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# Inequality in access to urban amenities

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**Alessandra Michelangeli [1], John Östh [2,3] ✉, Marina Toger [4] & Umut Türk [5]**

This paper provides an overview of urban inequality in the Stockholm Metropolitan Area analyzing the spatial distribution of amenities and their accessibility. Inequality in urban amenities is measured by a multidimensional index at a fine geographical scale and it can be decomposed into the sum of inequality indices computed on the marginal distributions of amenities across locations plus a residual term accounting for their joint distribution. Our research leverages a unique dataset that combines income data for approximately 90,000 geocoded individuals residing in the metropolitan area with information from the OpenStreetMap platform, enabling us to examine the distribution of both natural and urban design-related amenities. Furthermore, we integrate data from online platforms to analyze the housing market. Our findings reveal moderate levels of inequality in amenities within the Stockholm Metropolitan Area, with social segregation emerging as the primary driver of this inequality.

Individual wellbeing is affected by a variety of issues and factors, some of which are strictly related to locations where people live. Indeed, individual well-being depends on resources, services, or general outcomes that are specific to an area[1]. introduce the concept of amenities defined as location specific characteristics with positive or negative effects on individuals' utility. The contribution of amenities to well-being has been widely studied in the literature of urban quality of life[2–4] that shows how higher socioeconomic status households can afford to live in locations with more desirable amenities. Spatial sorting determined increases with income inequality across and between geographical areas[5–7]. However, the causal link between income inequality and uneven distribution of amenities in the urban space is less explored. People living in different areas are likely exposed to different bundles of amenities and this generates inequalities across individuals in their level of wellbeing.

In this paper, we start from the consideration that a society is fair if its members enjoy the same level of well-being, whenever they live. We therefore need to establish when different areas, each with a specific bundle of amenities, ensures equivalent livability. Consider the simple example of a city divided into two neighborhoods, A and B, each endowed with only two amenities, infrastructure and climate conditions. If the two neighborhoods have an equal number of amenities, residents have an equal access to them, regardless of their economic endowment and willingness to pay. As[8] points out, an equal amount of amenities do not guarantee equal individual well-being, since individual needs and preferences contribute to the process of transformation from commodities to functioning. However, several studies argue that an equal availability of local facilities mitigates well-being inequality[9–11]. Moreover, an equal amount of amenities is partly consistent with the idea of leveling the playing field developed in equality of opportunity literature[12,13].

Coming back to our example, any ranking generated by comparing each amenity at any time is incomplete, whenever we observe less infrastructure and better climate in A than in B. The first aim of the paper is to evaluate the disparities in the distribution of amenities across areas using a multidimensional index that allows to disentangle the effect of the distribution of each amenity on overall inequality, as well as the effect of the joint distribution of amenities in determining overall inequality across areas. We use register data about wages, data from open map services and housing prices to decompose inequality in access to amenities. The decomposition approach holds the potential to establish a connection between income inequality and disparities in the distribution of amenities, an aspect that has received less attention in existing literature. The methodology relies on the hedonic approach that considers both the housing market and the labor market[14].

Secondly, we aggregate the different determinants of well-being in a single index in order to produce a complete ranking of areas based on their level of well-being provided by amenities. The aim is to investigate the relationship between our measure of well-being and the average income by area. We expect a positive relationship between the two measures reflecting the fact that affluent people reside in better-endowed amenities.

Thirdly, we show how our analysis can provide a range of techniques and tools for policy actions aiming at reducing inequality.

We employ our methodology to assess inequality within the Metropolitan Area of Stockholm relying on a unique dataset composed of geocoded register data on socioeconomics, scraped real estate data from an online platform, and land use data extracted from open map services. In our analysis, we utilize register data to generate key socioeconomic variables within the Metropolitan Area of Stockholm. Specifically, we create averages for the wages of individuals within the 100 nearest neighbors, the proportion of visible minorities within the 100 nearest neighbors, and the share of

[1]University of Milan-Bicocca, DEMS, CefES, CISEPS, RCEA, Milan, Italy. [2]Oslo Metropolitan University, Department of Built Environment, Oslo, Norway. [3]Uppsala University, Institute for Housing and Urban Research, Uppsala, Sweden. [4]Uppsala University, Department of Human Geography, Uppsala, Sweden. [5]Abdullah Gül University, Economics Department, Kayseri, Turkey. ✉e-mail: John.Osth@oslomet.no

highly educated population within the 100 nearest neighbors from each populated unit. Register data is characterized by a geographic scale as fine as 100 square meters, serving as our initial reference point until calculations are extended to the nearest 100th neighbor at any distance. To complement the socioeconomic variables, we merge unaggregated housing price data obtained through web scraping (at the listing level) with the geocoded register at 100 square meters aggregates. This approach allows us to associate each sold apartment with socioeconomic characteristics in its immediate $100 \times 100$ scale neighborhood. Moreover, it enables us to maintain information about sold apartments at the individual level, preserving categorical details such as floor and size. Furthermore, we extract land use data from the OpenStreetMap platform. This data serves as a source for assessing the domination of natural and urban qualities within a 500 meter radius of the geocoded locations of residents. Access to amenities is then weighted by the distance from individual coordinates within the geographical constraint of 500 m. Using 500 m or similar sized radii to denote neighborhoods and neighborhood functions has a long tradition (see for instance[15,16]) and the use of bespoke, individual centered smaller neighborhoods to capture neighborhood effects has become common practice in more recent studies[17]. Individual, fixed radius centered neighborhoods fails to capture individual level variation in access to different modes of transport or individual preferences for different types of amenities. This is due to the lack of individual level statistics concerning transport mode and preferences.

By analyzing this land use data, we gain insights into the distribution and influence of natural and urban features in the immediate vicinity of residents' locations. From all scraped housing price locations, the areal share of lake, river and sea water within a 500 meter radius is used to describe how dominant water is on a neighborhood level using a focal statistics analysis in GIS[18]. Similarly, the areal share of commercial activities (shopping malls, retail areas), residential qualities (houses, private gardens, residential parking, etc.) and parks are calculated and used in the analyses. Urban form is measured using a line density variable, expressing the total length of road infrastructure within a 500 meter radius from each house (GIS derived variable) and the Cartesian distance to the urban core (defined as the most central housing price location). The geography of the study region comprises sales in Stockholm County, wherein all urban, suburban and peri-urban parts of the greater Stockholm region are included, but also a substantial number of rural areas within commutable distance. Stockholm is a monocentric city with a dense urban core area, and with residential areas concentrated around public transport hubs and major roads located outside the central parts[19,20]. Social inequality, in particular segregation, has been increasing in later years in Sweden. Recent papers have also turned the attention to the segregation patterns outside the residential sphere, where segregation in schools, labor market and in daily lives are added to the measured segregation. In[21–25], segregation after taking into account diurnal mobility of the population in the greater Stockholm region clearly showed that residential segregation is only one part of the overall picture. This means that the residential segregation, at least partially, can be decreased by facilitating access to amenities, are promoting mobility trajectories that lead to more mixed interactions.

## Results

### The implicit price of amenities

In this section, we begin by presenting our findings concerning the relationship between the distribution of amenities and wage and housing equations in our empirical approach. Following that, we delve into our discoveries regarding inequality in Stockholm, which we calculated using hedonic price theory and implicit prices. Implicit prices of amenities are the households' annual willingness to pay to have access to an additional (arbitrarily small) amount of them.

The analysis of housing prices and wages in Stockholm reveals interesting insights about the relationship between amenities and the quality of life. Firstly, the domination of water demonstrates a positive correlation with both housing prices and wages.

Moreover, the domination of amenities resulting from urban planning and policies, such as commercial activities, residential qualities, and parks within a 500 meter radius, also exhibit positive correlations with housing prices and wages (see[26] for a review on subjective well-being and green places). These findings indicate that the accessibility of such amenities, which are created and facilitated through deliberate urban design, adds value to the local housing market and enhances the income potential of residents. Notably, the implicit price for residential qualities is estimated to be 10,919 euros annually, highlighting their substantial monetary importance. Implicit prices for residential amenities indicate that, on average, residents assign a value equivalent to 23% of their annual income (€48,120) to the qualities of their residential environment. These encompass private gardens, parks, detached houses, and similar features.

In addition to physical amenities, the social composition of neighborhoods plays a significant role in determining wages. Variables reflecting the share of non-visible minorities and the share of highly educated individuals among the 100 nearest neighbors show positive correlations with wages and housing prices. This underscores the importance of social factors and community dynamics in shaping individuals' earning potential. These findings suggest that the composition of neighborhoods, in terms of both diversity and educational attainment, has a notable monetary impact.

Furthermore, accessibility, as measured by the road network, is another crucial factor influencing housing prices and wages. The road network variable, representing the line density of road networks within a 500 meter radius of all individuals and all home sales, serves as a measure of accessibility. Importantly, the interaction between the road network and the distance of individuals to the center of Stockholm reveals a positive correlation in both equations. This implies that improved accessibility, particularly with respect to proximity to the city center, contributes to higher housing prices and wages. The implicit price for this interaction is estimated to be around 767 euros.

The analysis of housing prices incorporates control variables such as the size of the housing and the type of dwelling (e.g., apartments, villas, etc.). These variables are essential in capturing additional factors that influence housing prices, beyond the amenities discussed earlier. (Table 1).

### Inequality in Stockholm Metropolitan area

We examine the findings related to inequality in Stockholm, considering both total inequality and decomposing it into the contributions of social, urban planning, and natural amenities. Table 2 presents the results, indicating that the total inequality measure is 0.09.

The analysis reveals that a significant portion of this total inequality stems from social structure, suggesting the presence of segregation within the city (see also refs. 27,28). Social amenities, including the composition of neighborhoods in terms of demographics and educational attainment, contribute significantly to the overall inequality.

Furthermore, urban design or planning factors account for ~15% of the total inequality. This implies that variations in access to amenities resulting from deliberate urban planning decisions, such as the distribution of commercial activities, residential qualities, and parks, contribute to inequality within the city.

In terms of natural amenities, specifically access to the sea, around 11% of the total inequality can be attributed to this factor. The presence or absence of natural amenities, like water bodies, can influence property values and the overall quality of life (see also ref. 29).

Overall, the findings underscore the multidimensional nature of inequality in Stockholm. The majority of the total inequality is driven by social factors, indicating the existence and influence of segregation. Urban planning and the distribution of amenities contribute to a significant portion of the inequality, and access to natural amenities also plays a role.

To further investigate the spatial pattern of inequality, a spatial autocorrelation analysis using Moran's I tests was conducted for total amenities, as well as social, natural, and urban planning-related amenities. The results, presented in the second column of Table 2, indicate a Moran's index of 0.658 for total amenities, suggesting a moderate level of spatial autocorrelation.

**Table 1 | Summary statistics of variables used in the analysis**

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| House Prices (Log) | 89,969 | 12.537 | 0.581 | 6.665 | 15.178 |
| Wages (Log) | 89,969 | 10.199 | 0.441 | 2.332 | 12.247 |
| Water | 89,969 | 0.010 | 0.0494 | 0 | 1 |
| Commercial | 89,969 | 0.017 | 0.084 | 0 | 1 |
| Residential qualities | 89,969 | 0.478 | 0.290 | 0 | 1 |
| Parks | 89,969 | 0.031 | 0.049 | 0 | 0.506 |
| Non visible minorities | 89,969 | 0.891 | 0.098 | 0.263 | 1 |
| Highly Educated | 89,969 | 0.369 | 0.105 | 0.129 | 0.963 |
| Road Networks | 89,969 | 0.309 | 0.142 | 0 | 1 |
| Distance Center | 89,969 | 0.214 | 0.135 | 0.000 | 1.005 |
| SqrMeter | 89,969 | 96.990 | 44.960 | 10 | 300 |
| Type of House | 89,969 | 4.003 | 1.332 | 1 | 6 |

**Table 2 | Inequality in amenities and Moran's I indices: total and by the type of amenity**

| | I | Moran's I |
|---|---|---|
| Total Inequality | 0.090 | 0.658 |
| Inequality Due to Social Structure | 0.067 | 0.840 |
| Inequality Due to Urban Design | 0.014 | 0.902 |
| Inequality Due to Natural Amenities | 0.010 | 0.664 |

Notably, the highest Moran's I value is observed for urban design-related amenities, recording a value of 0.902. This high Moran's I value indicates a strong spatial autocorrelation, suggesting a clustering of urban design amenities in certain areas of Stockholm. This spatial concentration of urban design amenities contributes to the observed inequality patterns.

Furthermore, the analysis also confirms a high spatial autocorrelation for social structure-related amenities, with a Moran's I value of 0.840. This finding aligns with the earlier decomposition of inequality, which highlighted the substantial contribution of social amenities to overall inequality. The spatial autocorrelation of social amenities suggests the presence of spatial segregation and clustering of neighborhoods based on social characteristics.

The spatial autocorrelation analysis adds an additional layer of evidence to the inequality decomposition, indicating that there is indeed a spatial pattern to inequality in Stockholm. The strong spatial autocorrelation of urban design and social structure-related amenities suggests that certain areas in the city benefit disproportionately from these amenities, contributing to spatial inequality. Additionally, we conducted a local spatial autocorrelation analysis (LISA) to examine the spatial patterns and statistical significance of amenity distributions within the Metropolitan Area of Stockholm. The LISA analysis allows us to identify clusters of amenities and understand their spatial relationships. The LISA maps, included as supplementary information, reveal high clusters of amenities in affluent neighborhoods of Stockholm. These areas are characterized by a concentration of desirable amenities, reflecting the advantages enjoyed by residents in more affluent parts of the city that are located in the city center. Furthermore, the decomposition of amenities and corresponding LISA values highlight interesting patterns related to social amenities. We observe low-low clusters of social amenities in areas with a higher concentration of immigrants. Specifically, areas such as the South, Southwest, and Northwest exhibit low levels of social amenities. This suggests a potential lack of access to social amenities in these neighborhoods, which may contribute to socioeconomic disparities. Supplementary Fig. 5, available in supplementary information, makes a comparison between two areas belonging to these two clusters: Kungsholmen south waterfront is a high-education and high-income, relatively central, waterfront urban residential area; Husby in Stockholm is a low education and low-income suburban residential area.

Natural amenities, by definition, tend to cluster around water bodies within the Metropolitan Area. These areas showcase the presence of natural amenities that contribute to the overall quality of life and recreational opportunities for residents. In contrast, urban design-related amenities appear to be more evenly distributed across the Metropolitan Area, indicating a wider availability of such amenities throughout various neighborhoods. Low-low clusters generally indicate areas characterized by affluent villa-type dwellings, where the need for parks or public green spaces may be relatively low due to the presence of private amenities within individual properties.

## Discussion

The strength of our approach lies in the detailed and localized scale of variable generation and analysis, which allowed us to gain in-depth insights into inequality patterns within Stockholm. In previous studies, the analysis was often conducted at a larger scale, providing limited understanding of the dynamics at the neighborhood or local level. The findings of our study shed light on the spatial inequalities within Stockholm and reveal the influence of social structure. Our analysis highlights that social structure plays a dominant role in shaping these spatial inequalities, which in turn indicates the presence of strong segregation patterns within the city.

The results are striking considering how the implicit pricing varies between types of amenities. Amenities that are reinforcing social segregation are valued at a greater cost than all other types of amenities, while amenities that are related to urban design are considerably less costly and amenities associated with residential qualities and natural amenities are priced in between. The results suggest that property costs and ethnic and/or class/education composition may have developed in accordance with a Schelling type of segregation (see[30]), and that amenities such as parks, infrastructure accessibility and commercial amenities are perceived as amenities that are within reach or widespread in the urban landscape.

A few policy implications can be derived from our findings. This paper puts in perspective inequality not only limited to social dimension but also adding urban design and nature amenities into consideration, which from a policy-making perspective allow a better maneuvering capacity. In particular:

- Policies can affect social inequality indirectly by compensating the lack of social interactions opportunity by improving the natural and design-related amenity opportunities.
- Stockholm can still benefit from inclusive housing policies aimed at reducing disparities according to our results, providing good access to natural- and urban-design amenities.
- Due to the restricted availability of natural amenities, particularly access to the sea, in certain parts of the Stockholm area, modifying building permit regulations in high-amenity zones could lead to more integrative forms of planning and execution of urban districts. This adjustment aims to accommodate a more diverse range of tenure forms, fostering a mix of social backgrounds among the local population.
- By nurturing a sense of belonging and reciprocal trust among residents from diverse backgrounds, these initiatives can contribute to a more integrated and cohesive city fabric. As indicated in earlier studies of mobility and segregation in the Stockholm region (see introduction), mobility has the potential to improve chances of social interaction across different social backgrounds. Natural and urban design related amenities are potential destinations for mobility, and by promoting diverse environment with good connectivity to various neighborhoods has the potential of addressing those three dimensions of inequality analyzed in this paper, with a particular emphasis on diversifying monotonous low-income suburbs.
- Investing in the expansion of public transportation networks and infrastructure holds significant potential for enhancing access to

opportunities and elevating the overall quality of life for residents in every neighborhood. Specifically, the expansion of public transportation networks to bridge underserved neighborhoods with employment centers and essential services can be a transformative step in reducing the isolation experienced by certain communities.

- Continuously monitoring and analyzing data on housing prices, demographics, and the availability of amenities is essential for detecting emerging patterns of segregation and inequality. This data-driven approach could inform policy adjustments and interventions as necessary to address these issues proactively. Planners could focus on natural and urban design related amenities, which are easier to directly affect by planning policies, and thus a quarter of the calculated inequality that could be attributed to these amenities.
- This analysis can be complemented with the study of other forms of inequality such as the digital divide which is the inequality in access to the Internet and ICT leading to a division and inequality around access to information and resources. Recent studies, such as[14], show that urban smartness is in fact negatively associated with internal digital divide. Another example of dimension that needs to be monitored by policy makers interested in maintaining a fair value of inequality in society is the risk of energy poverty. The latter can be excessively high for low-income segments of the population, and minorities located in institutionally and economically weak contexts, as shown by[31], leading to an exacerbation of inequality. Finally, policy makers should also consider the size of city in relation to inequality and its effects on social discontent. A recent study by[32] shows that bigger cities are characterized by structurally higher inequalities with respect to smaller urban areas, and also that compositional effects on discontent are particularly harmful in cities.

## Methods

### Data

Amenities have been broadly categorized as natural, built, social and cultural[33]. The data for housing prices was collected from Hemnet.se, which is a major online platform for the real estate market in Sweden. Hemnet.se provides comprehensive information on housing listings, including prices, property types, sizes, and addresses of sold houses. To collect the housing price data, we utilized web scraping techniques to extract information from the Hemnet.se website. The scraped data allowed us to obtain a large sample of housing listings in Stockholm, capturing a wide range of property types and sizes. In addition to the basic listing information, we leveraged the addresses of the sold houses to obtain their corresponding geographic coordinates. By geocoding the addresses, we were able to pinpoint the exact locations of the properties on the map.

The acquisition of amenity data was made from the global wiki-mapping web OpenStreetMap, and further curation and variable development was conducted in a GIS framework. Downloaded GIS data was originally stored as vector GIS (shape-file format) but during curation, rasterization of data in order to obtain focal statistics and line density output was conducted. Matching of wage data and of housing price data to GIS results was executed using value extraction functions where coordinates of wage holders and house sales are transferred from raster to coordinates based on location.

Sociodemographic data was derived from the Uppsala University population register database PLACE, which contains a geocoded full population register of pseudonymized individuals with data indicating level of education and country/region of birth. Using a spatial k-nearest neighbor approach we calculated the share of higher educated (university degree or equivalent) and share of people not being at risk of visible discrimination (indicated as being born in Europe, USA, Canada, Australia or New Zealand) among the 100 nearest neighbors from each populated unit and geocoded address of home sale[34]. The PLACE register database contains residential coordinates on 100 m × 100 m units which roughly represents a small block unit. In total 89,969 locations are used in our analyses. Depending of population density, the listed locations contain different number of individuals and sales.

### Multidimensional inequality in the distribution of amenities

The multidimensional inequality index used in the analysis assumes that social well-being depends on local amenities that are defined as location-specific characteristics with positive or negative effects on individuals' utility[1,2].

Let us consider $n$ blocks, indexed by $i = 1, \ldots, n$. Each block is endowed with $k$ amenities that are all strictly positive. The element $z_{ij} \in R_{++}$ indicates the level of amenity $j$ in the block $i$. The quantities owned by block $i$ are denoted by the vector $\boldsymbol{z}_i = (z_{i1}, \ldots, z_{ij} \ldots, z_{ik}) \in R^k_{++}$. Let

$$w\left(\boldsymbol{z_i} = \prod_{j=1}^{k} z_{ij}^{\sigma_j}\right) \tag{1}$$

be the function measuring the level of social well-being in block $i$. The parameter $\sigma_j$ captures the aversion to an unequal distribution of amenities across blocks. In this section we discuss the role of this parameter in the setup and present how to determine its value associated with each amenity. Notice that the function measuring well-being in society has a Cobb-Douglas form that provides the level of well-being via a geometric aggregation of the different amenities. The geometric aggregation has been preferred to a linear function, such as the sum of amenities or their arithmetic mean, since the latter is based on the following two strong assumptions: the independence among amenities, and a constant compensability between amenities. This implies that a greater quantity of one of the amenities compensates for the loss in another amenity. The Cobb-Douglas function assumes only some degree of compensability. Thus, a lower quantity of a given amenity is not able to compensate fully in other amenities[35].

The multidimensional inequality index, denoted by $I$, complements to 1 with the equality index developed by[36] and denoted by $E$, i.e.

$$I = 1 - E \tag{2}$$

where $E = \sum_{j=1}^{k} \sigma_j \ln \gamma_j + \ln \rho$. The terms $\gamma_j$, with $j = 1, \ldots, k$, are $k$ unidimensional indices of the Atkinson[37] type, i.e.

$$\gamma_j = \frac{1}{\bar{z}_j}\left[\frac{1}{n}\sum_{i=1}^{n} z_{ij}^{\sigma_j}\right]^{\frac{1}{\sigma_j}} \tag{3}$$

where $\bar{z}_j = \frac{1}{n}\sum_{i=1}^{n} z_{ij}$; the term $\rho = \frac{n^{k-1}\sum_{i=1}^{n}\left(\prod_{j=1}^{k} z_{ij}^{\sigma_j}\right)}{\prod_{j=1}^{k}\left(\sum_{i=1}^{n} z_{ij}^{\sigma_j}\right)}$ accounts for the interaction among amenities.

Several studies on inequality, such as[38] and[39], assume equal weights $\sigma_j$ for the different amenities under exam. In this paper, we follow[40] to endogenously determine the values of $\sigma_j$. They are set to their respective weight on the monetary assessment of the amenity bundle with sample average quantities. The monetary value of amenities, denoted by $p_j$, is determined on the basis of hedonic regressions based on the housing prices individuals are willing to pay and the wages they are willing to accept to locate in a given city. The parameter $\sigma_j$ is defined as:

$$\sigma_j = \frac{1 - \varepsilon_j}{k - 1} \tag{4}$$

where $\varepsilon_j = \frac{p_j \bar{z}_j}{\sum_{l=1}^{k} p_l \bar{z}_l}$. Each parameter $\varepsilon_j$ is set to be equal to the ratio between the estimated value of the average quantity of the amenity $j$ and the value of all amenities. The implicit assumption is that the higher the contribution of amenity $j$ in determining the amenity bundle value, the more intense is the

**Table 3 | Regression outputs from housing and wage models and implicit prices of amenities**

| VARIABLES | (1) Housing Model | (2) Wage Model | (3) Implicit Prices euros |
|---|---|---|---|
| Water | 0.430*** | 0.180*** | 16628.26 |
| | (0.039) | (0.021) | |
| Commercial Activities | 0.272*** | 0.442*** | 3040.31 |
| | (0.023) | (0.016) | |
| Residential Qualities | 0.098*** | 0.175*** | 10919.69 |
| | (0.005) | (0.005) | |
| Parks | 0.147*** | 0.127*** | 9353.441 |
| | (0.032) | (0.028) | |
| NonVMs | 0.402*** | 1.073*** | 58233.24 |
| | (0.015) | (0.016) | |
| Highly Educated Pop. | 1.424*** | 1.144*** | 58145.55 |
| | (0.020) | (0.017) | |
| Road Networks | −0.257*** | −0.577*** | |
| | (0.022) | (0.016) | |
| DistancetoCenter | −0.889*** | −0.3624*** | |
| | (0.028) | (0.016) | |
| Road NetworksXDistancetoCenter | 0.625*** | 0.671*** | 767.0873 |
| | (0.088) | (0.057) | |
| SqrCentimeter | 0.002*** | | |
| | (0.000) | | |
| FarmHouse (Ref:Leisure House) | 1.413*** | | |
| | (0.070) | | |
| Apartment | 0.033* | | |
| | (0.018) | | |
| Terraced House | 0.539*** | | |
| | (0.017) | | |
| Villa | 0.843*** | | |
| | (0.017) | | |
| Constant | 11.462*** | 8.943*** | |
| | (0.024) | (0.015) | |
| Observations | 89,969 | 89,969 | |
| R-squared | 0.504 | 0.225 | |

Robust standard errors in parentheses.
***$p < 0.01$, *$p < 0.1$.

aversion for its uneven distribution across blocks, the lower will be the value of $\sigma_j$.

The implicit prices of amenities, $p_j$, are determined by estimating two separate equations for the log of housing prices and wages:

$$\ln v_{hit} = \beta_0 + \beta_1 X_{hit} + \beta_2 Z_{it} + \xi_{hit} \tag{5}$$

$$\ln w_{mit} = \delta_0 + \delta_1 X_{mit} + \delta_2 Z_{it} + \zeta_{mit} \tag{6}$$

where $v_{hit}$ is the real price of housing unit $h$ in block $i$ at time $t$; $X_{hit}$ is a vector of housing characteristics; $Z_{it}$ is the vector of amenities in block $i$ at time $t$; $w_{mit}$ is the real wage of individual $m$ in block $i$ at time $t$; $Y_{mit}$ is a vector of individual characteristics; $\xi_{hit}$ and $\zeta_{mit}$ are the usual error terms. The implicit price of amenity $z_j$ is given by

$$p_j = \frac{der\, v}{der\, z_j} - \frac{der\, w}{der\, z_j}. \tag{7}$$

On the theoretical ground, the amenity full implicit prices are determined in a general equilibrium setting that considers both the housing market and the labor market. Households with a preference for amenity-rich areas will move to those areas, which are also the most expensive, and will be willing to earn lower wages to enjoy the higher level of amenities. Conversely, households living in low-amenity areas will be compensated with higher wages, and lower housing prices. In equilibrium, no-one has an incentive to move, since the relocations costs are higher than the utility gains generated by moving. The representative household experiences the same level of utility in all areas, and unit production costs are equal to the unit production prices[41].

We estimate the empirical model using ordinary least square regressions, which allows us to analyze the relationship between wage, housing prices and the distribution of amenities. It is important to note that, despite incorporating various spatially constructed covariates, the OLS model may still exhibit some degree of spatial autocorrelation in residuals. Future studies may delve into this aspect and consider adjusting the model using a spatial regression framework. However, such an exploration is beyond the scope of the current paper. In the second step of our analysis, we employ a global spatial autocorrelation measure, specifically the Moran's I index, to assess the overall spatial pattern of amenity distribution. Additionally, we conduct a local autocorrelation analysis to identify specific areas with significant clustering of amenities. Table 3 shows the estimation results for the housing price equation and wage equation, as well as the implicit prices $p_j$, with $j = 1, \ldots, k$. In order to obtain the annual full implicit price of each amenity the estimated coefficients in housing price equation are converted into imputed annual rents by applying a 7.85% discount rate, as in[42].

The model explains >50% of the variability of housing prices (column[1]) and 22.5% of the variability of wages (column[2]). In both equations, amenity variables are individually statistically significant. Estimated coefficients in the wage equation have the same sign as in the housing equation, thus implying implicit prices with opposite signs. Similar results are obtained by[43,44] and, more recently, by[45], and[46]. The finding of counter-intuitive implicit prices in the wage equation can be interpreted as an indication that local amenities affect the location decisions of both households and firms, so that the net effect of wages of the presence of local amenities is ambiguous[42]. The estimated implicit prices are reported in Column[3] and commented in the Results section.

## Data availability

The study uses population register data obtained from third parties and cannot be shared with public due to privacy agreement. We provide details about data and how the results were obtained in Section Materials and methods. Although data are from a proprietary data source that is not accessible to other researchers, we are certainly available to make them available for any reviewer.

## Code availability

The code is available upon request.

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## References

1. Bartik, T. J. & Smith, V. K. In *Handbook Of Regional And Urban Economics* (eds. Henderson, J. V. & Strange, W.) 1207–1254 (Elsevier, 1987).

2. Blomquist, G. C. In *A Companion to Urban Economics* (eds. Arnott, R. J. & McMillen, D. P.) 483–502 (John Wiley & Sons, Inc., 2006).
3. Albouy, D., Leibovici, F. & Warman, C. Quality of life, firm productivity, and the value of amenities across Canadian cities. *Can. J. Econ.* **46**, 379–411 (2013).
4. Kresl, P. K. *The City and Quality of Life* Vol. 136 (Edward Elgar Publishing, 2021).
5. Moretti, E. Real wage inequality. *Am. Econ. J. Appl. Econ.* **5**, 65–103 (2013).
6. Diamond, R. The determinants and welfare implications of US workers' diverging location choices by skill: 1980–2000. *Am. Econ. Rev.* **106**, 479–524 (2016).
7. Couture, V. & Handbury, J. Urban revival in America. *J. Urban Econ.* **119**, 103267 (2020).
8. Sen, A. *Commodities and Capabilities* (Elsevier, 1985).
9. Aaberge, R., Langørgen, A. & Lindgren, P. *The Distributional Impact Of Public Services In European Countries*. https://ec.europa.eu/eurostat/documents/3888793/5857249/KS-RA-13-009-EN.PDF (2017).
10. Brambilla, M., Michelangeli, A. & Peluso, E. Equity in the city: on measuring urban (ine) quality of life. *Urban Stud.* **50**, 3205–3224 (2013).
11. Brambilla, M., Michelangeli, A. & Peluso, E. In *Quality Of Life In Cities: Equity, Sustainable Development And Happiness From A Policy Perspective* (ed. Michelangeli, A.) 91–110 (Routledge, 2015).
12. Roemer, J. E. *Equality of Opportunity*. (Cambridge University Press, 1998).
13. Van De Gaer, D. *Equality Of Opportunity And Investment In Human Capital*, Vol. 172 (Kath. Univ.,1995).
14. Caragliu, A. & Del Bo, C. F. Smart cities and the urban digital divide. *npj Urban Sustain.* **3**, 43 (2023).
15. Howard, E. *Garden cities of To-morrow* 2nd edn (Duke university Library, 1965).
16. Perry, C. *The Neighbourhood Unit: From the Regional Survey of New York and Its Environs: Volume VII: Neighbourhood and Community Planning*, Vol. 7 (Routledge, 1929).
17. Galster, G. On the nature of neighbourhood. *Urban Stud.* **38**, 2111–2124 (2001).
18. Osland, L., Östh, J. & Nordvik, V. House price valuation of environmental amenities: an application of GIS-derived data. *Reg. Sci. Policy Pract.* **14**, 939–959 (2022).
19. Söderström, P., Schulman, H. & Ristimäki, M. *Urban Form In The Helsinki And Stockholm City Regions-Development Of Pedestrian, Public Transport And Car Zones*. http://hdl.handle.net/10138/155224 (2015).
20. Bamford, G. Urban form and housing density, Australian cities and European models: Copenhagen and Stockholm reconsidered. *Urban Policy Res.* **27**, 337–356 (2009).
21. Östh, J., Dolciotti, M., Reggiani, A. & Nijkamp, P. Social capital, resilience and accessibility in urban systems: a study on Sweden. *Netw. Spat. Econ.* **18**, 313–336 (2018).
22. Hedman, L., Kadarik, K., Andersson, R. & Östh, J. Daily mobility patterns: reducing or reproducing inequalities and segregation? *Soc. Incl.* **9**, 208–221 (2021).
23. Toger, M., Kourtit, K., Nijkamp, P. & Östh, J. Mobility during the covid-19 pandemic: a data-driven time-geographic analysis of health-induced mobility changes. *Sustainability* **13**, 4027 (2021).
24. Müürisepp, K., Järv, O., Sjöblom, F., Toger, M. & Östh, J. Segregation and the pandemic: the dynamics of daytime social diversity during COVID-19 in Greater Stockholm. *Appl. Geogr.* **154**, 102926 (2023).
25. Türk, U. & Östh, J. Introducing a spatially explicit Gini measure for spatial segregation. *J. Geogr. Syst.* **25**, 469–488 (2023).
26. Papastergiou, E., Latinopoulos, D., Evdou, M. & Kalogeresis, A. Exploring associations between subjective well-being and non-market values when used in the evaluation of urban green spaces: a scoping review. *Land* **12**, 700 (2023).
27. Türk, U. & Östh, J. How much does geography contribute? measuring inequality of opportunities using a bespoke neighbourhood approach. *J. Geogr. Syst.* **21**, 295–318 (2019).
28. Michelangeli, A., Östh, J. & Türk, U. Intergenerational income mobility in Sweden: a look at the spatial disparities across municipalities. *Reg. Sci. Policy Pract.* **14**, 981–1004 (2022).
29. Stromberg, P. M., Öhrner, E., Brockwell, E. & Liu, Z. Valuing urban green amenities with an inequality lens. *Ecol. Econ.* **186**, 107067 (2021).
30. Schelling, T. C. Dynamic models of segregation. *J. Math. Sociol.* **1**, 143–186 (1971).
31. Rio, D. D. F., Sovacool, B. K., Griffiths, S., Foley, A. M. & Furszyfer Del Rio, J. A cross-country analysis of sustainability, transport and energy poverty. *npj Urban Sustain.* **3**, 41 (2023).
32. Lenzi, C. & Perucca, G. Economic inequalities and discontent in European cities. *npj Urban Sustain.* **3**, 26 (2023).
33. Power, T. M. The supply and demand for natural amenities: An overview of theory and concepts. In, *Amenities And Rural Development: Theory, Methods And Public Policy* (eds. Marcouiller, D. D., Green, G. P. & Steven C. Deller, S. C.) 360 (Edward Elgar Publishing Ltd, 2005).
34. Östh, J. & Türk, U. 22. Integrating infrastructure and accessibility in measures of bespoke neighbourhoods. In *Handbook of Urban Segregation* (ed.Musterd) 378 (Elgar online, 2020).
35. Liberati, C., Longaretti, R. & Michelangeli, A. Measuring tolerant behavior. *Jahrbücher für Nationalö. Konomie und Statistik* **241**, 149–171 (2021).
36. Naga, R. H. A. & Geoffard, P.-Y. Decomposition of bivariate inequality indices by attributes. *Econ. Lett.* **90**, 362–367 (2006).
37. Atkinson, A. B. On the measurement of inequality. *J. Econ. Theory* **2**, 244–263 (1970).
38. Becker, G. S., Philipson, T. J. & Soares, R. R. The quantity and quality of life and the evolution of world inequality. *Am. Econ. Rev.* **95**, 277–291 (2005).
39. Angelini, E. C. & Michelangeli, A. Axiomatic measurement of multidimensional well-being inequality: some distributional questions. *J. Socio. Econ.* **41**, 548–557 (2012).
40. Michelangeli, A. & Peluso, E. Cities and inequality. *Appl. Geogr*. **160**, 103059 (2016).
41. Andreoli, F. & Michelangeli, A. The hedonic value of urban quality of life. In *Quality of Life in Cities: Equity, Sustainable Development and Happiness From a Policy Perspective* (ed. Michelangeli, A.) 186 (2015).
42. Colombo, E., Michelangeli, A. & Stanca, L. La Dolce Vita: hedonic estimates of quality of life in Italian cities. *Reg. Stud.* **48**, 1404–1418 (2014).
43. Blomquist, G. C., Berger, M. C. & Hoehn, J. P. New estimates of quality of life in urban areas. *Am. Econ. Rev.* **78**, 89–107 (1988).
44. Gyourko, J. & Tracy, J. The structure of local public finance and the quality of life. *J. Political Econ.* **99**, 774–806 (1991).
45. Buettner, T. & Ebertz, A. Quality of life in the regions: results for German Counties. *Ann. Reg. Sci.* **43**, 89–112 (2009).
46. Caragliu, A., Smith, M. & Van Oort, F. *Who's Right, Weber or Glaeser?* https://blogs.cornell.edu/crp/2019/11/06/andrea-caragliu-whos-right-weber-or-glaeser/ (2022).



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## Author contributions
A.M. conceptualized the study, developed the econometric models, contributed to theoretical framing and to writing and editing. J.Ö. served as corresponding author, contributed to spatial data analysis, theory and writing and editing. M.T. contributed to data processing, spatial modeling, GIS-handling and writing and editing. U.T. contributed to data collection, the statistical analysis, validation and writing and editing. All authors read and approved the final manuscript.

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**Correspondence** and requests for materials should be addressed to John Östh.