated residents, and we did not find statistically significant treatment effects for the household income or share of low-income households. Our results indicate that after the first stage of West Metro opened, there was a significant increase of 2.1% in the share of highly educated residents within 800 m of the new metro stations compared to the control areas (Table 4). This is somewhat surprising as some studies have found opposite results. In the US context, the gentrification effect was found for household incomes, but not for the educational levels of the neighbourhoods (Bardaka et al., 2018). On the other hand, our results on the increase in the share of highly educated residents around the stations partly support the findings of Kahn (2007: 174), who found positive treatments effects for the income and educational levels close to the "walk and ride" stations in the US.

One possible explanation would be the age differences between the new and old residents as people achieve educational degrees at a relatively young age, but income levels tend to increase with age. This explanation is supported by the fact that people tend to move more in their 20s and 30s (Bernard et al., 2014). We partially control for this in the models by adding the share of young adults as a control variable, but this might still influence the results. The age differences between old and new residents are relatively small, but we can see that in the treated areas the share of young adults has increased by 0.02 percentage points in contrast to 0.06 percentage points increase in the matched control group (Table 2). However, as the differences are small, the age selection probably does not have a major role in explaining the results. In previous research the share of multi-family housing has been seen as a possible explanation for the increasing rates of highly educated residents (Nilsson and Delmelle, 2018). In our analysis we control for the share of detached houses, and this correlates very strongly (0.82) with the share of multi-family housing, and thus this explanation is unlikely.

The household income and the share of highly educated have increased in HMA in the control and treated areas during our study period. Based on the results we see that in the treated areas the household income and the share of highly educated residents is higher than in the control group already before the treatment. This might be explained by the locational differences and the rather close travel distance to the main roads and Helsinki city centre, since this connection has been

Table 3
Descriptive statistics for treated and control groups before and after matching for years 2008–2017 and 2018–2020. Household's disposable median income is in 2020 euros.

Variable name / unit	Pre-treatment years 2008–2017			After treatment years 2018–2020	
	Treated group	Control group	Control group after matching	Treated group	Control group after matching
	Mean (St. Dev)	Mean (St. Dev)	Mean (St. Dev)	Mean (St. Dev)	Mean (St. Dev)
Dependent variables					
Household income (log)	3.47 (0.22)	3.51 (0.24)	3.41 (0.28)	3.53 (0.22)	3.46 (0.31)
Low-income households (%)	0.31 (0.15)	0.24 (0.16)	0.36 (0.17)	0.3 (0.14)	0.37 (0.18)
Highly educated residents (%)	0.44 (0.13)	0.33 (0.15)	0.33 (0.16)	0.51 (0.13)	0.38 (0.17)
Control variables					
Young adults (%)	0.32 (0.11)	0.25 (0.12)	0.22 (0.10)	0.34 (0.11)	0.28 (0.10)
Small households (%)	0.69 (0.13)	0.48 (0.16)	0.69 (0.13)	0.69 (0.14)	0.69 (0.13)
Detached houses	0.19 (0.28)	0.7 (0.37)	0.19 (0.28)	0.18 (0.28)	0.19 (0.28)
New residential buildings	0.04 (0.12)	0.07 (0.13)	0.03 (0.1)	0.08 (0.16)	0.07 (0.14)
Population density	4230.03 (3115.68)	1945.47 (2188.11)	4520.18 (4379.62)	4696.24 (3478.07)	4698.46 (4497.24)
Distance to CBD (log)	1.95 (0.42)	2.53 (0.43)	1.99 (0.62)	1.95 (0.42)	1.99 (0.62)
Observations	1306	13,853	1319	396	396

found with accessible areas and high-income households (Barton and Gibbons, 2017). If high-income households find accessibility to public transportation valuable amenity, even commuting time and costs can be related to gentrification and neighbourhood change (Su, 2022).

4.2. *What is driving the neighbourhood change? – results for different subsamples*

With our unique register data, we can look closer for the potential drivers for neighbourhood change, and we run our regression model for the subsamples including residents living in the owner- and renter-occupied housing units and residents living in the pre-existing residential buildings, i.e., in the buildings that are built before 2008, when the decision to build the West Metro was made.

For the residents living in the pre-existing housing stock (models 4–6, Table 5), we can see that the treatment effects for the share of highly educated residents and the share of low-income households are significant when the treatment effect for the household income is not significant. After the first stage of opening the West Metro, the share of highly educated residents increased 2.5% when compared to the control group. One potential explanation to this result is that the accessibility improvements have capitalised on the housing prices, and some of the original residents have "cashed out" their property, as shown by Nilsson and Delmelle (2020), who noticed that middle and high-income households have higher probability of moving to a higher income neighbourhood prior to opening a new rail transit station. Even though, the potential out-move of the middle- and high-income households, the 2.2% decrease in the share of low-income households might be

Table 4
DID regression model results for household median income, highly educated residents and low-income households of areas comparing the effect of new metro line with other grids in the Helsinki metropolitan area. Household income is fixed to 2020 euros. Pre-treatment period is 2008–2017 and post-treatment period is 2018–2020. Treatment group: grids within 800 m of the new metro stations. Control group: grids that are matched after 800 m of new metro line without previous metro or rail stations. We are controlling for neighbourhood fixed effects at zip-code-level and ip-code clustered standard errors in parentheses: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

	(1) Household income	(2) Highly educated residents	(3) Low-income households
Post	0.046 *** (0.011)	0.050 *** (0.006)	0.005 (0.008)
Treat: 0–800 m	−0.329 *** (0.123)	−0.161 ** (0.062)	0.095 (0.072)
Post x Treat: 0–800 m	0.016 (0.015)	0.021 *** (0.008)	−0.014 (0.010)
Young adults	−0.498 *** (0.152)	−0.011 (0.116)	0.263 ** (0.111)
Small households	−0.360 *** (0.134)	−0.258 *** (0.063)	0.206 ** (0.080)
Detached houses	0.127 *** (0.038)	0.028 (0.030)	−0.092 *** (0.034)
New residential buildings	0.100 ** (0.042)	0.015 (0.027)	−0.046 (0.039)
Population density	−0.000 ** (0.000)	−0.000 (0.000)	0.000 ** (0.000)
Distance to CBD	−0.163 (0.177)	−0.117 (0.097)	0.121 (0.117)
Constant	4.330 *** (0.127)	0.729 *** (0.075)	−0.053 (0.081)
NFE	Yes	Yes	Yes
Adjusted R^2	0.675	0.725	0.595
Observations	3417	3417	3417

explained by the in-movers being wealthier and more educated when compared to control group instead of out-move or displacement of low-income households. This is supported by the previous studies by Delmelle and Nilsson (2020) and Nilsson and Delmelle (2020) who did not find evidence for out-move or displacement of low-income households. In our case we cannot conclusively tell whether the cash-out or the displacement is the mechanism at work.

We then move our attention to effects in different tenure groups. Models 7–9 report the results for homeowners and models 10–12 for renters. In the subsample of homeowners (models 7–9, Table 5), the models for household income and share of low-income households are not reported because of violation of parallel trends assumption. In the sub-sample of homeowners, the opening the West Metro increased the share of highly educated residents by 1.4% within 800 m of the new metro stations compared to the control group. In Finland, home ownership rates are increasing with age, and among 35-year-olds, almost two-thirds own their own home (Karhula, 2015). If the wealthier and more educated households are purchasing their own homes instead of renting, the possible higher housing prices caused by the West Metro are more directly related to the homeowners moving into these areas compared to the renters.

Results for the renters (models 10–12, Table 5) are similar in sign, but statistically insignificant. Our results support the findings of Deka (2017: 2969), who did not find either significant results on rents or renter-occupied housing units. One explanation for the insignificant findings could be that the free-market rents in the treated areas are not relatively higher than in the comparison areas, even though the housing units might be newer, and the sizes could be smaller. This might lead to a situation where the high amount of free market rental units available keep the rents stable and the residents that value high accessibility locate in the treated areas. However, in the supplementary analysis of

Table 5
The sample DID results for the data including only residents living in owner-occupied housing units, rental-occupied housing units or residential building build before the pre-treatment year 2008. Variables of interest are median household income, share of highly educated residents and share of low-income households' areas comparing the effect of new metro stations with other areas without the metro or train station in HMA. Household income is fixed to 2020 euros. We are controlling for neighbourhood fixed effects at zip-code level except for the renter subsample models (10)–(12), where adding postal-code fixed effects caused multicollinearity problem. ZIP-code clustered standard errors in parentheses: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Subsample	Pre-existing buildings			Homeowners			Renters		
	(4) Household income	(5) Highly educated residents	(6) Low-income households	(7) Household income	(8) Highly educated residents	(9) Low-income households	(10) Household income	(11) Highly educated residents	(12) Low-income households
Post x Treat: 0–800 m	0.022 (0.015)	0.025 *** (0.007)	−0.022 ** (0.009)		0.014 ** (0.006)		0.035 (0.022)	0.020 (0.013)	−0.032 (0.019)
Controls	Yes	Yes	Yes	Not reported because parallel trends assumption is violated	Yes	Not reported because parallel trends assumption is violated	Yes	Yes	Yes
NFE	Yes	Yes	Yes		Yes		No	No	No
Adjusted R^2	0.587	0.681	0.530		0.786		0.253	0.549	0.231
Observations	3398	3398	3398		3198		2209	2209	2209
Number of clusters	55	55	55		49		35	35	35

renters living in the old housing stock the results were similar.[2] Other explanation for the insignificant results could be the sticky rents that the landlords have not yet been able to increase in this short period after the West Metro opened. In Finland, the rents are agreed in the contracts between the landlord and the renter, and the rent can be increased only according to the contract. Most contracts allow for yearly increases in rent only based on the cost-of-living index or some pre-defined percentage. This means that the possible higher rents caused by the West Metro, are to an extent only faced by the new renters. One methodological explanation for the statistically non-significant results could be that the propensity score matching was unable to adjust the treatment and control groups to resemble each other before the treatment.

We can conclude that the extension to the metro network has triggered the gentrification among the pre-existing buildings and, to a certain extent, homeowners within 800 m of the new metro stations, since we find positive and significant treatment effects. Even though, treatment effects for the low-income households are negative, these findings might not necessarily mean that low-income households have moved-out of the treated areas (Brummet and Reed, 2019; Delmelle and Nilsson, 2020; Nilsson and Delmelle, 2020), but in the long-term, poverty rate and unemployment can decrease in the areas close to the stations (Deka, 2017: 2964). This might indicate that in the long-term educated high-income households become majority which decreases the relative share of low-income households, or the factors related to low-income households such as poverty rate and unemployment, if the in-movers are wealthier and more educated. There is also possibility that if the educated in-movers stay in these areas in the long-term, they increase the area's average household income if their income levels increase by age.

5. Conclusions

Our study contributes to the discussion on the effects of transit-oriented development by estimating the short-term causal effect of accessibility improvement on neighbourhoods' socioeconomic ascent overall and, for the first time, separately for residents in pre-existing buildings, homeowners and renters. We do this in the relatively highly regulated and subsidized housing market of the Helsinki Metropolitan area in Finland, providing an important case study from a Nordic welfare state, and providing an extension to the literature that has mostly focused on US context. Using high-quality and uniquely geographically precise register data, we show that in the entire sample, the opening of new metro stations did not have a statistically significant effect on the median household income or the share of low-income households, but it did increase the share of highly educated residents. In addition, as our main contribution to the literature, our data enables us to analyse whether the new metro stations triggered gentrification among residents living in owner- and renter-occupied housing units and in the buildings predating West Metro decision. We found a significant and positive treatment effect for the share of highly educated residents and a negative treatment effect for the share of low-income households among the pre-existing housing stock. For homeowners, the share of highly educated increased in a significant manner. For renters, no significant results were found.

We were unable to find a treatment effect for household income in the whole sample, contrary to the previous research that found a positive treatment effect for household income (e.g. Bardaka et al., 2018; Heilmann, 2018). However, our results show that the share of highly educated residents increased within 800 m of the new metro stations, which is partly consistent with Kahn (2007), who found that "walk and ride" stations were associated with higher income and educational levels. Based on the results of the whole data sample, we agree with the previous literature suggesting that transportation itself does not cause gentrification (Nilsson and Delmelle, 2018). In the long term, the area's socioeconomic structure, housing stock, and housing tenures will affect its development (Barton and Gibbons, 2017). The effects of accessibility on socioeconomic ascent can differ significantly depending on the context, as previous studies have reported varying results within the same country or even within the same city.

Our positive and significant results for the residents living in the pre-existing housing stock indicate that for the gentrification and socioeconomic ascent to occur, the context and the urban renewal linked to TOD are the drivers of the neighbourhood's socioeconomic change. We found positive and significant treatment effects within 800 m of the newly built metro stations for the household income and the share of highly educated residents, and negative effect for the share of low-income households, for the residents living in the pre-existing housing stock. For homeowners, a positive and significant effect is reported for the share of highly educated. Even though gentrification and neighbourhood change typically occurs in a longer period, we were able to find positive and significant short-term treatment effects in the context of Finland, and these findings are fascinating, since Finland is typically a very equal country from the perspective of residential segregation and wealth inequality (Pfeffer and Waitkus, 2021; Skifter Andersen et al., 2016). Further, without the subgroup analysis some of these effects would not have been found. The results underline the importance of not drawing definite conclusions concerning subgroups from overall statistically non-significant results.

Surprisingly, we could not find significant results with the subsample including only the residents living in the renter-occupied housing units. This finding is similar to Deka (2017), who did not find gentrification

[2] Available from authors upon request.

among renters, even though, in the long-term, areas around the stations might have a relative high share of highly educated residents and high-shares of multifamily housing, including renter-occupied housing units (Nilsson and Delmelle, 2018). The results might in part be explained by the Finnish housing system, where the rent raises are typically controlled in the rental agreements between renters and landlords. The landlords might not be able to raise rents in the short term even if there are significant rises in the housing prices in the neighbourhood. Also, if the renters are receiving housing benefits, these are typically tied to rent and rent increases are thus in part compensated by the state.

Overall, our results indicate that there has been transit-induced socioeconomic ascent following the building of the West Metro, yet the effects are not very strong nor universal. The changing socioeconomic structure can be clearly observed in the residents living in the pre-existing housing stock, and less so, if at all, in the overall development of the neighbourhoods and residents in the rental housing. Transit-induced socioeconomic ascent, and gentrification, are important topics in terms of sustainability, since large transit-oriented developments are justified with the arguments related to environmental sustainability, and social sustainability is left to the policymakers. From a policy perspective, it follows that planning TODs should pay attention to impacts on socioeconomic segregation even in the context of Nordic welfare states. We did not observe negative forced out-moves among low-income residents in rental housing, but the overcrowding of low-income residents among homeowners can lead to increases in residential segregation. However, given that the overall level of income was not statistically significantly affected, the newly built housing stock seems to balance out these effects in the context of West Metro.

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Data availability

The data that has been used is confidential.

Appendix A. Supplementary data

Supplementary material to this article can be found online at https://doi.org/10.1016/j.jtrangeo.2023.103758.

References

Abadie, A., Athey, S., Imbens, G.W., et al., 2022. When should you adjust standard errors for clustering? Q. J. Econ. 138 (1), 1–35.
Anguelovski, I., Connolly, J.J.T., Masip, L., et al., 2018. Assessing green gentrification in historically disenfranchised neighborhoods: a longitudinal and spatial analysis of Barcelona. Urban Geogr. 39 (3), 458–491.
Bardaka, E., Delgado, M.S., Florax, R.J.G.M., 2018. Causal identification of transit-induced gentrification and spatial spillover effects: the case of the Denver light rail. J. Transp. Geogr. 71, 15–31.
Barton, M.S., Gibbons, J., 2017. A stop too far: how does public transportation concentration influence neighbourhood median household income? Urban Stud. 54 (2), 538–554. SAGE Publications Ltd.
Bernard, A., Bell, M., Charles-Edwards, E., 2014. Life-course transitions and the age profile of internal migration. Popul. Dev. Rev. 40 (2), 213–239.
Bowes, D.R., Ihlanfeldt, K.R., 2001. Identifying the impacts of rail transit stations on residential property values. J. Urban Econ. 50 (1), 1–25.
Brummet, Q., Reed, D., 2019. The Effects of Gentrification on the Well-Being and Opportunity of Original Resident Adults and Children, 3421581, SSRN Scholarly Paper. Rochester, NY. Available at. https://papers.ssrn.com/abstract=3421581.
City of Helsinki, 2023. City of Helsinki Map Service. Available at: https://kartta.hel.fi (accessed 6 March 2023).
Deka, D., 2017. Benchmarking gentrification near commuter rail stations in New Jersey. Urban Stud. 54 (13), 2955–2972. SAGE Publications Ltd.
Delmelle, E., Nilsson, I., 2020. New rail transit stations and the out-migration of low-income residents. Urban Stud. 57 (1), 134–151. SAGE Publications Ltd.
Delmelle, E.C., Nilsson, I., Bryant, A., 2021. Investigating transit-induced displacement using eviction data. Hous. Policy Debate 31 (2), 326–341.
Dong, H., 2017. Rail-transit-induced gentrification and the affordability paradox of TOD. J. Transp. Geogr. 63, 1–10.
Dorsey, B., Mulder, A., 2013. Planning, place-making and building consensus for transit-oriented development: Ogden, Utah case study. J. Transp. Geogr. 32, 65–76.
Ellen, I.G., Horn, K.M., Reed, D., 2019. Has falling crime invited gentrification? J. Hous. Econ. 46, 101636.
Freeman, L., 2005. Displacement or succession?: Residential mobility in gentrifying neigborhoods. Urban Aff. Rev. 40 (4), 463–491.
Gibbons, S., Machin, S., 2005. Valuing rail access using transport innovations. J. Urban Econ. 57 (1), 148–169.
Glaeser, E.L., Kahn, M.E., Rappaport, J., 2008. Why do the poor live in cities? The role of public transportation. J. Urban Econ. 63 (1), 1–24.
Grube-Cavers, A., Patterson, Z., 2015. Urban rapid rail transit and gentrification in Canadian urban centres: a survival analysis approach. Urban Stud. 52 (1), 178–194. SAGE Publications Ltd.
Guerrieri, V., Hartley, D., Hurst, E., 2013. Endogenous gentrification and housing price dynamics. J. Public Econ. 100, 45–60.
Hammel, D.J., Wyly, E.K., 1996. A model for identifying gentrified areas with cencus data. Urban Geogr. 17 (3), 248–268.
Harjunen, O., 2018. How Much Does the Housing Market Anticipate the Impact of a New Metro Line? Part of: Essays in Urban Economics and Housing Market Capitalization. Aalto University. Epub ahead of print 2018. DOI: https://aaltodoc.aalto.fi:443/handle/123456789/34854.
Heilmann, K., 2018. Transit access and neighborhood segregation. Evidence from the Dallas light rail system. Reg. Sci. Urban Econ. 73, 237–250.
Hess, C.L., 2020. Light-rail Investment in Seattle: gentrification pressures and trends in neighborhood ethnoracial composition. Urban Aff. Rev. 56 (1), 154–187. SAGE Publications Inc.
HSL, 2023. Open data - Helsinki Region Transport (HSL). Available at: https://www.hsl.fi/en/hsl/open-data (accessed 6 March 2023).
Immergluck, D., 2009. Large redevelopment initiatives, housing values and gentrification: the case of the Atlanta beltline. Urban Stud. 46 (8), 1723–1745. SAGE Publications Ltd.
Kahn, M.E., 2007. Gentrification trends in new transit-oriented communities: evidence from 14 cities that expanded and built rail transit systems. Real Estate Econ. 35 (2), 155–182.
Karhula, A., 2015. Comparing overall effects of family background on homeownership during early life course. Hous. Stud. 30 (8), 1281–1298. Routledge.
Kauria, E., 2021. The anticipation effect of a light rail transit line on housing prices in the Helsinki region. J. Finn. Econ. Assoc. 2 (1), 49–73, 1.
Kim, S.K., Wu, L., 2022. Do the characteristics of new green space contribute to gentrification? Urban Stud. 59 (2), 360–380. SAGE Publications Ltd.
Mayer, T., Trevien, C., 2017. The impact of urban public transportation evidence from the Paris region. J. Urban Econ. 102, 1–21.
Nilsson, I., Delmelle, E., 2018. Transit investments and neighborhood change: on the likelihood of change. J. Transp. Geogr. 66, 167–179.
Nilsson, I., Delmelle, E.C., 2020. Impact of new rail transit stations on neighborhood destination choices and income segregation. Cities 102, 102737.
Owens, A., 2012. Neighborhoods on the rise: a typology of neighborhoods experiencing socioeconomic ascent. City Community 11 (4), 345–369. SAGE Publications.
Pathak, R., Wyczalkowski, C.K., Huang, X., 2017. Public transit access and the changing spatial distribution of poverty. Reg. Sci. Urban Econ. 66, 198–212.
Pfeffer, F.T., Waitkus, N., 2021. The wealth inequality of nations. Am. Sociol. Rev. 86 (4), 567–602. SAGE Publications Inc.
Rigolon, A., Németh, J., 2020. Green gentrification or 'just green enough': do park location, size and function affect whether a place gentrifies or not? Urban Stud. 57 (2), 402–420. SAGE Publications Ltd.
Skifter Andersen, H., Andersson, R., Wessel, T., et al., 2016. The impact of housing policies and housing markets on ethnic spatial segregation: comparing the capital cities of four Nordic welfare states. Int. J. Hous. Policy 16 (1), 1–30. Routledge.
Statistics Finland, 2022. Disposable income. In: Concepts. Statistics Finland. Available at: https://www.stat.fi/meta/kas/kayt_ol_tulot_en.html (accessed 8 November 2022).
Statistics Finland, 2023. Taika - Research Data Catalogue. Available at: https://taika.stat.fi/en/ (accessed 1 March 2023).
Su, Y., 2022. The rising value of time and the origin of urban gentrification. Am. Econ. J. Econ. Pol. 14 (1), 402–439.
Zheng, S., Kahn, M.E., 2013. Does government investment in local public goods spur gentrification? Evidence from Beijing. Real Estate Econ. 41 (1), 1–28.
Zuk, M., Bierbaum, A.H., Chapple, K., et al., 2018. Gentrification, displacement, and the role of public investment. J. Plan. Lit. 33 (1), 31–44. SAGE Publications Inc.