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Urban Accessibility, Housing Prices and Socio-Economic Status: A Spatial Analysis of Istanbul Neighbourhoods

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ABSTRACT

Multidimensional accessibility shapes both housing markets and the socio-economic composition of neighbourhoods, yet fine-grained evidence from rapidly urbanising contexts remains limited. This study examines how pedestrian accessibility to 88 urban services relates to listed housing prices and socio-economic status across 816 Istanbul neighbourhoods with at least 1,000 residents. Indicators from the municipal 34dakika.istanbul platform, measured as the population share reaching each service within a 17-minute walk, are aggregated into ten equally weighted categories and a Combined Accessibility Index. Least squares residuals display pronounced spatial dependence (Moran's $I = 0.340$, $p = 0.001$), so spatial lag and spatial error models are estimated and selected on robust Lagrange multiplier tests and information criteria. In the preferred spatial lag specification, only Transport and Mobility accessibility remains associated with higher prices after Holm correction ($\beta = 0.397$, $p = 0.001$); a 0.10 increase corresponds to a 4.4 per cent direct and a 9.1 per cent total price difference. For socio-economic status, transport ($\beta = 13.35$), health ($\beta = 11.74$) and economy ($\beta = 11.51$) accessibility are positive, whereas basic-needs coverage is negative ($\beta = -20.28$). A paired bootstrap shows that economy and basic-needs services are spread more evenly than education, health and transport services.

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Highlights:

- Transport access is the only category linked to higher housing prices
- Spatial lag models remove residual autocorrelation in the price equation
- Basic-needs services are spread more evenly than health and education
- Composite accessibility predicts status but not prices in Istanbul

Contribution to the field statement:

The study builds a ten-domain pedestrian accessibility index for 816 Istanbul neighbourhoods from 88 service indicators and tests it against housing prices and socio-economic status, separating capitalised transport advantage from the wider geography of everyday service provision.

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1. Introduction

Urban accessibility, defined as residents' ability to reach opportunities and essential services from their places of residence, has become a central concern in urban research and policy since Geurs and van

Wee (2004) established its analytical foundations. Rapid urban growth and increasing socioeconomic polarisation have intensified disparities in access to education, healthcare, employment, public transport, and other urban services, making accessibility inequality a significant dimension of intra-urban disadvantage (Lucas, 2012; Martens, 2016). In Istanbul, a metropolitan region of approximately 16 million residents, inequalities between central and peripheral neighbourhoods have direct implications for the spatial distribution of economic opportunities, public services, and residential welfare.

This study is informed by two complementary theoretical traditions. Hedonic pricing theory, formalised by Rosen (1974), conceptualises housing prices as bundles of implicit prices associated with structural, neighbourhood, and locational attributes. It therefore provides a basis for estimating the extent to which accessibility is capitalised into land and housing values. This approach has been widely applied to examine the effects of access to public transport, schools, healthcare facilities, and retail services on residential prices Dubé et al., 2014; Gibbons & Machin, 2008; Sirmans et al., 2005). The spatial equity literature, in contrast, builds on Harvey's (1973) argument that spatial injustice arises not from distance alone but from the unequal distribution of the opportunities and resources provided by the city (Martens, 2016; Neutens, 2015). By integrating these perspectives, the present study treats accessibility both as a locational attribute that may be reflected in housing prices and as an indicator of socioeconomic and spatial inequality.

The conceptual foundations of accessibility can be traced to Hansen (1959), who defined it in terms of the number of opportunities reachable from a location, weighted by the friction of distance. Subsequent research expanded this concept to incorporate travel time, financial cost, service quality, transport modes, and individual characteristics (Ben-Elia & Benenson, 2019; Geurs & van Wee, 2004). Contemporary urban policy has increasingly linked accessibility to sustainability through initiatives such as the fifteen-minute city (Vale & Lopes, 2023). However, aggregate proximity targets may conceal substantial differences in how accessibility is experienced across social groups, neighbourhoods, and urban fabrics. Measuring average proximity alone may therefore be insufficient for identifying the distributional consequences of unequal access.

Within the hedonic pricing literature, the meta-analysis conducted by Sirmans et al. (2005) identifies school quality, transport accessibility, and neighbourhood amenities as consistent determinants of housing prices. Gibbons and Machin (2008) distinguish the value of physical proximity to schools from the price premium associated with school quality. Similarly, Dubé et al. (2014) report housing price increases of between 26% and 45% within 500 metres of newly constructed stations in Quebec. In Istanbul, Demircan and Oğuztimur (2023) find that proximity to metro stations increases housing prices, although their analysis is limited to selected central districts and a single transport mode. Turkish accessibility research has otherwise concentrated primarily on the relationship between rail investment and residential values (Celik & Yankaya, 2006) or on commuting patterns. Neighbourhood-level analysis has remained comparatively limited, partly because of the spatial granularity of publicly available administrative statistics.

A more recent body of research has developed composite accessibility indices that extend beyond transport infrastructure. Páez et al. (2012) formalise positive and normative accessibility indicators and construct a composite measure of service deprivation. Tahmasbi et al. (2019) evaluate multimodal accessibility equity across different categories of public facilities, while Azmoodeh et al. (2021) propose socially differentiated accessibility measures. Ashik et al. (2024) further examine the dynamic equity of urban amenity distribution. A key distinction within this literature concerns horizontal and vertical equity. Horizontal equity refers to the provision of comparable access regardless of residential location, whereas vertical equity prioritises disadvantaged populations and underserved areas. This distinction provides the normative basis for the present study and is consistent with the principles of the Territorial Agenda (2020) and Sustainable Development Goal 11.

Despite these advances, three important research gaps remain. First, composite accessibility indices are rarely evaluated against housing-market and socioeconomic outcomes simultaneously. Consequently, it remains unclear whether the accessibility domains capitalised into housing prices are

also associated with neighbourhood socioeconomic composition. Second, neighbourhood-level studies frequently rely on ordinary least squares estimation without adequately testing for spatial dependence, even though accessibility, housing prices, and socioeconomic conditions commonly exhibit spatial clustering. Ignoring such dependence may produce biased or inefficient estimates and obscure the effects of individual accessibility domains. Third, accessibility measured as service coverage, defined as the proportion of residents able to reach at least one service point, has seldom been compared with accessibility measured as the intensity of reachable service supply. These two approaches represent different dimensions of accessibility and have distinct policy implications.

The 34dakika.istanbul platform developed by the Istanbul Metropolitan Municipality helps address the persistent limitations associated with fine-scale accessibility data. The platform estimates pedestrian travel time to service points using a 17-minute one-way threshold, representing the outbound component of its 34-minute round-trip criterion. Travel times are calculated through the pedestrian network within hexagonal cells and subsequently aggregated to neighbourhoods using population weights. The platform contains 88 service types, enabling multidimensional accessibility to be assessed at a detailed spatial scale across Istanbul.

Using these data, the present study constructs a ten-domain Combined Accessibility Index from the 88 service indicators and incorporates it into a spatial econometric framework. The selection between spatial lag and spatial error specifications is based on diagnostic evidence rather than an a priori assumption. The analysis further decomposes estimated effects into direct and spatial spillover components. Housing sale prices and neighbourhood socioeconomic status are modelled as parallel outcomes, allowing the market valuation of accessibility and its association with welfare composition to be examined within the same metropolitan context. This integrated framework provides a more comprehensive assessment of whether accessible neighbourhoods command higher housing values, accommodate populations with higher socioeconomic status, or demonstrate both characteristics.

Accordingly, the study addresses three research questions. First, does multidimensional service accessibility predict neighbourhood housing sale prices in Istanbul? Second, is higher overall accessibility associated with higher socioeconomic status at the neighbourhood level? Third, are economic and basic-needs services distributed more evenly across neighbourhoods than education, healthcare, and transport services? These questions are examined through the following hypotheses:

H1: Higher neighbourhood accessibility is associated with higher housing prices, conditional on other neighbourhood characteristics.

H2: Higher neighbourhood accessibility is associated with higher socioeconomic status, conditional on other neighbourhood characteristics.

H3: Essential service categories related to economic activity and basic needs are distributed more evenly across neighbourhoods than education, healthcare, and transport services.

2. Materials and Methods

2.1 Study area and analytical sample

The analysis covers the area within the boundaries of the Istanbul Metropolitan Municipality. The unit of observation is the mahalle, the lowest official administrative unit in the statistical system of the Turkish Statistical Institute and the level at which socio-economic data are published. The compiled dataset contains 955 neighbourhoods across 39 districts, matched to boundary polygons in the TUREF / TM30 projection (EPSG:5254).

Neighbourhoods with fewer than 1,000 registered residents are excluded, and this is the only population threshold applied. The rule balances coverage against measurement stability. Retaining as much of the city as possible matters because higher thresholds remove two distinct kinds of area at once: peripheral neighbourhoods with rural characteristics, and central business, commercial and tourism districts whose resident population is small relative to their daytime function. Means computed over very small populations are nonetheless volatile, and price indicators are particularly exposed because they rest on few listings. Among the 139 neighbourhoods below the threshold, mean population is 428 residents and 51.1 per cent have no price observation, against 3.8 per cent among

those retained, which is consistent with thin market activity in very small settlements without establishing that low population is the cause.

Applying the threshold retains 816 neighbourhoods, all matched to a boundary polygon. Exclusions are geographically concentrated: 85.5 per cent of neighbourhoods in Şile, 41.8 per cent in Fatih, 41.0 per cent in Çatalca, 25.0 per cent in Beyoğlu and 23.7 per cent in Arnavutköy fall below the threshold, alongside Beykoz, Silivri and Eyüpsultan at 15 to 20 per cent. The pattern combines rural and former village settlements on the metropolitan fringe with low-residence central areas in the historic peninsula and Beyoğlu. Figure 1 maps the sample and the excluded units. Because the outcomes are missing for different subsets, models use outcome-specific complete cases: 783 neighbourhoods for prices and 814 for socio-economic status.

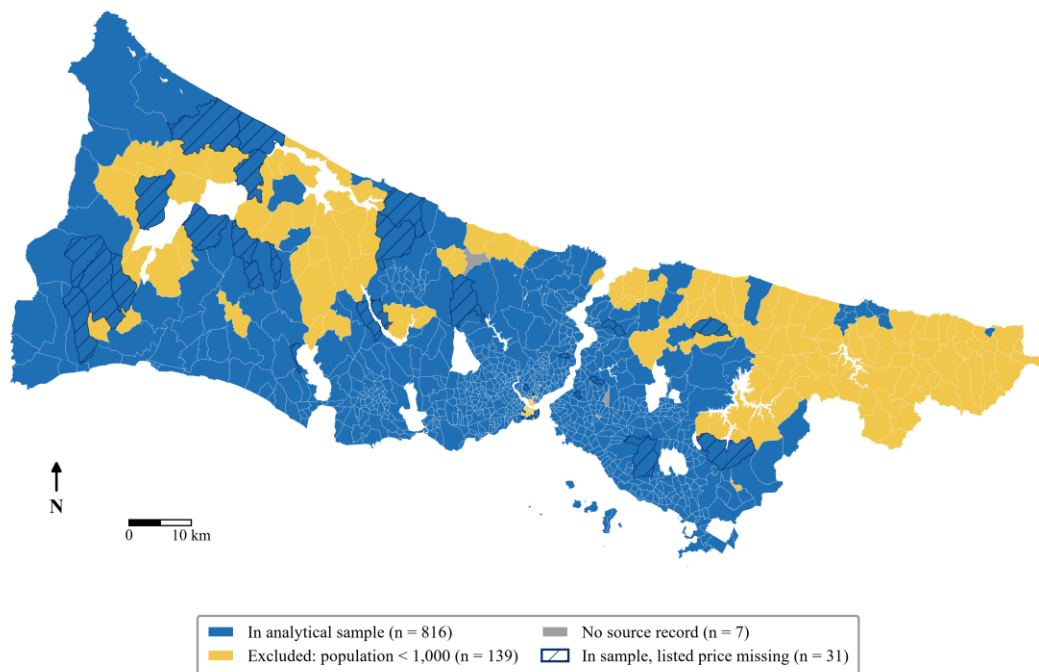


Figure 1. *Analytical sample and excluded neighbourhoods, Istanbul*

Note. Hatching marks sample neighbourhoods without a listed price. Projection: TUREF / TM30 (EPSG:5254). Sources: TUIK ADNKS (2023); sahibinden.com (2023).

2.2 Data sources and measurement

Accessibility data come from the 34dakika.istanbul open platform of the Istanbul Metropolitan Municipality. For each of 88 service indicators the platform computes, for hexagonal cells, whether and how many service points can be reached within a 17-minute one-way walk on the pedestrian network. Hexagons are assigned to the neighbourhood containing them and aggregated with population weights. Two measures are available. Binary coverage records the population share able to reach at least one service point of a given type,

$$BC_{ij} = \sum_h \left(\frac{P_{ih}}{P_i} \right) I(N_{ihj} \geq 1)$$

where P_{ih} is the population of hexagon h in neighbourhood i , P_i is neighbourhood population, N_{ihj} is the number of reachable service points of type j and $I(\cdot)$ is the indicator function. This measure lies between 0 and 1. Nominal intensity instead weights the count of reachable service points, and can exceed unity; 53.1 per cent of its values do so in the present data, which means it cannot be read as a population share. Binary coverage is used for the main analysis because it corresponds directly to the equity question of whether residents can reach a service at all, and nominal intensity is retained as a robustness measure describing the density of reachable supply.

Socio-demographic data for 2023 are drawn from the Address-Based Population Registration System and comprise total population, population density, average household size and average years of schooling. The composite socio-economic status score for the same year comes from the Istanbul Metropolitan Municipality Open Data Portal. It is expressed on a standardised scale running from -38.0 to 64.1 within the analytical sample, with negative values denoting positions below the metropolitan average; it is not a 0 to 100 index.

Housing market data are the mean listed asking price per square metre for 2023, in Turkish lira, compiled by the authors from residential sale listings on sahibinden.com, the dominant online property marketplace in Turkey, and averaged to the neighbourhood. Listings are the only price source with complete metropolitan coverage at this scale, since notarised transaction values are not published for neighbourhoods. Asking prices exceed realised prices by a margin that varies with market conditions, so the level of the variable is not a market valuation. The models use logged prices and are identified from variation across neighbourhoods, which a proportional asking-to-transaction gap leaves unaffected unless the gap itself varies systematically across the city; Section 5 returns to this.

Two data properties required correction during the audit. The density variable is labelled in the source file as residents per 1,000 square metres, but comparison with polygon areas from the boundary file shows it corresponds to residents per square kilometre (correlation 0.999, median ratio 1.000); it is reported accordingly, in thousands per square kilometre. Average household size contains five values above six persons, three of them above 17 and inconsistent with any plausible neighbourhood mean; these are retained in the main models and removed in a robustness check.

2.3 Thematic categories and index construction

The 88 indicators are assigned to ten thematic categories following the functional type of the service, its expected user group and its spatial pattern of use, in the tradition of Geurs and van Wee (2004) and consistent with the typologies of Ashik et al. (2024) and Azmoodeh et al. (2021). The categories are Emergency and Public Safety (3 indicators), Accommodation and Infrastructure (4), Economy and Employment (4), Basic Needs and Food Retail (8), Public, Administrative and Financial Services (10), Commercial and Personal Services (10), Social, Cultural and Recreational Amenities (16), Education Services (16), Health Services (9), and Transport and Mobility (8). Each indicator is assigned to exactly one category and the assignments sum to 88.

Category scores are equal-weighted arithmetic means of the indicators they contain,

$$C_{ik} = \frac{1}{m_k} \sum_{j \in k} BC_{ij}$$

where m_k is the number of indicators in category k . Because binary coverage values are already population shares bounded by 0 and 1, no rescaling is applied before aggregation. Averaging within categories before combining them prevents categories with many indicators from dominating the composite. The Combined Accessibility Index is the equal-weighted mean of the ten category scores,

$$CAI_i = \frac{1}{10} \sum_{k=1}^{10} C_{ik}$$

and therefore also lies between 0 and 1. Equal weighting is a transparent and reproducible baseline embodying the horizontal equity premise that no domain is assumed a priori to matter more than another; theory-driven weights remain an avenue for further work. The index enters the models only in separate parsimonious specifications, never alongside its own components, since including both would produce mechanical collinearity.

Nominal intensity values are highly right-skewed (median skewness 2.30 across the 88 indicators, maximum 6.32). A log1p transformation reduces median skewness to 0.37 and is applied before aggregation; untransformed values are also estimated for comparison.

2.4 Empirical strategy

Two outcomes are used for modelling. The price equation uses the natural logarithm of mean price per square metre listed, which removes skewness, falling from 2.07 to 0.28. The status equation uses the 2023 composite score, in levels. Given that the score incorporates income, education and employment components, the average years of education is conceptually linked with the outcome, so both estimations are provided.

Control variables are population density, natural log of population size, average household size, and average years of education. Density provides the context of congestion and building density, which could affect prices as amenities or disamenities depending on their impact. Population size differentiates between small central and large peripheral neighbourhoods and accounts for scale effects. Household size reflects family composition, while years of schooling reflects neighbourhood human capital, a typical determinant of housing demand and neighbourhood status (Glaeser et al., 2001).

The baseline estimator is OLS with HC3 heteroskedasticity-consistent standard errors. As ten accessibility coefficients are tested simultaneously in each model, Holm-corrected p-values (Holm, 1979) are provided together with the standard values and inference about categories is based on the corrected ones. The presence of multicollinearity is checked through the correlation matrix, VIF, and the condition number (Dormann et al., 2013).

Ridge and Lasso regressions (Hoerl & Kennard, 1970; Tibshirani, 1996) supplement instead of replacing these estimates. They examine predictability, not hypotheses and model stability as penalized estimators provide no valid hypothesis tests. Both used nested CV with 5-fold outer loop for performance and 5-fold inner loop for penalty choice, so the penalty is chosen only within the training folds, which prevents information leakage. Predictors were standardized inside the training fold, and outcomes unscaled. The seed was fixed at 42 in all model estimations.

Spatial dependence is addressed explicitly. The primary weights matrix uses first-order Queen contiguity, row-standardised. Fifteen polygons have no contiguous neighbour, mostly Marmara islands and detached peripheral units; each is linked symmetrically to the nearest centroid before row standardisation. A four-nearest-neighbour matrix serves as a robustness alternative. Global Moran's I on model residuals is computed with 999 permutations and seed 42, together with Lagrange multiplier tests for lag and error dependence and their robust variants. Spatial lag and spatial error models are then estimated by maximum likelihood for each outcome, and the preferred specification is chosen jointly on the robust tests, log-likelihood, information criteria, residual Moran's I and the plausibility of the implied mechanism. Where the lag model is preferred, direct, indirect and total effects follow LeSage and Pace (2009), with standard errors from 1,000 parameter draws.

Hypothesis H3 concerns the evenness with which categories are distributed and is therefore tested directly rather than inferred from insignificant regression coefficients, which carry no information about spatial uniformity. Between-neighbourhood dispersion of each category is measured by its standard deviation, coefficient of variation and interdecile range. The test statistic is the difference in mean dispersion between the economy and basic-needs group and the education, health and transport group,

$$D = \overline{disp}(A_3, A_4) - \overline{disp}(A_8, A_9, A_{10})$$

where $disp(\cdot)$ denotes the mean of the chosen dispersion measure over the categories listed. Intervals and two-sided probabilities come from 10,000 paired bootstrap replications resampling neighbourhoods jointly across categories, seed 42.

All estimation was carried out in Python 3.14.6 using pandas 3.0.3, numpy 2.4.6, scipy 1.17.1, statsmodels 0.14.6, scikit-learn 1.9.0, geopandas 1.1.4, libpysal 4.15.0, esda 2.8.2 and spreg 1.9.0. Analysis scripts, fixed seeds and the derived dataset accompany the article.

3. Results

3.1 Descriptive patterns

Table 1 reports descriptive statistics for the analytical sample. Coverage differs markedly across domains. Basic Needs and Food Retail records the highest mean (0.889), followed by Commercial and Personal Services (0.867) and Economy and Employment (0.859), so everyday retail and commercial employment sites are reachable on foot for most residents in most neighbourhoods. Accommodation and Infrastructure (0.484) and Social, Cultural and Recreational Amenities (0.494) record the lowest means, while Transport and Mobility (0.582), Education Services (0.616) and Health Services (0.620) are intermediate. The composite index averages 0.658 and ranges from 0.038 to 0.958. Mean listed prices are 49,059 Turkish lira per square metre (SD 32,253, range 2,611 to 254,118), the status score averages -2.11 (SD 19.31), density 20,851 residents per square kilometre and schooling 8.60 years.

Table 1: *Descriptive statistics for the analytical sample (n = 816)*

Variable	Mean	SD	Min	Median	Max
Accessibility categories (binary coverage, 0–1)					
Emergency and Public Safety (A1)	0.584	0.276	0.000	0.620	1.000
Accommodation and Infrastructure (A2)	0.484	0.285	0.000	0.500	1.000
Economy and Employment (A3)	0.859	0.199	0.000	0.984	1.000
Basic Needs and Food Retail (A4)	0.889	0.205	0.000	0.996	1.000
Public, Administrative and Financial Services (A5)	0.581	0.228	0.024	0.646	1.000
Commercial and Personal Services (A6)	0.867	0.222	0.000	0.988	1.000
Social, Cultural and Recreational Amenities (A7)	0.494	0.198	0.044	0.508	0.938
Education Services (A8)	0.616	0.263	0.000	0.697	1.000
Health Services (A9)	0.619	0.270	0.000	0.708	1.000
Transport and Mobility (A10)	0.582	0.227	0.000	0.625	1.000
Combined Accessibility Index	0.658	0.209	0.038	0.722	0.958
Outcome variables					
Listed price (TRY per m ² , 2023)	49,059	32,253	2,611	37,769	254,118
Log listed price per m ²	10.646	0.529	7.867	10.539	12.446
SES score (2023)	-2.11	19.31	-38.00	-7.01	64.05
Control variables					
Population density (000s per km ²)	20.85	19.17	0.01	16.10	89.24
Total population	19,151	16,244	1,012	15,396	112,367
Log total population	9.437	1.044	6.920	9.642	11.630
Average household size	3.229	1.231	1.806	3.148	25.819
Average years of schooling	8.60	1.38	5.36	8.33	12.67

Note: Each category is the equal-weighted mean of its indicators, which record the population share reaching at least one service point within a 17-minute walk; indicator counts per category are given in Section 2.3. Listed price is observed for 785 neighbourhoods. Sources: 34dakika.istanbul; TUIK ADNKS (2023); IMM Open Data Portal (2023); sahibinden.com (2023).

The ten category scores are strongly intercorrelated, with a mean absolute pairwise correlation of 0.757 and a maximum of 0.930 between Basic Needs and Commercial Services. This co-location is a feature of the urban fabric rather than a data artefact, and it motivates both the Holm correction and the penalised-regression checks. Bivariate associations already point to a divergence between the outcomes: the composite index correlates negatively with log prices ($r = -0.112$) but positively with socio-economic status ($r = 0.268$), while Transport and Mobility is positively associated with both ($r = 0.127$ and $r = 0.407$).

Figure 2 maps the composite index and all ten categories on a common scale. Every panel shows a centre-periphery gradient, highest on the historic peninsula and in the dense inner districts on both sides of the Bosphorus, lowest in peripheral Şile, Çatalca, Silivri and Arnavutköy. The panels also make the differences between domains visible: basic needs, commercial services and economic activity are close to saturated across the built-up area, whereas accommodation, social amenities and transport thin out sharply beyond the inner ring. Global spatial autocorrelation in the index is very high (Moran's $I = 0.858$), and the local indicators of spatial association identify 223 neighbourhoods in high-high clusters and 138 in low-low clusters at pseudo- $p < 0.05$.



Figure 2. *Pedestrian accessibility across Istanbul neighbourhoods, composite index and ten service categories*

Note: Common 0–1 scale: population share reaching a service point within a 17-minute walk; $n = 816$. Grey polygons lie outside the sample. Source: 34dakika.istanbul.

Figure 3 crosses the two distributions directly. Splitting the 783 neighbourhoods with price data at the sample median of the composite index and of the log listed price, 196 are high on both and 195 low on both, while 197 combine high accessibility with low prices and 197 the reverse. Only 49.8 per cent therefore fall into concordant categories, close to what independence would produce, and the discordant cases form coherent clusters. High accessibility with low prices concentrates in the dense inner and middle districts of the European side, led by Fatih (24 neighbourhoods), Esenyurt (18), Bağcılar (15) and Esenler (14); low accessibility with high prices clusters along the northern Bosphorus and the outer coastal belt, led by Beykoz (30) and Sarıyer (29).

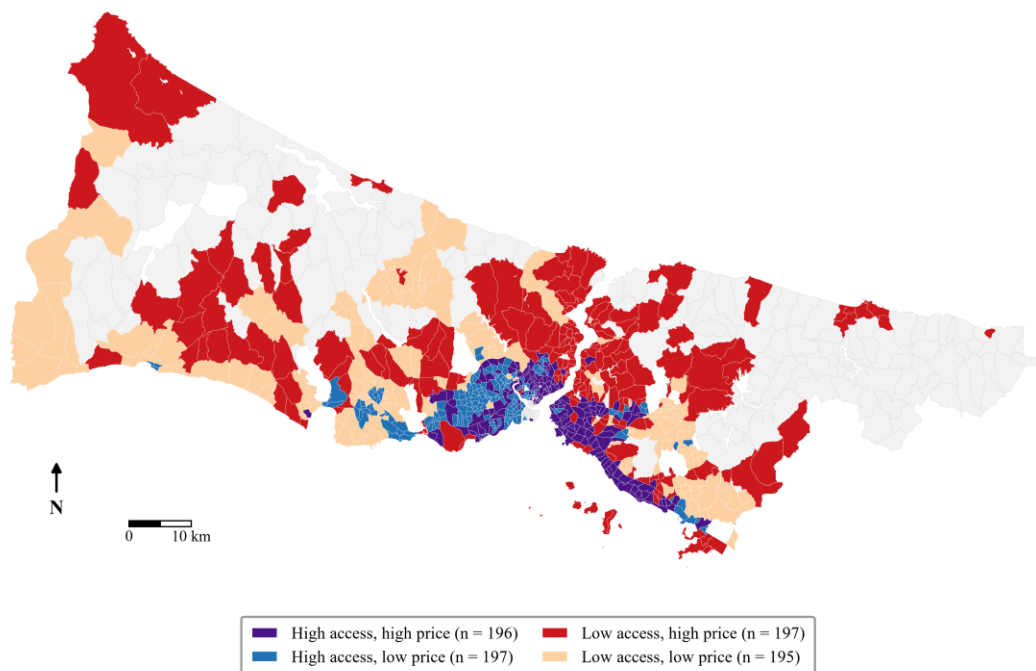


Figure 3. Accessibility and listed price relative to the metropolitan median.

3.2 Least squares estimates

Table 2 presents the least squares estimates. The housing price model explains 55.2 per cent of the variance in log prices after adjustment, and the status model with the schooling control 73.8 per cent. Variance inflation factors reach a maximum of 13.83 in the price model and 15.26 in the status model, both attributable to Commercial and Personal Services; condition numbers are 664 and 641. Collinearity is therefore material but bounded, and does not approach the magnitudes that would indicate near-exact linear dependency.

Table 2: Ordinary least squares estimates for listed prices and socio-economic status.

Variable	(1) Log listed price	(2) SES, with schooling	(3) SES, without schooling
A1 Emergency and safety	-0.090 (0.078)	-1.554 (1.691)	0.405 (2.702)
A2 Accommodation	-0.035 (0.081)	0.339 (2.048)	-2.007 (3.160)
A3 Economy and employment	0.009 (0.147)	15.869*** (4.158)	6.441 (6.349)
A4 Basic needs	-0.213 (0.208)	-18.630** (6.314)	-43.907*** (8.627)
A5 Public and financial	-0.428* (0.161)	-15.445*** (4.236)	-16.783* (6.652)
A6 Commercial services	0.024 (0.237)	10.952 (6.399)	14.222 (9.941)
A7 Social and recreational	0.313 (0.140)	14.961*** (3.884)	34.063*** (6.582)
A8 Education	-0.416** (0.128)	-13.244*** (3.762)	-16.571** (5.609)
A9 Health	0.082 (0.139)	12.416** (4.230)	31.806*** (5.503)
A10 Transport	0.696*** (0.135)	9.148** (3.365)	32.604*** (5.336)
Population density (000s/km ²)	-0.005*** (0.001)	-0.147*** (0.028)	-0.465*** (0.033)
Log population	-0.071*** (0.023)	1.669** (0.656)	3.104*** (0.921)
Household size	0.002 (0.018)	-0.803 (0.790)	-2.122** (1.000)
Years of schooling	0.190*** (0.016)	9.977*** (0.489)	



Constant	9.904*** (0.263)	-107.081*** (6.423)	-28.508*** (7.237)
Observations	783	814	814
Adjusted R ²	0.552	0.738	0.415
AIC	609.4	6,052.4	6,705.8
BIC	679.3	6,123.0	6,771.7
Maximum VIF	13.83	15.26	15.25
Condition number	663.7	640.8	619.5

Note. HC3 standard errors in parentheses; full category names in Table 1. Accessibility significance uses Holm-corrected p-values, controls uncorrected. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

In the price model, Transport and Mobility carries a positive coefficient of 0.696 that survives Holm correction ($p < 0.001$), while Education Services is negative at -0.416 (Holm $p = 0.010$). Public, Administrative and Financial Services is negative and marginal (-0.428 , Holm $p = 0.061$), and the remaining seven categories are indistinguishable from zero. Among the controls, average schooling is the strongest predictor (0.190 , $p < 0.001$), and both density and population size carry small negative coefficients.

In the status model with the schooling control, seven categories reach Holm-corrected significance: Economy and Employment (15.87), Social, Cultural and Recreational Amenities (14.96), Health Services (12.42) and Transport and Mobility (9.15) are positive, while Basic Needs and Food Retail (-18.63), Public, Administrative and Financial Services (-15.44) and Education Services (-13.24) are negative. Removing the control lowers the adjusted R-squared to 41.5 per cent and enlarges the accessibility coefficients, most visibly Transport and Mobility (32.60) and Basic Needs (-43.91), confirming that schooling absorbs much of the variation the status score shares with accessibility.

The parsimonious specifications using the Combined Accessibility Index tell a consistent story. The index is unrelated to listed prices (-0.102 , $p = 0.424$) but positively related to socio-economic status both with the schooling control (13.02 , $p = 0.001$) and without it (51.25 , $p < 0.001$).

3.3 Penalised regression and coefficient stability

In the case of log prices, Ridge achieves an R^2 -based cross-validated RMSE of 0.357, R^2 of 0.540, and Lasso is only slightly better with 0.356 and 0.543. However, for the socio-economic status data set including the schooling control, both methods obtain the same cross-validated R^2 -based estimate of 0.730, but a much lower 0.403 in the absence of schooling. Penalties selected in the outer folds do vary in a small range over the data (alpha from 15.5 to 62.2) for the price model but more over for the status model without schooling.

Variable selection appears to move in step with the inference results. Transport and Mobility, Education Services, Public Admin and Financial Services, Basic Needs and Social Services had consistent signs over all 5 outer folds for the price model while Accommodation, Economy, Commercial services and health services exhibited conflicting signs across the 5 folds (these were also the ones that were set to zero by Lasso's solution in the final model). In Figure 4 we can compare the standardized OLS and Ridge coefficients - these are indeed highly correlated, categories are in the same order, and Ridge can be seen to be "shrinking the biggest" coefficients, as would be expected from the use of regularisation. It appears these two methods may be used complementary: least squares for inference on specific domains and the regularised fits as a check of stability across potentially confounding variables.

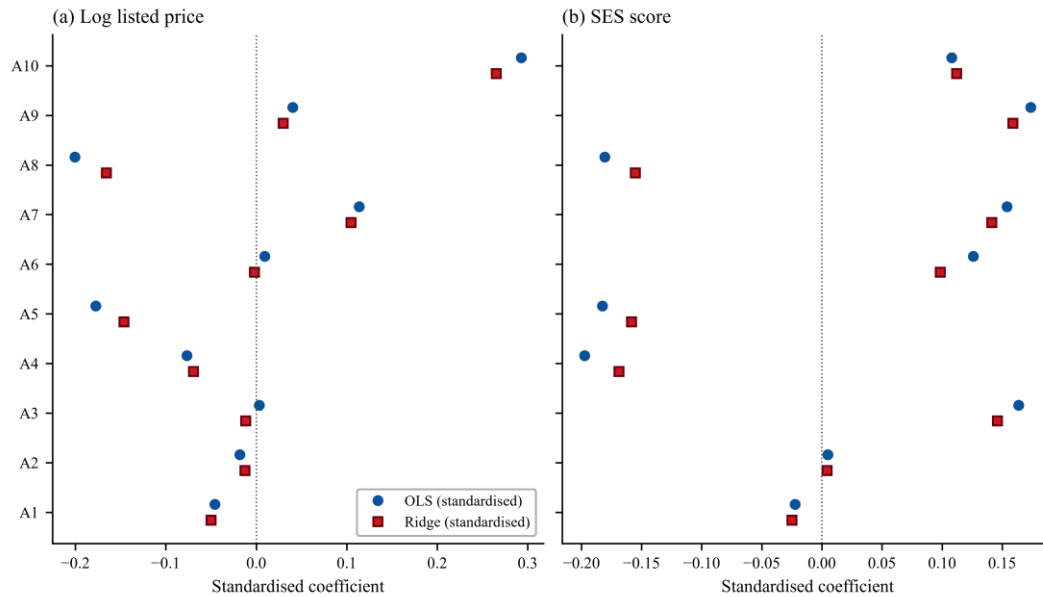


Figure 4. *Standardised least squares and Ridge coefficients for the ten accessibility categories.*

3.4 Spatial dependence and spatial models

Residual spatial autocorrelation is substantial in every least squares specification. Global Moran's I of the price model residuals is 0.340 under Queen contiguity ($p = 0.001$, 999 permutations) and 0.345 under four-nearest-neighbour weights; the values for the status model are 0.367 and 0.345. Figure 5 shows the Moran scatterplot. Ignoring this dependence would make the least squares standard errors unreliable, so the spatial models are the basis for inference.

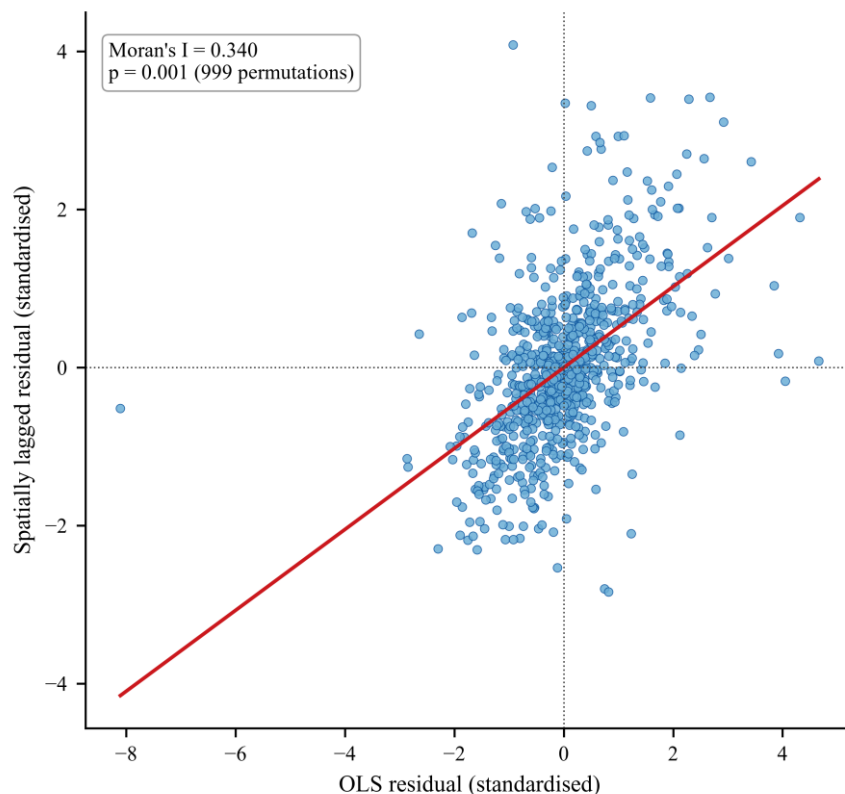


Figure 5. *Moran scatterplot of least squares residuals, listed price model.*

Note. Row-standardised Queen weights; 999 permutations, seed 42; $n = 783$.

Table 3 reports the diagnostic and selection evidence. For listed prices the robust Lagrange multiplier test for a spatial lag is significant ($p < 0.001$) while its error counterpart is not ($p = 0.105$); the lag model attains a lower information criterion (AIC 385.9 against 413.1) and leaves no detectable residual autocorrelation (Moran's $I = -0.014$, $p = 0.304$). All three criteria select the lag specification. For socio-economic status with the schooling control, both robust tests are significant but the error variant is far stronger, the error model attains the lower criterion (AIC 5,847.2 against 5,892.1), and only its filtered residuals approach spatial randomness, so the error specification is preferred. When schooling is excluded the ordering reverses and the lag model is preferred (AIC 6,234.1 against 6,241.8, residual Moran's $I = -0.019$, $p = 0.252$). The two outcomes are governed by different spatial structures, and no single specification is imposed on both.

Table 3: Spatial dependence diagnostics and model selection under Queen contiguity

Outcome	OLS residual Moran's I	Robust LM-lag	Robust LM-error	AIC (SAR)	AIC (SEM)	SAR residual I	SEM residual I	Preferred
Log listed price	0.340 (0.001)	49.07 (0.000)	2.63 (0.105)	385.9	413.1	-0.014 (0.304)	-0.049 (0.026)	SAR
SES, with schooling	0.367 (0.001)	12.06 (0.001)	78.40 (0.000)	5,892.1	5,847.2	0.099 (0.001)	-0.046 (0.028)	SEM
SES, without schooling	0.524 (0.001)	71.65 (0.000)	8.46 (0.004)	6,234.1	6,241.8	-0.019 (0.252)	-0.064 (0.005)	SAR

Note: p-values in parentheses. Moran's I uses 999 permutations, seed 42, on a row-standardised Queen contiguity matrix. SEM autocorrelation is evaluated on spatially filtered residuals.

Table 4 reports the preferred models. In the lag model for listed prices the autoregressive parameter is 0.543 ($p < 0.001$), so prices in a neighbourhood are strongly related to those in adjoining neighbourhoods. Transport and Mobility is the only category that survives Holm correction (0.397, Holm $p = 0.001$). Education Services and Public, Administrative and Financial Services, both significant under least squares, fall to -0.098 and -0.209 and are no longer distinguishable from zero. Their apparent significance in the non-spatial model reflected the clustering of central districts rather than an independent association with price.

Table 4: Preferred spatial models for listed prices and socio-economic status

Variable	(1) Log listed price, SAR	(2) SES with schooling, SEM	(3) SES without schooling, SAR
A1 Emergency and safety	-0.035 (0.055)	-2.644 (1.861)	0.491 (1.913)
A2 Accommodation	-0.050 (0.069)	-2.763 (2.556)	-2.974 (2.389)
A3 Economy and employment	0.119 (0.116)	11.512** (3.832)	6.970 (3.983)
A4 Basic needs	-0.190 (0.147)	-20.278*** (4.555)	-30.026*** (4.987)
A5 Public and financial	-0.209 (0.131)	-4.553 (4.760)	-2.652 (4.554)
A6 Commercial services	-0.180 (0.189)	1.299 (5.817)	0.790 (6.338)
A7 Social and recreational	0.056 (0.130)	2.838 (4.702)	11.970* (4.491)
A8 Education	-0.098 (0.112)	-3.205 (4.045)	-3.785 (3.851)
A9 Health	0.153 (0.113)	11.737** (3.880)	18.728*** (3.857)
A10 Transport	0.397*** (0.100)	13.353*** (3.929)	13.403*** (3.443)
Population density (000s/km ²)	-0.005*** (0.001)	-0.227*** (0.026)	-0.298*** (0.027)
Log population	-0.028* (0.017)	2.660*** (0.508)	2.830*** (0.553)



Household size	0.004 (0.017)	-0.795*** (0.236)	-1.096*** (0.301)
Years of schooling	0.095*** (0.011)	8.984*** (0.372)	
Constant	4.488*** (0.350)	-99.467*** (5.399)	-18.315*** (4.525)
Spatial parameter (ρ or λ)	0.543*** (0.031)	0.591*** (0.034)	0.681*** (0.025)
Observations	783	814	814
Log-likelihood	-177.0	-2,908.6	-3,102.0
AIC	385.9	5,847.2	6,234.1
BIC	460.5	5,917.8	6,304.6
Residual Moran's I	-0.014 (0.304)	-0.046 (0.028)	-0.019 (0.252)

Note: Maximum likelihood estimates; asymptotic standard errors in parentheses. Row-standardised Queen weights, fifteen isolated polygons linked to the nearest centroid. Specification chosen per outcome (Table 3). Accessibility significance uses Holm-corrected p-values. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5 reports the effect decomposition. For Transport and Mobility the direct effect is 0.432 ($p < 0.001$), the indirect effect 0.437 ($p < 0.001$) and the total effect 0.868 ($p < 0.001$). On the price scale, a 0.10 increase in transport coverage corresponds to a 4.4 per cent direct difference within the neighbourhood, a 4.5 per cent difference transmitted through neighbouring units and a 9.1 per cent total difference. Moving across the full range corresponds to 54.0 per cent direct and 138.3 per cent total, although few neighbourhoods span that range and the figure is a scale illustration rather than a policy scenario. Average schooling carries a direct effect of 0.104 and a total effect of 0.208.

Table 5: *Direct, indirect and total effects in the spatial lag model for listed prices*

Variable	Direct	Indirect	Total	Total, % per 0.10
A1 Emergency and safety	-0.038	-0.039	-0.077	-0.76
A2 Accommodation	-0.054	-0.055	-0.109	-1.08
A3 Economy and employment	0.129	0.131	0.260	2.63
A4 Basic needs	-0.207	-0.209	-0.417	-4.08
A5 Public and financial	-0.228	-0.230	-0.458	-4.48
A6 Commercial services	-0.196	-0.198	-0.394	-3.86
A7 Social and recreational	0.061	0.062	0.122	1.23
A8 Education	-0.107	-0.108	-0.215	-2.13
A9 Health	0.167	0.169	0.335	3.41
A10 Transport	0.432***	0.437***	0.868***	9.07
Years of schooling	0.104***	0.105***	0.208***	2.11

Note. Effects follow LeSage and Pace (2009) with $\rho = 0.543$; standard errors from 1,000 draws, seed 42. Percentage change from $100[\exp(\beta \times 0.10) - 1]$

In the error model for socio-economic status the spatial parameter is 0.591 ($p < 0.001$). Four categories reach Holm-corrected significance: Transport and Mobility (13.35, $p = 0.006$), Health Services (11.74, $p = 0.020$) and Economy and Employment (11.51, $p = 0.020$) are positive, and Basic Needs and Food Retail (-20.28 , $p < 0.001$) is negative. Education Services is not distinguishable from zero (-3.21 , $p = 0.428$). Estimates without the schooling control, from the lag model preferred there, are similar in sign and larger in magnitude, with Basic Needs at -30.03 , Health Services at 18.73 and Transport at 13.40, all significant after correction. Figure 6 maps the residuals of the preferred price model, which show no visible regional pattern.

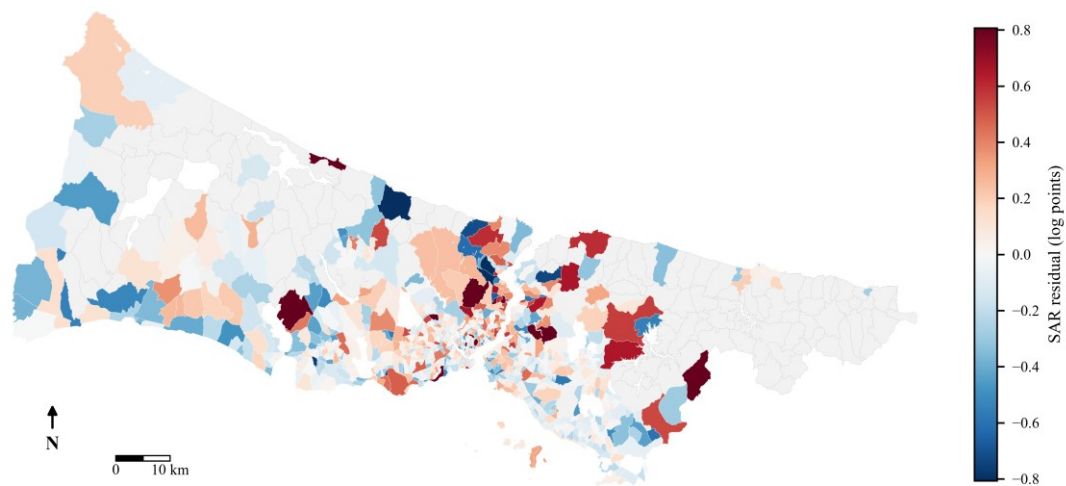


Figure 6. *Residuals of the preferred spatial lag model for listed prices.*

3.5 Distributional evenness of service categories

Table 6 reports the direct test of H3. The economy and basic-needs group has a mean between-neighbourhood standard deviation of 0.202, against 0.253 for the education, health and transport group. The paired bootstrap difference is -0.052 , 95 per cent interval $[-0.059, -0.044]$, two-sided probability below 0.001, and negative in all 10,000 replications. Because the first group also has higher mean coverage, the comparison is repeated on scale-free measures: the coefficient of variation differs by -0.187 $[-0.200, -0.174]$ and the interdecile range by -0.222 $[-0.238, -0.179]$, both below 0.001. The relative gap is larger on the scale-free measures, 57.6 per cent against 22.6 per cent, so the finding does not rest on the higher mean of the first group. A within-neighbourhood version yields the same sign and significance. Figure 7 displays the dispersion of all ten categories.

Table 6: *Paired bootstrap test of the even-distribution hypothesis (H3).*

Dispersion measure	Economy and basic needs (A3, A4)	Education, health, transport (A8, A9, A10)	Difference	95% CI	p	Relative difference (%)
Standard deviation	0.2018	0.2533	-0.0515	$[-0.0591, -0.0439]$	< 0.001	-22.6
Coefficient of variation	0.2309	0.4175	-0.1866	$[-0.1998, -0.1737]$	< 0.001	-57.6
Interdecile range (P90 – P10)	0.4639	0.6863	-0.2224	$[-0.2375, -0.1794]$	< 0.001	-38.7

Note: Between-neighbourhood dispersion, averaged within groups. Intervals and probabilities from 10,000 paired bootstrap replications, seed 42, $n = 816$. Negative differences indicate a more even distribution in the first group.

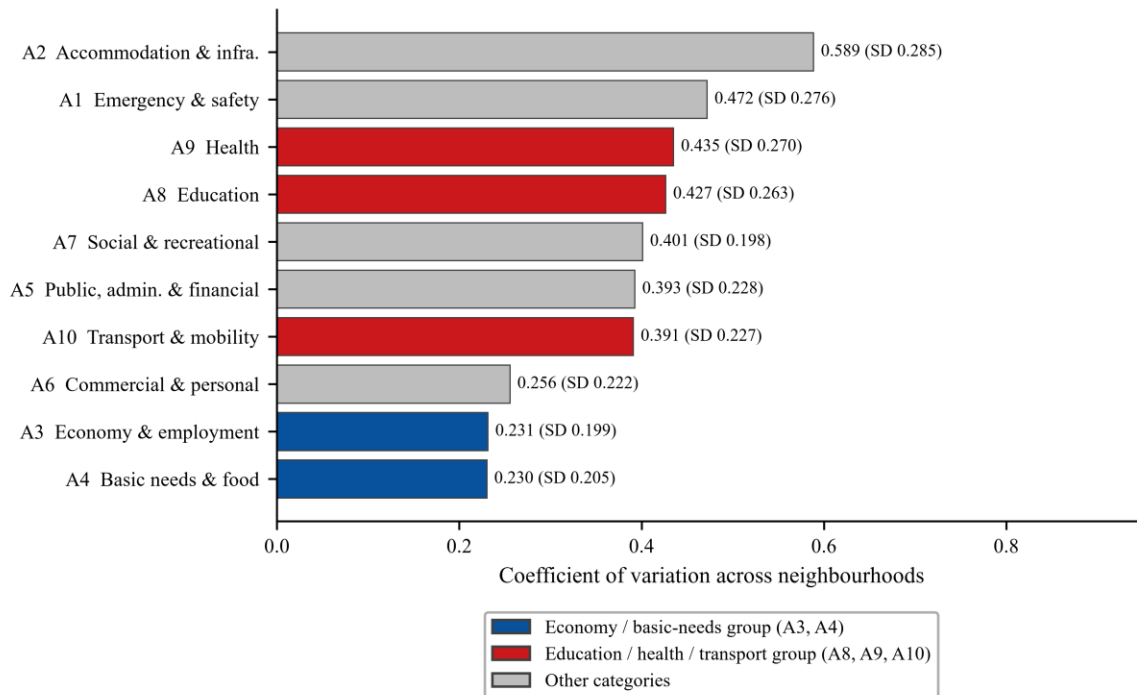


Figure 7. *Between-neighbourhood variability of the ten accessibility categories.*

Note. Coefficient of variation, with standard deviations in parentheses. Shading identifies the two groups compared in the H3 test.

3.6 Hypothesis assessment

H₁ is supported only in part. In the preferred spatial model, one category out of ten, Transport and Mobility, is associated with higher prices after correction for multiple testing, and the composite index shows no association with prices at all. Broad service access is therefore not capitalised in Istanbul; transport connectivity is.

H₂ is supported. Higher accessibility is associated with higher socio-economic status through the transport, health and economic domains, and the composite index is positively associated with status in the parsimonious specification with the schooling control. Basic-needs coverage runs in the opposite direction. The conclusion holds with and without the schooling control, although magnitudes are sensitive to it.

H₃ is supported on all three dispersion measures, with the difference negative in every bootstrap replication.

4. Discussion

The most robust finding is the singular position of transport accessibility. It is the only domain associated with higher listed prices once spatial dependence and multiple testing are accounted for, and it is among the strongest correlates of socio-economic status in both specifications. This is consistent with the hedonic evidence on transit capitalisation (Demircan & Oğuztimur, 2023; Dubé et al., 2014) and with work linking transit accessibility to economic opportunity (El-Geneidy et al., 2016; Foth et al., 2013). In a metropolitan region where much commuting depends on public transport, walking access to transit nodes plausibly reflects a scarce locational advantage, compatible with the role Burger and Meijers (2012) assign to connectivity in integrating sub-centres into a polycentric urban economy. The cross-sectional design does not identify a causal effect, and the association may equally reflect the historical placement of transit lines through already-valuable corridors.

The contrast between the two outcomes is the more informative result. The Combined Accessibility Index is unrelated to prices yet positively related to socio-economic status, and Figure 3 shows how weak the spatial correspondence is: barely half of neighbourhoods sit on the same side of the median

for both. Everyday services in Istanbul are close to universal in coverage terms, reachable on foot for roughly 86 to 89 per cent of residents on average, and a nearly saturated dimension cannot generate price variation because markets capitalise scarcity rather than ubiquity. Transport coverage, at 0.582 on average with an interdecile range of 0.625, remains genuinely scarce and unevenly distributed, and it is exactly the domain that is priced. This refines the fifteen-minute city debate: aggregate proximity targets can be met across most of a city while the dimension carrying economic value stays highly unequal (Vale & Lopes, 2023).

The negative association between basic-needs coverage and socio-economic status is the most counterintuitive result and warrants caution. It should not be read as evidence that food retail access reduces welfare. Dense, older, lower-status neighbourhoods support the fine-grained street-level retail the indicator records, whereas higher-status low-density areas on the periphery combine car-oriented retail formats with lower pedestrian coverage. The coefficient is consistent with a sorting mechanism in which built form, retail structure and residential composition are jointly determined, but the design tests none of these channels directly and the interpretation remains a hypothesis for future work.

A related caution applies to education services. Education accessibility carries a significant negative least squares coefficient in both equations, which earlier work would attribute to the concentration of public institutions in dense, historically older districts. Once spatial dependence is modelled, that coefficient loses significance for both outcomes. The apparent education effect was largely a spatial artefact: neighbourhoods with high education coverage are clustered, and their shared unobserved characteristics, not education coverage itself, carried the association. Residual autocorrelation diagnostics therefore matter for substantive conclusions and not only for standard errors, which fits the distinction Gibbons and Machin (2008) draw between physical proximity to schools and the quality premium that is capitalised.

The spillover structure of the price model has direct policy relevance. Half of the total association between transport accessibility and price operates through neighbouring units rather than within the neighbourhood itself, with an indirect effect of 0.437 against a direct effect of 0.432. Accessibility advantage does not stop at administrative boundaries, so appraisals confined to the immediate catchment understate the geographical extent of the associated value differences. The same logic applies to displacement pressure, which may extend beyond the corridor where investment occurs.

The H3 result carries an equity reading. The most evenly distributed domains are those supplied predominantly by the market, namely food retail, commercial services and economic activity, while education, health and transport, the domains most dependent on public investment decisions, are the least evenly distributed. Under the horizontal equity criterion of Ashik et al. (2024), the uneven domains are precisely those where public allocation could act, and they are also the domains the analysis links to socio-economic status. This gives the spatial-justice argument of Harvey (1973) and Martens (2016) an empirical target: the binding constraint is not the density of everyday amenities but the geography of publicly provided services.

The robustness analysis carries a measurement lesson. Binary coverage and nominal intensity agree in sign for 14 of 20 coefficient comparisons and both identify transport as positive for each outcome, but they diverge where a few central neighbourhoods accumulate very large service counts: in the economy category the nominal measure reaches 3,889 in Fatih neighbourhoods whose coverage is already saturated at 1.000. Coverage answers whether residents can reach a service, the equity question; intensity answers how much supply is reachable, closer to an agglomeration measure.

5. Conclusion

This study measured pedestrian accessibility to 88 urban services across 816 Istanbul neighbourhoods, aggregated it into ten equally weighted domains and a composite index, and related it to listed housing prices and socio-economic status within a spatial econometric framework.

Three findings stand out. Transport and Mobility accessibility is the only domain associated with higher listed prices once spatial dependence and multiple testing are accounted for, with a 0.10 increase in coverage corresponding to a 9.1 per cent total price difference. Composite accessibility is associated

with socio-economic status but not with prices, so the market prices a specific scarce dimension rather than general service proximity. Economy and basic-needs services are distributed significantly more evenly across neighbourhoods than education, health and transport services on all three dispersion measures.

The study contributes to urban economic analysis in three ways. Theoretically, it separates capitalised accessibility from welfare-relevant accessibility and shows the two need not coincide within a single city. Methodologically, it shows that conclusions about individual domains can reverse when spatial dependence is modelled, and it tests distributional equity directly rather than inferring it from insignificant coefficients. For policy, it identifies publicly provided services as the domains where distribution is least even and where accessibility is most strongly associated with socio-economic composition, while showing that transport advantage carries value implications beyond the neighbourhood itself.

Five limitations qualify these conclusions. The design is cross-sectional and associational; reverse causality and omitted variables cannot be ruled out. The price variable records listed asking prices rather than notarised transaction values, so the estimates describe what sellers ask rather than what buyers pay, and the two coincide only if the gap between them is proportionally similar across the city. Accessibility is measured only for walking, which understates opportunity where cycling and motorised access matter more. Service points are counted without regard to quality or capacity, so a well-resourced and a poorly-resourced facility enter identically. The status score partly overlaps with one of the controls, which is why estimates are reported with and without it. Transaction microdata, panel data on service openings and quality-weighted accessibility measures would each address part of these limitations.

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Conflicts of Interest

The author(s) declare(s) no conflicts of interest.

Data availability statement

The accessibility indicators are publicly available from the 34dakika.istanbul platform of the Istanbul Metropolitan Municipality, socio-economic status scores from the Municipality's Open Data Portal, and demographic data from the Address-Based Population Registration System of the Turkish Statistical Institute. Listed residential prices were compiled by the authors from sahibinden.com; the underlying listings cannot be redistributed under the platform's terms of use. The derived neighbourhood-level dataset, the indicator-to-category mapping, the supplementary tables and figures and the analysis code with fixed random seeds are available from the corresponding author on reasonable request, and will be provided to the editorial office at any stage of the review process.

Institutional Review Board Statement

This study did not require ethical approval as it does not involve human or animal subjects. It uses only aggregated neighbourhood-level data with no identifiable personal information.

CRedit author statement

Conceptualization: M.Ş., A.S. Methodology: M.Ş., A.S. Software: M.Ş., A.S. Validation: M.Ş., A.S. Formal analysis: M.Ş., A.S. Investigation: M.Ş., A.S. Data curation: M.Ş., A.S. Writing—original draft: M.Ş., A.S. Writing—review and editing: M.Ş., A.S. Visualization: M.Ş., A.S. Supervision: M.Ş., A.S. Project administration: M.Ş., A.S. Both authors contributed equally to every role listed, and both have reviewed and approved the final manuscript.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used a generative artificial intelligence assistant (Claude, Anthropic) to write and debug the analysis code, to produce the figures and to edit the language of the manuscript. All research questions, methodological choices, model specifications and interpretations are the authors' own, and every reported statistic was verified against the analysis output accompanying the article. The authors reviewed and edited the resulting content and take full responsibility for the published work.

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