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Evidence from Denmark

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Transportation and quality of life

Evidence from Denmark

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Abstract

This paper investigates the importance of transportation for quality of life in Denmark. We first calibrate a simple general equilibrium model to analyse how local wage levels, housing costs, and commuting costs vary across urban areas as well as to construct a quality of life index that measures a representative household's willingness to pay for local amenities. We find that the quality of life is high in large cities. Wages and rents are also substantially higher in urban areas. We then regress the quality of life index on observed amenities to infer how quality of life is associated with transportation. Our empirical results suggest that the quality of the public transport system is particularly important for the quality of life.

Keywords: quality of life, rent gradients, wage gradients, commuting costs, amenities, transportation.

JEL codes: H4, J3, O52, R1, R4.

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1 Introduction

Countries around the world devote a significant share of public funds to transport infrastructure investments and maintenance. For high-income countries the investment in transport infrastructure has stabilized around 1% of the GDP and is expected to rise in the coming decades (OECD and ITF, 2013). Moreover, households devote about 20% of their expenditures to transportation (see e.g. Berri et al., 2014 and Couture et al., 2018) and the average commuter in 2016 spent about 1 hour per day on commuting (OECD, Statista 2019). This paper investigates the importance of transportation for the Quality Of Life (QOL).

Transportation infrastructure impacts the spatial organisation of economic activity between urban areas and the sorting of households across neighbourhoods (Redding and Turner, 2015). Moreover, it facilitates interaction within cities. It enables workers to combine living in high quality residential areas, with working at the most productive places (Redding and Rossi-Hansberg, 2017). Ahlfeldt et al. (2015) demonstrate that because of the presence of clustering benefits, better transportation possibilities, that reduce the burden of commuting, result in more specialisation. Heblich et al. (2020) confirm this by showing how emergence of rail mass transport in 19th century London implied a substantial increase in inner city's production specialisation. Moreover, Glaeser et al. (2001) provide empirical evidence on the growing importance of consumer amenities, which are often clustered in central cities. Baum-Snow (2007) shows that the construction of highways has contributed to the suburbanisation of households, while there is a simultaneous decrease in central city employment. Transport infrastructure is therefore related to the attractiveness of urban areas and consequently to the QOL.

Moreover, transportation can have a negative impact on the QOL. Due to land use regulations and the development of road networks and real estate stocks in many urban areas centuries ago, expansion of traffic capacity is strongly constrained. This often results in severe traffic congestion and contributes to the main environmental stressors in larger cities: air pollution and noise. Moreover, when land is scarce, on-street parking demand often exceeds parking supply and results in cruising for parking, which imposes external costs on all drivers by increasing congestion (Inci, 2015). The impact of transport infrastructure on attractiveness of urban areas is therefore likely to be heterogeneous and often also related to gentrification (Autor et al., 2014; Guerrieri et al., 2013).

Transportation is derived demand, as individuals often consume the service not because they benefit from consumption directly, but because they partake in other consumption or activities elsewhere (see e.g. Small and Verhoef (2007)). Transportation allows households to buy consumption goods and activities, get to work and have leisure time.[1] Households, therefore, when choosing residence location, face a trade-off between, on one hand, productivity and consumption advantages, and on the other hand, higher costs of living and dis-amenities. It is therefore important to recognize the importance of commuting costs for the QOL.[2]

Roback (1982) and Rosen (1979) pioneered estimation of the QOL index for urban areas by adjusting the urban wages for local cost-of-living.[3] They show that, in cities, higher nominal wage levels may compensate for both higher housing costs and disamenities. This implies that (homogenous) households accept lower real wages or bear higher housing costs to live in a place with desirable amenities as assessed by using the QOL index as a measure of neighbourhood quality. Beeson and Eberts (1989) and Gabriel and Rosenthal (1996) also compare local wages to rents to measure QOL. This methodology implicitly includes the value of all – observed and unobserved – local urban amenities. Albouy (2008) estimates a more plausible QOL index by adjusting the quality of life indices for taxes, non-housing costs and non-labour income, and shows that these measures are positively correlated with popular "liveability" rankings. While hedonic methods are usually applied to estimate value of specific amenities (e.g. traffic noise (Theebe, 2004), air quality (Chay and Greenstone, 2005), crime (Pope, 2008; Gautier et al., 2009) and proximity to water (Rouwendal et al., 2017)), the one-dimensional QOL index offers an economically intuitive measure of "liveability" that provides the value households place on all local amenities.[4] Albouy (2008) argues convincingly that

[1] Travel may also have direct consumption value (Couture et al., 2018). This value is however negligible, so we ignore it in this study.

[2] The relationships between commuting, housing and labour markets are very complex (see eg. Haas and Osland (2014)) and commuting can also be a substitute for migration (Haas and Osland, 2014; Guirao et al., 2020).

[3] See Albouy and Lue (2015) for an exhaustive review of literature on the estimation of the QOL index.

[4] Rosen (1974) showed that the first derivative of the hedonic price function with respect to the individual attribute equals the marginal willingness to pay (wtp) for this attribute. Economists have relied on Rosens hedonic model of market equilibrium to measure the wtp for specific amenities. See Palmquist (2006) for a review of the empirical hedonic literature.

QOL indices from the empirical hedonic literature in practice offer counter-intuitive results, e.g. by producing odd rankings of cities and city rankings that negatively correlates with city size (Burnell and Galster, 1992).[5]

Although the property value hedonics is the workhorse model for valuation of urban amenities, these methods are often biased by the housing sorting (Kuminoff et al., 2010). Structural approaches, on the other hand, account for the household residential sorting and relate household sorting to local urban amenities, including the provision of local public goods.[6] This may be important while studying the importance of transportation for the QOL, because the provision of public transport and transport infrastructure has some of the characteristics of a local public good and is likely associated with Tiebout sorting (see e.g. Epple and Sieg (1999)). For example, the density of railroad stations and bus stops is related to the population density and usually shows substantial differences over space. The structural models are however computationally-intensive and do not offer a clear measure of the QOL but instead provide the value that heterogeneous households place on considered local urban amenities. The main objective of our study is to investigate the importance of transportation for the quality of life. We are therefore interested in one-dimensional QOL indices as a measure of neighbourhood quality that implicitly includes the value of all local amenities.

This paper follows Albouy and Lue (2015) and estimates a transport adjusted QOL index for the 98 urban areas - municipalities - covering Denmark. We first compare housing and commuting costs to local wages to estimate a representative household´s willingness-to-pay (wtp) for local amenities, namely the QOL index. We consider household *taste heterogeneity* as well as *commuting costs*. More precisely, we estimate local wages by place of work to reduce potential biases from unobserved skills, correct for local taxes and add commuting costs to housing expenditures.[7] We then regress the estimated QOL indices on the observed amenities

[5]The observed housing prices are also affected by the long-run relationship between house prices and rents (Gallin, 2008), transaction costs and pecuniary and nonpecuniary costs of moving residence (including loss of neighbourhood-specific capital) (Haas and Osland, 2014), the housing boom and busts, and the regulation of financial markets (Agnello and Schuknecht, 2011).

[6]See Kuminoff et al. (2013) for an overview of the literature on residential sorting models. The methodology employed in the residential sorting models was developed by Berry (1994) and Berry et al. (1995). Bayer et al. (2007) pioneered the application of this approach to housing market analysis.

[7]It is important to consider household taste heterogeneity and to correct local wages for

to infer the extent of the association of QOL with urban amenities, particularly with transportation.

The remainder of the paper is organized as follows. Section 2 describes the theoretical model that guides our empirical methodology. Section 3 presents the data, provides descriptive statistics and discusses our empirical strategy. Empirical findings are presented and discussed in Section 4, emphasising the associations between transportation and the QOL. Section 5 concludes.

2 Theoretical framework

This section describes the theoretical framework that we use. We first introduce the basic model in subsection 2.1. In subsection 2.2 we show how to operationalize this model.

2.1 The model

We follow Albouy and Lue (2015) and extend the Rosen (1979) model by including commuting costs. Households are assumed to be homogeneous, perfectly mobile and fully informed about the municipalities characteristics. This implies that households have full information on housing prices, wages, commuting costs and amenities. We further simplify by assuming zero moving costs, which implies a spatial equilibrium in which utility levels are equalized across municipalities.

Households consume housing y at municipality specific price p_j, a traded good x with the price normalized to one, as well as leisure time l and commuting time f. Each municipality provides access to a vector of amenities $\mathbf{Z}$ aggregated into a single index $Q = Q(\mathbf{Z})$.[8] The preferences of households are represented by the quasi-concave utility function $U(x, y, l, h, f, Q)$ that is increasing in x, y, l, Q and decreasing in commuting time f and work hours h.

worker heterogeneity. For example, McLafferty and Preston (2019) find using data for the New York region that minorities are concentrated in jobs that have long commutes and lower wages.

[8] Amenities in municipalities that are physically close to municipality j may have a direct impact on the utility of households with residence or/and job in that municipality (j), e.g. restaurants, parks or recreational facilities. van Duijn and Rouwendal (2015) develop a model in which this is explicitly taken into account. In our model this is captured by municipality specific indices.

Households choose combination (j, k) of a municipality of residence j and a municipality where they work k. Residence locations (j) differ in local prices p_j and local amenities Q_j, while workplace locations k differ in local wages w_k and monetary commuting costs cf_{jk}, where $c \geqslant 0$ is the monetary cost per unit of time spent on commuting. They also choose consumption levels of x, y and labour supply h, and pay local taxes τ. The resulting household budget constraint is then $x + p_j y \leq w_k h - \tau(w_k h) - cf_{jk}$. Households are also constrained with respect to the time available which is standardized to 1 and used on commuting f, working h and leisure l, so $h + l + f_{jk} \leq 1$. Assuming the spatial equilibrium, the net expenditure for a household with the utility $\overline{u}$ can be expressed as:

$$E(p_j, w_k, f_{jk}; Q_j, \overline{u}) = \min_{x,y,h,l} \{x + p_j y - w_k h + \tau(w_k h) + cf_{jk} \tag{1}$$

$$: l + f_{jk} + h \leq 1, U(x, y, l, f_{jk}; Q_j) \geq \overline{u}\},$$

where $\overline{u}$ is the equilibrium level of utility. This expenditure function is increasing in the local prices p_j and the time of commute f_{jk} and decreasing in local wages w_k and local amenities Q_j, i.e. assuming that eq.(1) is differentiable, $\frac{\partial E}{\partial p} \geq 0$, $\frac{\partial E}{\partial f} \geq 0$, $\frac{\partial E}{\partial w} \leq 0$ and $\frac{\partial E}{\partial Q} \leq 0$. Moreover, in equilibrium households chose combinations (j, k) providing the same level of utility $\overline{u}$, so all households are equally satisfied. For households with homogeneous preferences, free mobility and perfect information, the expenditure incurred at equilibrium utility $\bar{u}$ must be the same for all locations j. Formally this can be written:

$$E(p_j, w_k, f_{jk}; Q_j, \overline{u}) = 0 \tag{2}$$

In order to learn about differences in local prices and local wages, we implicitly differentiate eq.(2) with respect to j and k (by varying the municipality of residence or municipality of work):

$$\frac{\partial E}{\partial p} dp_j + \frac{\partial E}{\partial f} df_j + \frac{\partial E}{\partial Q} dQ_j = 0 \tag{3}$$

$$\frac{\partial E}{\partial w} dw_k + \frac{\partial E}{\partial f} df_k = 0. \tag{4}$$

Eq.(3) represents the housing price gradient and shows that households are compensated for higher housing prices by lower commutes or higher level of amenities. Eq.(4), the wage gradient, shows that wages increase with commutes, or in other words, that (representative) workers are compensated for longer commutes with higher wages.[9]

Finally, we combine eq.(3) and eq.(4) and derive a household's willingness to pay (wtp) for change in their QOL (dQ_j):

$$-\frac{\partial E}{\partial Q}dQ_j = \frac{\partial E}{\partial p}dp_j + \frac{\partial E}{\partial f}df_{jk} + \frac{\partial E}{\partial w}dw_k \tag{5}$$

where $df_{jk} = df_k + df_j$ is the total difference in commuting time. Applying the envelope theorem and evaluating the derivatives at the national average we can rewrite eq.(5) to:

$$-\frac{\partial E}{\partial Q}dQ_j = \bar{y}\bar{p}_j + [c + (1-\tau')\bar{w} - \alpha]df_{jk} - (1-\tau')\bar{h}dw_k, \tag{6}$$

where $\alpha = (\partial U/\partial f)/(\partial U/\partial x)$ is the the "leisure-value" of commuting. Note here that $\frac{\partial E}{\partial Q}dQ_j$ is the marginal willingness-to-pay for QOL (Q_j). Moreover, this expression relates urban benefits (amenities and employment opportunities) $\frac{\partial E}{\partial Q}dQ_j + (1-\tau')\bar{h}dw_k$ and urban costs $\bar{y}\bar{p}_j + [c + (1-\tau')\bar{w} - \alpha]df_{jk}$. For example, households pay higher urban costs to get access to higher level of urban amenities and better employment opportunities, or receive higher wages as compensation for high housing price. It also allows quantification of unobserved QOL (Q_j) as a weighted sum of local costs of living p_j, local wages w_k and commuting costs f_{jk}.

2.2 Model operationalization

In order to operationalize the model and construct the QOL index, we first express differentials in terms of log-differentials ($\hat{z} = (z - \bar{z})/\bar{z}$, $z = p, w, f$) and divide

[9]This is a standard result in monopsony models, see e.g. Manning (2003a,b). There is also evidence that in Denmark, the country of our study, employees who face longer commutes receive a small wage increase (Mulalic et al., 2014). This effect might be heterogeneous. For example, Le Barbanchon et al. (2021) show using French administrative data that women have a lower reservation wage and a shorter maximum acceptable commute than their male counterparts. We discuss household heterogeneity in Section 4.3.

eq.(6) with the national average of income $\bar{m}$:

$$-\frac{\partial E}{\partial Q}\frac{dQ_j}{\bar{m}} = s_y\hat{p}_j + \left[s_c + s_w\frac{\bar{f}}{\bar{h}}\right]\hat{f}_{jk} - s_w\hat{w}_k, \tag{7}$$

where $s_y = \bar{y}\bar{p}/\bar{m}$ is the income share for housing, $s_c = c\bar{f}/\bar{m}$ is share of income spent on commuting, and $s_w = (1-\tau')\bar{h}\bar{w}/\bar{m}$ is income share from labour. This model ignores household heterogeneity, so the shares apply only to a representative household. We furthermore assume that the marginal commuting time is valued as work time such that $\alpha = 0$. Finally we multiply with the share of residents in municipality j working in municipality k ($\pi(k|j)$) and sum over workplaces in order to get:

$$\hat{Q}_j = s_y\hat{p}_j + \left[s_c + s_w\frac{\bar{f}}{\bar{h}}\right]\hat{f}_j - s_w\hat{w}_j, \tag{8}$$

where $\hat{f}_j = \sum_k \hat{f}_{jk}\pi(k|j)$ and $\hat{Q}_j = -\frac{\partial E}{\partial Q}\frac{dQ_j}{\bar{m}}$. The left hand side is the marginal willingness-to-pay for local amenities as a fraction of household income.

The shares s_y, s_w and s_c are based on the official statistics from Statistics Denmark.[10] The labour share of income (household disposable income as a fraction of total expenditures) is 83%. This implies that about one fifth of income comes from other sources than labour. The expenditure on housing as a share of total income is 32% and the share of income spent on commuting is 14.0%. Moreover, the ratio of time spent commuting (one hour in average) to time spent working (about 8 hours a day) is approximately 12.4% of a working day.

We find that local wages and rents vary considerably between municipalities, and are substantially higher in the urban areas that are dense. We find also that worker heterogeneity is important when estimating wage differentials, i.e. correction for worker heterogeneity reduces the percentage wage gap between areas with the lowest and the highest wages by about 50%. The estimated QOL index

[10]See `https://www.statbank.dk`. As income $\bar{m}$ we use the total consumption as defined in Table `FU09`, which for the year 2010 is approximately Euro 41.000 (DKK 305.000). We also calculate the disposable income $(1-\tau)\bar{h}w$ as a share of consumption. To calculate s_y and s_c we use Table `FU02`. The average number of work hours is set at $\bar{h} = 7.4$ which is the official number of work hours for a full time employee. Based on the assumption that each worker travels to and from work every work day the average number of hours spent on transport is $\bar{f} = 0.91$ calculated as $\bar{f} = \sum_{jk}\pi_{jk}(f_{jk} + f_{kj})$.

ranks the Greater Copenhagen Area and other large cities in Denmark highest. This is plausible because these high density urban areas are considered as highly attractive. The QOL indices are also positively associated with the local urban amenities related to transportation demonstrating, in particular, the importance of public transport for the quality of life.

3 Data

The data we use to estimate local housing prices and local wages are derived from administrative registers for all Danish households for the year 2010. We observe about 2 M households, distributed over 98 municipalities, in which they choose to live and to work. The average area of a municipality is 432.59 km^2 and the average population density is 130 people per km^2. The geographical size of municipalities decreases with population density. The municipalities are therefore smaller in the Greater Copenhagen Area (GCA).[11] We discuss the data and the estimation of local housing prices and local wages in the following two subsections. In the last subsection we show how we estimate commuting costs by combining Danish register data on commuting flows with the data on travel times, mode choice and trip frequencies from the Danish National Transportation model.

3.1 Housing prices

The housing price index $\hat{p}_j$ is constructed using a dataset of all the real estate transactions for the year 2010. The data set includes transaction prices and the structural attributes of housing from the Building and Dwelling Register (BBR), such as age of building, size (sqm) and number of rooms. We restrict our sample to so-called "arm's length sales" where the buyer is a private individual. The final sample includes 13,087 realized real estate transactions. Table 1 shows the descriptive statistics. The mean realised price is DKK 1.8 M.[12] The average house is 57 years old (was constructed in 1953), has four rooms and is 123 sqm. About one third of the traded units were single-family houses. More importantly, there

[11]The GCA is part of the Danish island Zealand. Copenhagen (the capital city of Denmark) is its centre. It is the political, administrative and educational core region of Denmark.

[12]DKK 1 $\approx$ Euro 0.13.

is a high degree of variation in almost every quality attribute. This is very useful for the identification of the housing price indices.

Table 1: Descriptive statistics for the real estate transactions for year 2010

	mean	std. dev.	min	max
Price (1000 DKK)	1,822.01	1,014.23	190.0	5,900.00
Space (sqm)	123.55	43.31	10.00	680.00
Age	56.95	37.05	0.00	409.00
Number of rooms	4.26	1.44	1.00	16.00
Number of toilets	1.52	0.58	1.00	6.00
Single-family house (share)	0.23	0.42	0.00	1.00

Notes: Number of observations is 13,087. 1 DKK $\approx$ 0.13 EUR.

Standardised house price has been compiled from a hedonic model with municipality fixed effect. The log of the sales price is regressed on housing characteristics $\mathbf{X}_m$ and a municipality indicator $\mu_{j(m)}$ with $j(m)$ being the municipality where the house m is located. The regression equation is given as

$$\log(p_m) = \mathbf{X}_m^\top \beta + \mu_{j(m)} + \epsilon_m,$$

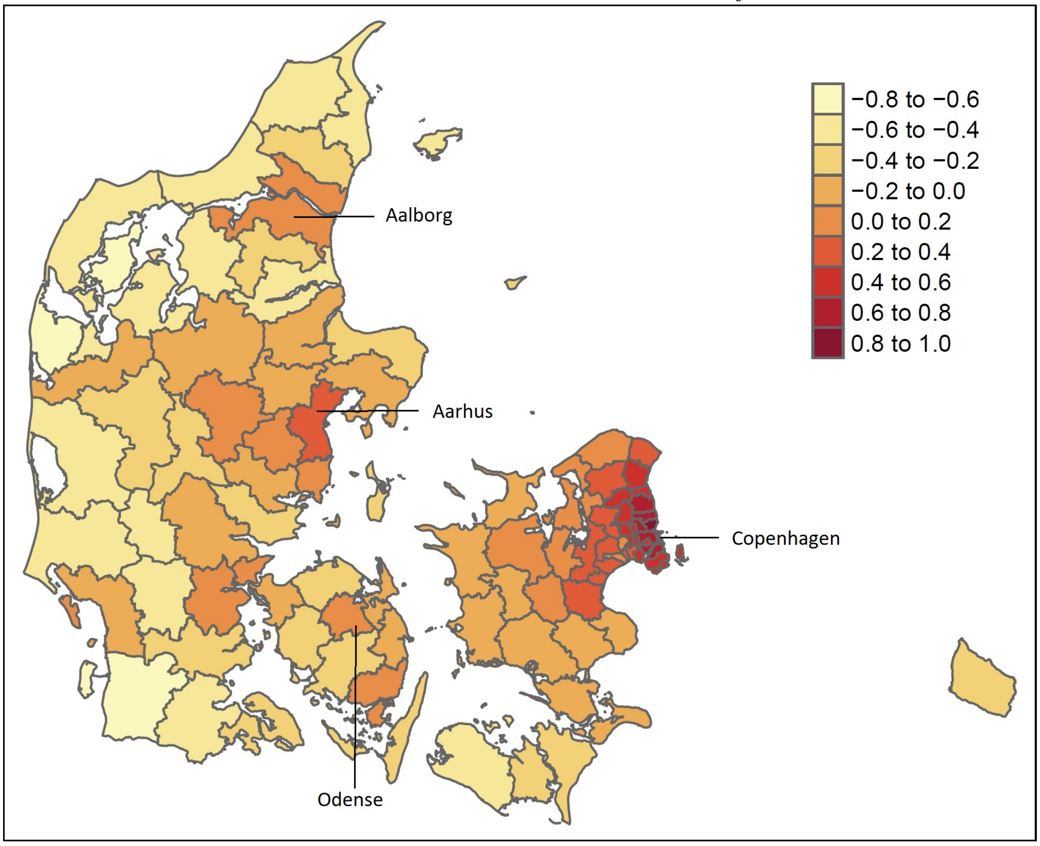
and the estimates $\hat{\mu}_j$ are used as the housing price index. Figure 1 shows the resulting housing price index across municipalities and Table A1 in the Appendix A reports the estimated coefficients.

Not surprisingly we find that the housing prices are higher in the GCA and in the north of this area that is considered as highly attractive, and in other larger cities in Denmark, e.g. in Aarhus (the second largest city in Denmark). Low price houses are spread throughout most of western and southern Denmark.

3.2 Local wages

We use a micro data set for the full population of workers to construct the wage index $\hat{w}_k$. The dataset is derived from the annual register data from Statistics Denmark for the year 2010 and includes information on workers' residence and workplace (both at the municipal level), hourly wages, and a range of explanatory variables for each worker: educational level, age, gender, full-time versus part-time, and the sector of employment. We select workers who had been employed

Figure 1: Housing price index $\hat{p}_j$



for at least one year. Our sample then includes 1,209,928 observations (workers). Table 2 reports the descriptive statistics for workers.

We regress the log of wages on the work place indicators μ_k (workers' workplace municipality) as well as controls for the observed worker attributes $\mathbf{X}_i$:

$$\log(w_i) = \mathbf{X}_i^\top \beta + \mu_{k(i)} + \epsilon_i \tag{9}$$

where $k(i)$ is the workplace municipality of individual i. More importantly, we first estimate $\hat{\mu}_k$ for the place of work, and then we use the estimated $\hat{\mu}_k$ to calculate the wage differentials $\hat{w}_j = \sum_k \hat{\mu}_k \pi(k|j)$ for workers with residence in municipality j, where $\pi(k|j)$ is the share of residents in municipality j working in municipality k. In other words, we average $\hat{\mu}_k$ according to the proportion of workers $\hat{\pi}_{jk}$ living in municipality j and working in municipality k. Note here that many workers work in a different municipality from their residence municipality.

Table 2: Descriptive statistics for workers

	mean	std.dev.	min	max
Hourly wage (DKK/hour)	215.99	91.35	85.58	1345.27
Age	43.57	10.58	16.00	93.00
Male (share)	0.55	0.50	0.00	1.00
Primary education (share)	0.15	0.35	0.00	1.00
Upper secondary education (share)	0.04	0.19	0.00	1.00
Vocational education and training (share)	0.40	0.49	0.00	1.00
Qualifying educational programmes (share)	0.02	0.15	0.00	1.00
Short cycle higher education (share)	0.06	0.24	0.00	1.00
Vocational bachelors educations (share)	0.20	0.40	0.00	1.00
Bachelors programmes (share)	0.01	0.12	0.00	1.00
Masters programmes (share)	0.11	0.31	0.00	1.00
PhD programmes (share)	0.01	0.09	0.00	1.00

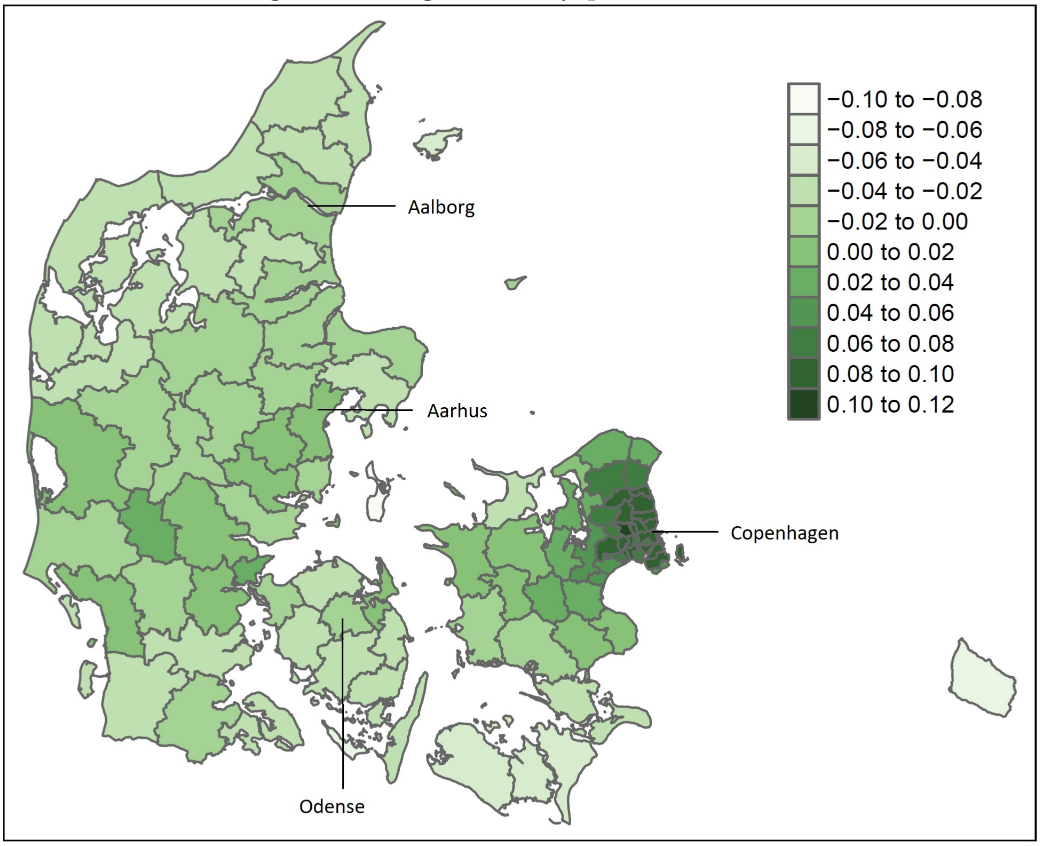
Notes: Number of observations is 1,209,928. 1 DKK ≈ 0.13 EUR.

We find that the wage differentials $\hat{w}_j$ are substantially higher in the GCA and other large cities in Denmark (Aarhus, Odense and Aalborg) as illustrated in Figure 2. Moreover, we find that the heterogeneity of workers is important when estimating wage differentials $\hat{w}_j$. For example, before correction for worker heterogeneity, the percentage wage gap between the municipality with the lowest and the municipality with the highest wages is about 50%. This gap reduces significantly when correcting for the observed heterogeneity. Table A2 in Appendix A reports the estimation results of the Mincerian wage regression. Moreover, local wages and housing prices are positively correlated. This suggests that households in Denmark are at least partly compensated for the higher housing costs by higher urban wages.

3.3 Commuting costs

The commuting time index $\hat{f}_{jk}$ is based on a data for the year 2010 on average weekday travel times, mode choice and trip frequencies between 907 traffic zones from the Danish National Transportation model designed for detailed traffic modelling (Rich and Hansen, 2015). The traffic zones are constructed as areas with homogeneous land use that never cross the administrative borders and are similar with respect to the number of addresses (down to 3,000 addresses), population and work places, proximity to train stations and connection to the road network (Rich

Figure 2: Wage index by place of work $\hat{w}_k$



et al., 2010). Specific traffic terminals (e.g. airports and harbours) are defined as individual zones. The travel times estimated by the Danish National Transportation model are based on the complete road network structure, including all minor roads, one-way restrictions, congestion delays and transition times for public transport. We use the average weekday travel times for commuters between the traffic zones for commuters. We consider two modes: public transport and car. The computations of the travel times within the traffic zones also include trips not crossing the zone borders, so the diagonal elements of the travel time O-D matrix are different from zeros (positive).

We combine the data on travel times with the register data on commuting flows between municipalities to compute the commuting time index. To see how, let the set M be the set of municipalities covering Denmark. The workers choose combination of a municipality of residence (j) and a municipality where they work

(k), where $(j,k) \in M \times M$. From the Danish National Transport Model we have data on the travel times $f(z_g, z_h, v)$ and the number of trips $n(z_g, z_h, v)$ from residence zone z_g to workplace zone z_h using the transport mode v, which can be either public transport or car. To aggregate the travel time data from the level of transport zones to the level of municipalities, we first estimate the expected travel time using the number of trips as weights. Specifically, we define the travel time from municipality j to municipality k as:

$$f_{jk} = \widehat{\mathbb{E}}[f(z_g, z_j, v) | z_g \in j, z_h \in k] =$$
$$\sum_{z_g \in j} \sum_{z_h \in k} \sum_{v} f(z_g, z_h, v) \frac{n(z_g, z_h, v)}{\sum_{z_g \in j} \sum_{z_g \in k} \sum_{l} n(z_g, z_h, v)},$$

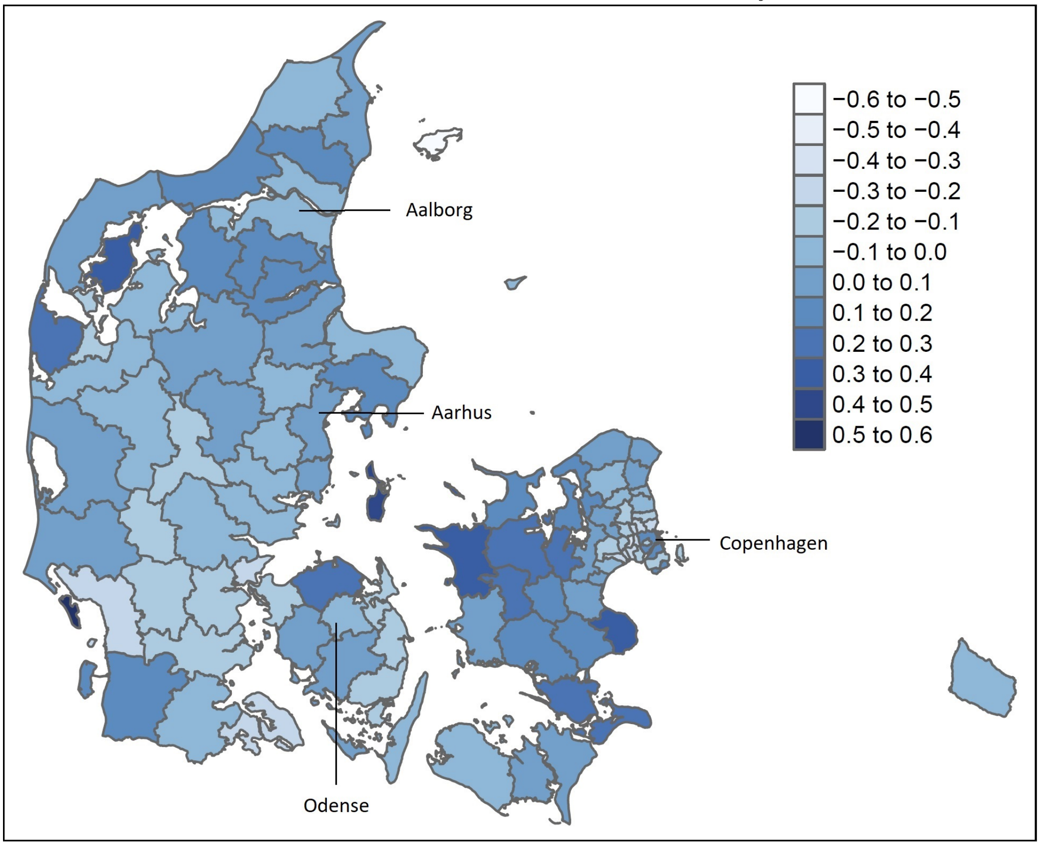
and then compute the commuting-time differentials $\hat{f}_j = (f_j - \bar{f})/\bar{f}$ for a specific municipality as:

$$f_j = \sum_{k \in M} \pi_{jk}(f_{jk} + f_{kj}), \qquad \bar{f} = \sum_{jk} \pi_{jk}(f_{jk} + f_{kj}) \tag{10}$$

where the commuting times differentials are averaged in proportion π_{jk} to the number of workers living in municipality j and working in municipality k. We assume that each worker travels to and from work every working day.

Figure 3 shows the results. The commuting time index is lower for the municipalities further away from the big cities located on Jutland, densely populated remoted municipalities and the suburban municipalities surrounding large cities. This is in particularly true for the capital region of Denmark. In the GCA, commuting times are significantly higher in the core municipality (København) and lower in the suburban municipalities surrounding the core of the region. Similar patterns were also observed for other large European cities. Brueckner et al. (1999) show that the location choice of different income groups depends on the spatial pattern of amenities in a city. This has an impact on the commuting patterns because workers trade-off housing prices, access to amenities and commuting costs (Alonso, 1964; Muth, 1969; Fujita, 1989). The commuting patterns might be different, for example, as in some US cities (Brueckner et al., 1999).

Figure 3: Commuting time index $\hat{f}_j$



4 Empirical Results

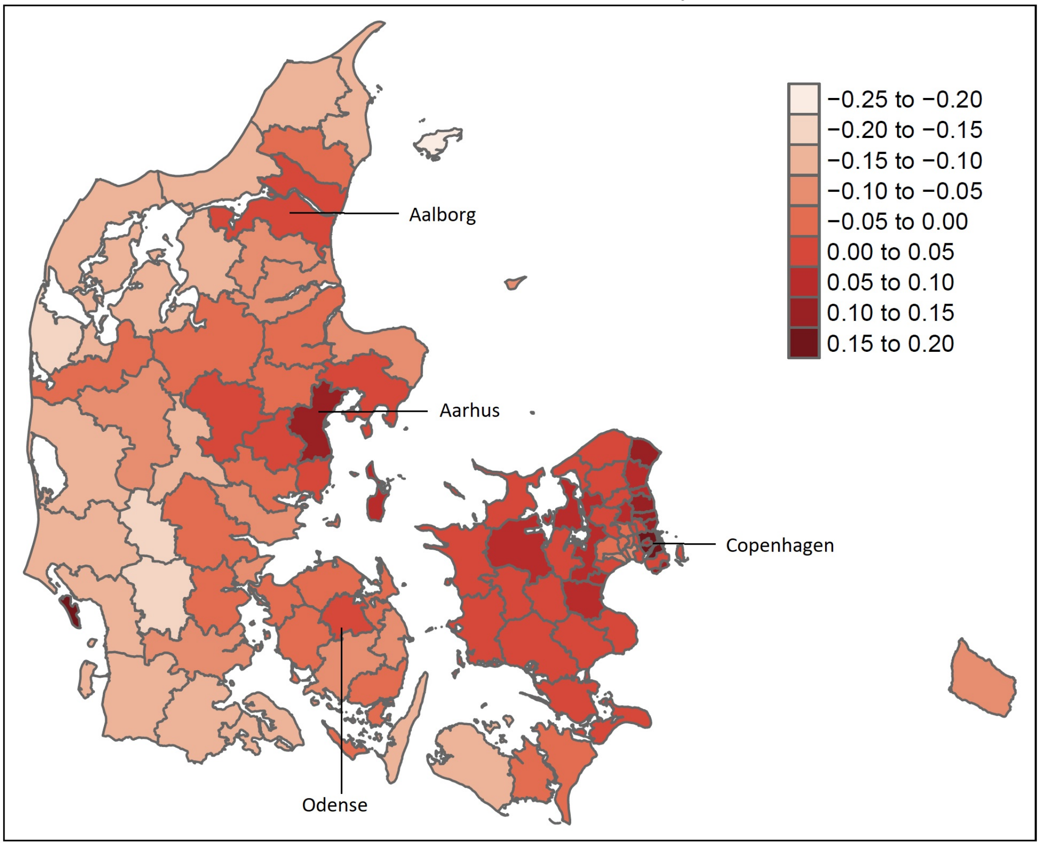
In this section, we turn to the empirical results. In the first subsection, we present information on the QOL index ($\hat{Q}_j$). The following subsection explores the role of transportation for the QOL in Denmark. In subsection 4.3, we discuss three important limitations that arise in estimation.

4.1 Quality of life index

We combine information on the estimated housing prices ($\hat{p}_j$), local wages ($\hat{w}_j$), and commuting differentials ($\hat{f}_j$) to estimate the average local willingness-to-pay for amenities (quality of life (QOL) index) from eq.(8). Our estimation results suggest as expected that the marginal willingness-to-pay for local amenities ($\hat{Q}_j$) is higher in the GCA and other larger cities in Denmark (Aarhus, Odense and

Aalborg), see Figure 4.

Figure 4: QOL index ($\hat{Q}_j$)



Notes: This QOL index represents the marginal willingness-to-pay for local amenities $\hat{Q}_j$.

Table 3 reports the top five and the bottom five municipalities based on the QOL.[13] The highest QOL index in Denmark is in the Municipality of Copenhagen, that is the core of the GCA and well-known for its high-quality restaurants, large number of museums and other cultural amenities, high quality public transport, shopping opportunities, and "the best place to work". This municipality is also characterised with high housing costs and high wages. This is also the case for the third (Dragør), the fourth (Rudersdal) and the fifth municipality (Lyngby-Taarbæk) on the ranking list, all located in the GCA. We find that there is

[13]Table A3 in Appendix A reports ranking of all municipalities in Denmark based on the QOL.

a strong positive correlation between $\hat{w}_j$ and $\hat{p}_j$ (correlation coefficient is 0.76). Moreover, commuting costs are higher for the central municipalities (København and Dragør) and significantly lower for the suburban municipalities surrounding the core of the GCA. One notable exception is the second ranked municipality. Fanø is a smaller (56 sqkm) island in the south-west Denmark (in the North Sea) with a population of about 3,000. It is connected to the main land with a ferry service.[14] Because of this, municipality wages are low and commuting costs are high, but the households are compensated with relatively low housing costs and high level of amenities, beautiful nature and clean air.[15] The lowest quality of life is found in municipalities further away from the big cities located on Jutland (Hjørring, Lemvig, Vejen and Billund) and the island of Læsø. These low populated municipalities are characterized with a small local workforce that both limits the number and the size of firms resulting in low job density, population outflows and a deteriorating quality of life, both in terms of income and urban amenities, e.g. access to services incl. high quality public transport. In these municipalities both wages and housing costs are low. Moreover, the commuting costs are low, most likely because many workers who reside in these localities work there. The exception is sparsely populated Lemvig located in the northern West Jutland with population density of only about 38 per km^2, for which commuting costs are relatively higher.[16]

We also find that population has grown faster in high-amenity areas, see Figure 5. It suggests that households in Denmark are attracted to high amenity areas, i.e. cities. This was observed for the United States of America by Glaeser et al. (2001) who show empirically that high amenity cities have grown faster than low amenity cities. Moreover, they find that urban rents have raised faster than urban wages in the US, suggesting that the demand for living in cities has risen because of increasing demand for urban amenities. Although we do not estimate changes in urban rents and urban wages, it is well-known that urban rents have raised faster than urban wages in Denmark and that the evolving urbanisation process is likely caused, not only by the rising incomes, but also by an increase in the demand for

[14]The ferry ride takes 12 minutes.

[15]The whole island's western shore is a long beach. About 30,000 tourists visit this island each summer.

[16]For comparison the population density for Copenhagen (København) is about 638 per km^2.

Table 3: Top- and bottom-five municipalities in Denmark based on the QOL

Rank	Municipality	$\hat{Q}_j$	$\hat{w}_j$	$\hat{p}_j$	$\hat{f}_j$
		Top five			
1	København	0.16	0.08	0.64	0.11
2	Fanø	0.16	-0.03	0.01	0.54
3	Dragør	0.15	0.06	0.49	0.16
4	Rudersdal	0.14	0.10	0.75	-0.07
5	Lyngby-Taarbæk	0.13	0.09	0.74	-0.12
		Bottom five			
94	Hjørring	-0.14	-0.03	-0.50	-0.05
95	Lemvig	-0.16	-0.02	-0.78	0.29
96	Vejen	-0.16	-0.02	-0.48	-0.11
97	Billund	-0.19	0.03	-0.42	-0.14
98	Læsø	-0.23	-0.06	-0.46	-0.53

urban amenities (Gutiérrez-i Puigarnau et al., 2016).[17]

4.2 Transportation and the QOL in Denmark

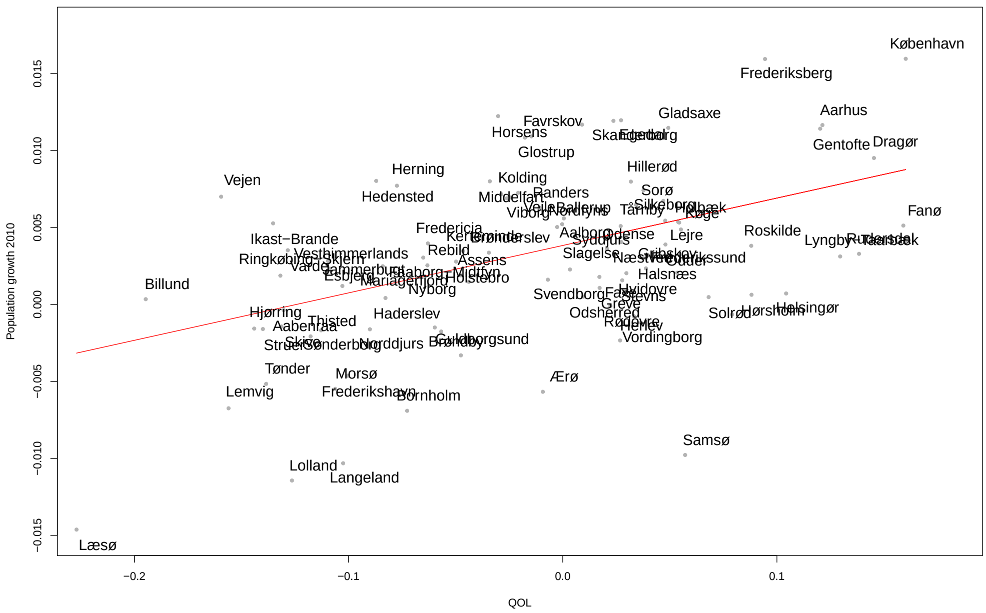
The QOL index captures the net value of all amenities within a municipality per definition. Some of these amenities are positively evaluated by at least some household types, such as parks, monuments and public transport, and some are not appreciated, such as pollution and congestion. Additionally, amenities that are not observable by researchers, such as nice neighbourhood parks, also exist.

Many amenities are related to transport. We use a multivariate regression of the estimated QOL index ($\hat{Q}_j$) on a vector of observed municipality-level amenities to explore the relationship between QOL and transport related amenities. The considered amenity variables are summarised in Table A4 in Appendix A.

In particular, we are interested in the impact of transport on the QOL. We use two variables – *number of departures with public transport per sq km* and *distance to the nearest highway ramp* – as proxies for different forms of transport infrastructure. The share of workers commuting to or from an municipality are also related to transportation. Moreover, we use four additional amenity variables to proxy

[17]Note here that rearranging eq.(8) gives $\hat{p}_j = \frac{s_w}{s_y}\hat{w}_j - \frac{\left(s_w(\bar{f}/\bar{h})+s_c\right)}{s_y}\hat{f}_j + \hat{Q}_j = A_j + \hat{Q}_j$, where A_j denotes the compensation for housing costs in terms of wages corrected for commuting costs. Figure A1 in Appendix A shows the relationship between housing price index and local wages corrected for commuting costs.

Figure 5: Population growth and QOL in Denmark



Notes: linear regression: $\Delta pop = 0.004 + 0.031QOL$, $R^2 = 0.13$.

for other relevant QOL aspects. The considered amenity variables are endogenous at different levels to the local population and are likely related to households residential sorting. Therefore, the derived and discussed monetary values of these amenities are only illustrative and should be considered with caution.[18]

Table 4 shows the estimation results. The important element of the QOL index in Denmark is the demographic composition of neighbourhoods. The regression shows significant and large coefficients of (1) *share of population with higher education*, and (2) *share of pupils in private schools.* It is often argued in the urban economics literature that the attractiveness of living in a particular area is partly determined by the demographic composition of that neighbourhood. The importance of this factor for location choice within the San Francisco Bay area was documented by Bayer and Timmins (2007) and for the GCA by Mulalic and Rouwendal (2020). The strongly significant coefficient related to private schools

[18]Notice here that the regression residuals result mostly from unobserved amenities and measurement error, but likely also from mis-specification. Consequently, the estimated regression models are not fulfilling requirements for an orthogonal error term.

Table 4: Urban amenities and the QLI

	Dependent variable: $\hat{Q}$		
	(1)	(2)	(3)
No. of publ. transp. departures per sq km	0.049***		0.164**
	(0.016)		(0.082)
Log distance to the nearest highway ramp	-0.016***		-0.003
	(0.006)		(0.004)
Service level (municipality service expenses)		0.293*	0.264*
		(0.150)	(0.149)
Share of population with higher education		0.006***	0.006***
		(0.001)	(0.001)
Share of pupils in private schools		0.002***	0.002***
		(0.001)	(0.001)
Population density		-0.002	-0.062**
		(0.005)	(0.031)
Share of workers commuting from munic.		0.003***	0.003***
		(0.001)	(0.001)
Share of workers commuting to munic.		-0.002***	-0.002***
		(0.001)	(0.001)
Constant	-0.001	-0.530***	-0.493***
	(0.013)	(0.146)	(0.146)
R^2	0.189	0.671	0.686
Adjusted R^2	0.172	0.649	0.658
Number of obs.	98	98	98

Notes: High education includes bachelor, long-cycle higher education and PhD-degree; *p<0.1; **p<0.05; ***p<0.01; standard errors are in parentheses.

comes as a surprise. All households in Denmark have universal access to primary schools and only a minor share of pupils attend private schools.[19] However, this positive correlation is likely related to school quality. Private schools allow for more time to be spent by teachers on each student, which results in better schooling. Moreover, the supply of private schools in cities is also related to parents who have had higher education, who are conscious of their children receiving high-quality

[19]Every child in Denmark is guaranteed a place in the tuition-free public schools in proximity to its residence. About 80% of all pupils in primary and lower secondary schools attended the tuition-free public schools, 15% attended the private schools, and only 5% attended the other (special) schools. Some parents also choose private schools because they have a particular educational approach, e.g. for religious reasons.

schooling, and with the provision of public goods. This is also confirmed by the positive significant correlation between the service level (the municipality service expenses) and the QOL index, despite the fact that local taxes are controlled for. The service level is usually higher in cities, where the concentration of economic activity is higher.

More importantly for this study, the second set of amenities that we show in the regressions illustrates the role of transport infrastructure. The main transport amenities explain about 17% of the variation in $\hat{Q}_j$ (see Model (1)) and all amenities together about 66% (see Model (3)). We find a negative relationship between *distance to the nearest highway ramp* and $\hat{Q}_j$. Our empirical results suggest that 1% reduction in the distance to the nearest highway ramp is related to 0.2% increase in the marginal willingness-to-pay for local quality of life $\hat{Q}_j$. This corresponds to about EUR 1,000 per kilometre. However, this relationship diminishes significantly when we include the full set of amenities. *The number of departures with public transport per sqkm* is also strongly associated with $\hat{Q}_j$. Additional 100 departures per sqkm per day, or 10 departures per hectare per day, are associated with about EUR 2. This strongly suggests that the provision and quality of public transport is an important urban amenity. Car ownership and use are relatively expensive in Denmark, car ownership is low (0.81 cars per household), and the share of multiple car households is low (8.2% of households), even though the share of households with two workers is high.[20] Many workers therefore have to use public transport and presumably, accessibility to this facility is important. Moreover, we find a significant negative relationship between population density and QOL. One interpretation of this fact is that, conditional on other amenities, population density variable is a proxy for disamenities such as congestion, noise and pollution. Finally, our empirical results also suggest that the specialised employment areas with many jobs are associated with the lower QOL, i.e. the coefficient associated with *the share of workers commuting to municipality* is negative. However, municipalities with a larger share of workers commuting from municipality are more attractive as areas in which to live. This suggests that, conditional on other con-

[20]In Denmark, the purchase-tax of a car is 105% for the value of the car below about EUR 10.500 and 180% of the value of the car above. In addition there is an annual ownership tax depending on the characteristics of the car. Mulalic and Rouwendal (2015) show that the mean annual total expenditure associated with ownership and use of a new car in Denmark is about EUR 11,000.

sidered amenities and commuting costs, households in Denmark prefer to separate workplace locations from residence locations in order to enjoy urban amenities in their neighbourhoods and benefit from production benefits from concentration (agglomeration) in the municipalities in which they work. The presence of these facts also suggests that better transportation facilities, which reduce the commuting burden, result in more specialisation, which has been identified for London as well (Heblich et al., 2020). So, on the one hand, production benefits from agglomeration (higher productivity and thus incomes) at the workplace location, and on the other hand, demand for urban amenities at the residence location (better consumption possibilities) induces workers to accept commutes, provided that better transportation facilities ease commuting. In summary, the empirical analyses have shown that the transport infrastructure, and in particular public transport, are important for the QOL in Denmark.

4.3 Household heterogeneity, transportation and the quality of life index

We estimate the quality of life index defined in equation (8) using local wage levels, housing costs and commuting costs for the 98 municipalities covering Denmark. We then use the estimated QOL indices to analyse the importance of transport for the quality of life. We discuss three important limitations that arise in estimation.

First, our estimation is based on the assumption that households are homogeneous, perfectly mobile and fully informed. These assumptions imply a spatial equilibrium in which utility levels are equalized across municipalities, which we can compute and analyse using observed housing prices, wages, commuting costs and amenities. However, they also imply that the estimated QOL and the following analyses are strictly speaking only valid for the representative household, viz. a 44 years old male worker with vocational education (see Table 2). The residential sorting models allow for household heterogeneity and relate household sorting to local urban amenities (Kuminoff et al., 2013). Rouwendal (1990) discusses the equilibrium properties of the residential sorting models and show that with "social interaction effects" the equilibrium of a residential sorting model of the kind discussed here is not unique. For example, if the presence of one group of households – the higher educated or singles – makes an area (in our case municipality) more attractive, multiple equilibria may occur (Bayer and Timmins, 2005). Moreover, the structural models are data demanding and computationally-intensive, while providing the value that heterogeneous agents place on considered urban amenities (usually selected by researcher) and do not offer a clear measure of the QOL as in the model used in this study.

However, we investigate the household heterogeneity and estimate models for three different types of households (workers) based on the highest education level obtained: low education, medium education and high education.[21] We do not observe the real estate transactions separately for these three types of households nor the income share for housing (s_y), share of income spent on commuting (s_w) and income share from labour (s_c), so the housing expenditures and the shares s_y, s_w and s_c are homogeneous across households. We estimate local wages by place of work for these three groups separately and then add commuting costs to housing expenditures. Appendix B shows the results. We find similar, but not identical, municipality rankings based on the QOL index for all three types of households. This moderate difference in QOL for considered types of households is likely due to the homogenous housing expenditures and the homogenous shares s_y, s_w and s_c.

Second, urban economic theory predicts that workers with higher incomes have different commuting patterns than those with lower incomes. When the workers' commuting costs include time costs that positively depend on income, the relation between income and commute depends on the difference between the income elasticity of residential space and the income elasticity of commuting time costs (Fujita, 1989). Wheaton (1977) shows that the effect of household income on commuting costs is close to zero. It is therefore likely that the observed spatial variation in wages is related more to other factors like urban amenities than commuting, and that the household heterogeneity of the commuting costs has limited impact on our estimates of the QOL.

Finally, we use a limited number of amenity variables to represent different aspects of the QOL. Multiple amenities of interest could exist, which are not observable by researchers or not available for this analysis, such as neighbourhood

[21]Low education includes: basic school, general upper secondary school, vocational upper secondary school and vocational education; medium education includes: short-cycle higher education and medium-cycle higher education, and high education includes: bachelor, long-cycle higher education and PhD-degree.

atmosphere, noise levels, walkability indicators and water quality. Moreover, all households in Denmark have a universal access to childcare institutions, a bus stop within walking distance from their homes and well developed bike infrastructure network. Consequently, there is no variation in these variables, so they are not useful in the model estimation. Therefore, we used only two variables as proxies for different forms of transport infrastructure. This is an important simplification of transport service quality and other relevant amenities such as ticket price, service frequency, cleanliness, comfort and punctuality, could be taken into account in future research.[22]

5 Conclusion

This paper estimates the Quality of Life (QOL) index that measures the value a representative household places on the local amenities. The estimated QOL index produces a plausible ranking of the 98 municipalities covering Denmark. It is high for the capital and other larger cities, while it is low in rural municipalities. We also find a strong positive relationship between the QOL index and the population growth, suggesting that the urbanisation process is likely related to the increasing demand for urban amenities.

The importance of transportation for the quality of life is confirmed by our empirical results. We find that proximity to the nearest highway ramp and the provision and quality of public transport are positively related to the QOL indices. Policymakers, transport authorities and urban planers may be interested in this result. For example, over the past years, policymakers and urban planners have expressed concerns regarding the urbanization. However, households tend to move to areas which best satisfy their preference for urban amenities (e.g. public goods and nature), or in other words, to the areas that offer higher QOL. Our empirical findings suggest that place-based policies which focus on improving the provision and the quality of public transport might have important implications on the attractiveness of the residential and work locations, and finally for the QOL.

One of the main objectives of the regional policy in many countries is to give the local authorities (e.g. municipalities) the same financial footing through the

[22]See Guirao et al. (2016) for an exhaustive discussion of service quality attributes in public transportation.

equalisation schemes. For example, the purpose of the equalisation scheme in Denmark is to even out the differences in the economic situation in the municipalities due to differences in the tax base and the demographic composition. This equalisation scheme is based on the so-called net equalisation method, i.e. municipality's estimated structural surplus or deficit per inhabitant. For the individual municipalities, the net payments or the net receipts can be substantial. However, the calculation of the structural surplus per inhabitant ignores the differences in the housing costs and the value of amenities. Our findings can be useful for improving the equalisation schemes.

However, the analysis has some obvious limitations as well. For instance, our findings were derived for Denmark, which has relatively low share of car-owners. It is therefore not obvious that the results can be transposed to other countries. Second, given our focus on representative household, the results of this paper have to be complemented with those of other studies that focus on household heterogeneity. Future work may extend the results of the present paper in several directions. For instance, our empirical analysis largely ignored some potentially important urban amenities. To do so, more attention should be paid to aspects that had to be treated in a relatively crude way here, like the household heterogeneity and those associated with public transport service quality.

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References

Agnello, L. and Schuknecht, L. (2011). Booms and busts in housing markets: Determinants and implications. *Journal of Housing Economics*, 20(3):171–190.

Ahlfeldt, G. M., Redding, S. J., Sturm, D. M., and Wolf, N. (2015). The economics of density: Evidence from the berlin wall. *Econometrica*, 83(6):2127–2189.

Albouy, D. (2008). Are big cities bad places to live? estimating quality of life across metropolitan areas. Working Paper 14472, National Bureau of Economic Research.

Albouy, D. and Lue, B. (2015). Driving to opportunity: Local rents, wages, commuting, and sub-metropolitan quality of life. *Journal of Urban Economics*, 89:74–92.

Alonso, W. (1964). *Location and Land Use. Toward a General Theory of Land Rent*. Harward University Press.

Autor, D. H., Palmer, C. J., and Pathak, P. A. (2014). Housing market spillovers: Evidence from the end of rent control in cambridge, massachusetts. *Journal of Political Economy*, 122(3):661–717.

Baum-Snow, N. (2007). Did Highways Cause Suburbanization?*. *The Quarterly Journal of Economics*, 122(2):775–805.

Bayer, P., Ferreira, F., and McMillan, R. (2007). A Unified Framework for Measuring Preferences for Schools and Neighborhoods. *Journal of Political Economy*, 115(4):588–638.

Bayer, P. and Timmins, C. (2005). On the equilibrium properties of locational sorting models. *Journal of Urban Economics*, 57(3):462–477.

Bayer, P. and Timmins, C. (2007). Estimating equilibrium models of sorting across locations. *Economic Journal*, 117(518):353–374.

Beeson, P. E. and Eberts, R. W. (1989). Identifying productivity and amenity effects in interurban wage differentials. *The Review of Economics and Statistics*, 71(3):443–452.

Berri, A., Lyk-Jensen, S. V., Mulalic, I., and Zachariadis, T. (2014). Household transport consumption inequalities and redistributive effects oftaxes: A repeated cross-sectional evaluation for france, denmark and cyprus. *Transport Policy*, 36:206–216.

Berry, S. (1994). Estimating discrete-choice models of product differentiation. *RAND Journal of Economics*, 25(2):242–262.

Berry, S., Levinsohn, J., and Pakes, A. (1995). Automobile prices in market equilibrium. *Econometrica*, 63(4):841–890.

Brueckner, J., Thisse, J., and Zenou, Y. (1999). Why is central paris rich and downtown detroit poor?: An amenity-based theory. *European Economic Review*, 43(1):91–107.

Burnell, J. D. and Galster, G. (1992). Quality-of-life measurements and urban size: An empirical note. *Urban Studies*, 29(5):727–735.

Chay, K. and Greenstone, M. (2005). Does air quality matter? evidence from the housing market. *Journal of Political Economy*, 113(2):376–424.

Couture, V., Duranton, G., and Turner, M. A. (2018). Speed. *The Review of Economics and Statistics*, 100:725–739.

Epple, D. and Sieg, H. (1999). Estimating equilibrium models of local jurisdictions. *Journal of Political Economy*, 107(4):645–681.

Fujita, M. (1989). *Urban Economic Theory*. Cambridge University Press.

Gabriel, S. A. and Rosenthal, S. S. (1996). Commutes, neighborhood effects, and earnings: An analysis of racial discrimination and compensating differentials. *Journal of Urban Economics*, 40(1):61–83.

Gallin, J. (2008). The long-run relationship between house prices and rents. *Real Estate Economics*, 36(4):635–658.

Gautier, P. A., Siegmann, A., and Van Vuuren, A. (2009). Terrorism and attitudes towards minorities: The effect of the theo van gogh murder on house prices in amsterdam. *Journal of Urban Economics*, 65(2):113 – 126.

Glaeser, E. L., Kolko, J., and Saiz, A. (2001). Consumer city. *Journal of Economic Geography*, 1(1):27–50.

Guerrieri, V., Hartley, D., and Hurst, E. (2013). Endogenous gentrification and housing price dynamics. *Journal of Public Economics*, 100(C):45–60.

Guirao, B., Casado-Sanz, N., and Campa, J. L. (2020). Labour opportunities provided by spanish high-speed rail (hsr) commuting services in a period of financial crisis: an approach based on regional wage disparities and housing rental prices. *Regional Studies*, 54(4):539–549.

Guirao, B., García-Pastor, A., and López-Lambas, M. E. (2016). The importance of service quality attributes in public transportation: Narrowing the gap between scientific research and practitioners' needs. *Transport Policy*, 49(C):68–77.

Gutiérrez-i Puigarnau, E., Mulalic, I., and van Ommeren, J. (2016). Do rich households live farther away from their workplaces? *Journal of Economic Geography*, 16(1):177–201.

Haas, A. and Osland, L. (2014). Commuting, migration, housing and labour markets: Complex interactions. *Urban Studies*, 51(3):463–476.

Heblich, S., Redding, S. J., and Sturm, D. M. (2020). The Making of the Modern Metropolis: Evidence from London*. *The Quarterly Journal of Economics*, 135(4):2059–2133.

Inci, E. (2015). A review of the economics of parking. *Economics of Transportation*, 4(1):50–63. Special Issue on Collective Contributions in the Honor of Richard Arnott.

Kuminoff, N. V., Parmeter, C. F., and Pope, J. C. (2010). Which hedonic models can we trust to recover the marginal willingness to pay for environmental amenities? *Journal of Environmental Economics and Management*, 60(3):145–160.

Kuminoff, N. V., Smith, V. K., and Timmins, C. (2013). The new economics of equilibrium sorting and policy evaluation using housing markets. *Journal of Economic Literature*, 51(4):1007–1062.

Le Barbanchon, T., Rathelot, R., and Roulet, A. (2021). Gender differences in job search: Trading off commute against wage. *The Quarterly Journal of Economics*, 136(1):381–426.

Manning, A. (2003a). *Monopsony in motion: Imperfect competition in labor markets*. Princeton University Press.

Manning, A. (2003b). The real thin theory: monopsony in modern labour markets. *Labour economics*, 10(2):105–131.

McLafferty, S. and Preston, V. (2019). Who has long commutes to low-wage jobs? gender, race, and access to work in the new york region. *Urban Geography*, 40(9):1270–1290.

Mulalic, I., Ommeren, J. N. V., and Pilegaard, N. (2014). Wages and Commuting: Quasi-natural Experiments' Evidence from Firms that Relocate. *Economic Journal*, 124(579):1086–1105.

Mulalic, I. and Rouwendal, J. (2015). The impact of fixed and variable cost on automobile demand: Evidence from denmark. *Economics of Transportation*, 4(4):227 – 240.

Mulalic, I. and Rouwendal, J. (2020). Does improving public transport decrease car ownership? evidence from a residential sorting model for the copenhagen metropolitan area. *Regional Science and Urban Economics*, 83:103543.

Muth, R. F. (1969). *Cities and Housing*. University of Chicago Press.

OECD and ITF (2013). ITF transport outlook 2013: Funding transport. Technical report, OECD.

Palmquist, R. B. (2006). Property value models. In Mäler, K. G. and Vincent, J. R., editors, *Handbook of Environmental Economics*, volume 2, chapter 16, pages 763–819. Elsevier, 1 edition.

Pope, J. C. (2008). Fear of crime and housing prices: Household reactions to sex offender registries. *Journal of Urban Economics*, 64(3):601 – 614.

Redding, S. J. and Rossi-Hansberg, E. (2017). Quantitative spatial economics. *Annual Review of Economics*, 9(1):21–58.

Redding, S. J. and Turner, M. A. (2015). Chapter 20 - transportation costs and the spatial organization of economic activity. In Duranton, G., Henderson, J. V., and Strange, W. C., editors, *Handbook of Regional and Urban Economics*, volume 5 of *Handbook of Regional and Urban Economics*, pages 1339–1398. Elsevier.

Rich, J. and Hansen, C. O. (2015). The danish national passenger model. Working Paper DOI: 10.13140/RG.2.1.3661.7040, Technical University of Denmark.

Rich, J., Nielsen, O., Brems, C., and Hansen, C. (2010). Overall design of the danish national transport model. Technical report, Annual Transport Conference at Aalborg University.

Roback, J. (1982). Wages, rents, and the quality of life. *Journal of Political Economy*, 90(6):1257–1278.

Rosen, S. (1974). Hedonic prices and implicit markets: Product differentiation in pure competition. *Journal of Political Economy*, 82(1):34–55.

Rosen, S. (1979). Wages-based indexes of urban quality of life. In Mieszkowski, P. and Straszheim, M., editors, *Current Issues in Urban Economics*, chapter 3, pages 74–103. John Hopkins University, Baltimore.

Rouwendal, J. (1990). Existence and uniqueness of stochastic price equilibria in heterogeneous markets. *Regional Science and Urban Economics*, 20(1):43–64.

Rouwendal, J., Levkovich, O., and van Marwijk, R. (2017). Estimating the value of proximity to water, when ceteris really is paribus. *Real Estate Economics*, 45(4):829–860.

Small, K. A. and Verhoef, E. T. (2007). *The Economics of Urban Transportation*. Routledge.

Theebe, M. A. J. (2004). Planes, trains, and automobiles: The impact of traffic noise on house prices. *The Journal of Real Estate Finance and Economics*, 28(2):209–234.

van Duijn, M. and Rouwendal, J. (2015). Sorting based on Urban Heritage and Income: Evidence from the Amsterdam Metropolitan Area. Tinbergen Institute Discussion Papers 15-030/VIII, Tinbergen Institute.

Wheaton, W. C. (1977). Income and urban residence: An analysis of consumer demand for location. *The American Economic Review*, 67(4):620–631.

A Appendix

Table A1: Hedonic price equation with municipality fixed effect, OLS

	log(price)
Space (sqm)	0.007***
	(0.001)
Space squared	-0.00001***
	(0.00001)
Age, years	-0.065***
	(0.005)
Age squared, years	0.00002***
	(0.00001)
Number of rooms	0.004
	(0.004)
Dummy indicating 2 toilets	0.125***
	(0.008)
Dummy indicating 3 toilets	0.196***
	(0.020)
Dummy indicating 4 toilets	0.039
	(0.107)
Dummy indicating 5 toilets	0.218*
	(0.129)
Dummy indicating 6 toilets	0.147
	(0.258)
Dummy indicating single-family house	0.267***
	(0.016)
Municipality fixed effect	*yes*
Constant	73.956***
	(4.628)
Adjusted R^2	0.589
Observations	13,087

Notes: *p<0.1; **p<0.05; ***p<0.01.

Table A2: Mincerian wage regression with municipality fixed effect, OLS

	log(wage)
Age	0.043^{***}
	(0.0002)
Age squared	-0.0004^{***}
	(0.00001)
Dummy indicating male	0.175^{***}
	(0.0005)
Dummy indicating primary education	-0.144^{***}
	(0.001)
Dummy indicating upper secondary education	0.020^{***}
	(0.002)
Dummy indicating vocational education and training	-0.054^{***}
	(0.001)
Dummy indicating short cycle higher education	0.045^{***}
	(0.002)
Dummy indicating vocational bachelors educations	0.104^{***}
	(0.001)
Dummy indicating bachelors programmes	0.126^{***}
	(0.002)
Dummy indicating masters programmes	0.301^{***}
	(0.001)
Dummy indicating PhD programmes	0.333^{***}
	(0.003)
Work place municipality fixed effect	*yes*
Constant	4.173^{***}
	(0.005)
Adjusted R^2	0.329
Observations	1,209,928

Notes: *p<0.1; **p<0.05; ***p<0.01.

Table A3: QOL ($\hat{Q}_j$), housing prices ($\hat{p}_j$), local wages ($\hat{w}_j$), and commuting differentials ($\hat{f}_j$) across municipalities in Denmark

Rank	Municipality	$\hat{Q}_j$	$\hat{w}_j$	$\hat{p}_j$	$\hat{f}_j$
1	København	0.16	0.08	0.64	0.11
2	Fanø	0.16	-0.03	0.01	0.54
3	Dragør	0.15	0.06	0.49	0.16
4	Rudersdal	0.14	0.10	0.75	-0.07
5	Lyngby-Taarbæk	0.13	0.09	0.74	-0.12
6	Aarhus	0.12	0.01	0.38	0.05
7	Gentofte	0.12	0.10	0.82	-0.23
8	Helsingør	0.10	0.03	0.40	0.03
9	Frederiksberg	0.09	0.08	0.59	-0.12
10	Hørsholm	0.09	0.09	0.58	-0.09
11	Roskilde	0.09	0.04	0.36	0.05
12	Fredensborg	0.08	0.07	0.41	0.02
13	Solrød	0.07	0.05	0.33	0.02
14	Samsø	0.06	-0.09	-0.39	0.42
15	Køge	0.06	0.03	0.20	0.08
16	Holbæk	0.05	0.01	0.02	0.22
17	Furesø	0.05	0.09	0.49	-0.13
18	Frederikssund	0.05	0.03	0.17	0.12
19	Gladsaxe	0.05	0.09	0.62	-0.27
20	Odder	0.05	-0.02	0.09	0.02
21	Lejre	0.05	0.03	0.06	0.22
22	Allerød	0.05	0.09	0.41	-0.03
23	Halsnæs	0.04	0.02	0.05	0.15
24	Gribskov	0.04	0.02	0.14	0.05
25	Silkeborg	0.04	-0.01	0.06	0.06
26	Vordingborg	0.04	-0.03	-0.13	0.23
27	Sorø	0.03	0.01	-0.04	0.20
28	Kalundborg	0.03	0.01	-0.13	0.35
29	Hillerød	0.03	0.06	0.29	-0.02
30	Hvidovre	0.03	0.08	0.43	-0.16
31	Stevns	0.03	0.01	-0.14	0.31
32	Næstved	0.03	-0.00	-0.05	0.17

Rank	Municipality	$\hat{Q}_j$	$\hat{w}_j$	$\hat{p}_j$	$\hat{f}_j$
33	Egedal	0.03	0.07	0.21	0.08
34	Tårnby	0.03	0.09	0.42	-0.14
35	Herlev	0.03	0.09	0.47	-0.20
36	Skanderborg	0.02	0.00	0.10	-0.03
37	Rødovre	0.02	0.07	0.46	-0.25
38	Odense	0.02	-0.00	0.13	-0.10
39	Greve	0.02	0.06	0.27	-0.07
40	Faxe	0.02	0.01	-0.08	0.20
41	Odsherred	0.01	-0.02	-0.18	0.18
42	Ringsted	0.01	0.02	0.00	0.11
43	Syddjurs	0.01	-0.02	-0.13	0.13
44	Slagelse	0.00	-0.00	-0.07	0.09
45	Aalborg	0.00	-0.01	0.02	-0.05
46	Ballerup	-0.00	0.10	0.41	-0.18
47	Nordfyns	-0.00	-0.03	-0.31	0.29
48	Svendborg	-0.01	-0.02	0.04	-0.16
49	Ærø	-0.01	-0.07	-0.28	0.08
50	Randers	-0.01	-0.01	-0.09	0.03
51	Favrskov	-0.01	-0.00	-0.05	-0.01
52	Glostrup	-0.02	0.09	0.46	-0.36
53	Vejle	-0.02	0.01	-0.05	-0.01
54	Høje-Taastrup	-0.02	0.08	0.22	-0.11
55	Viborg	-0.03	-0.01	-0.16	0.06
56	Kolding	-0.03	0.01	0.01	-0.11
57	Horsens	-0.03	0.00	-0.03	-0.08
58	Middelfart	-0.03	-0.01	-0.00	-0.15
59	Brønderslev	-0.03	-0.03	-0.31	0.16
60	Vallensbæk	-0.04	0.08	0.27	-0.22
61	Albertslund	-0.04	0.08	0.19	-0.15
62	Kerteminde	-0.05	0.01	-0.03	-0.12
63	Guldborgsund	-0.05	-0.04	-0.30	0.04
64	Assens	-0.05	-0.02	-0.25	0.05
65	Holstebro	-0.05	-0.02	-0.16	-0.06
66	Ishøj	-0.06	0.07	0.16	-0.21
67	Brøndby	-0.06	0.09	0.22	-0.23

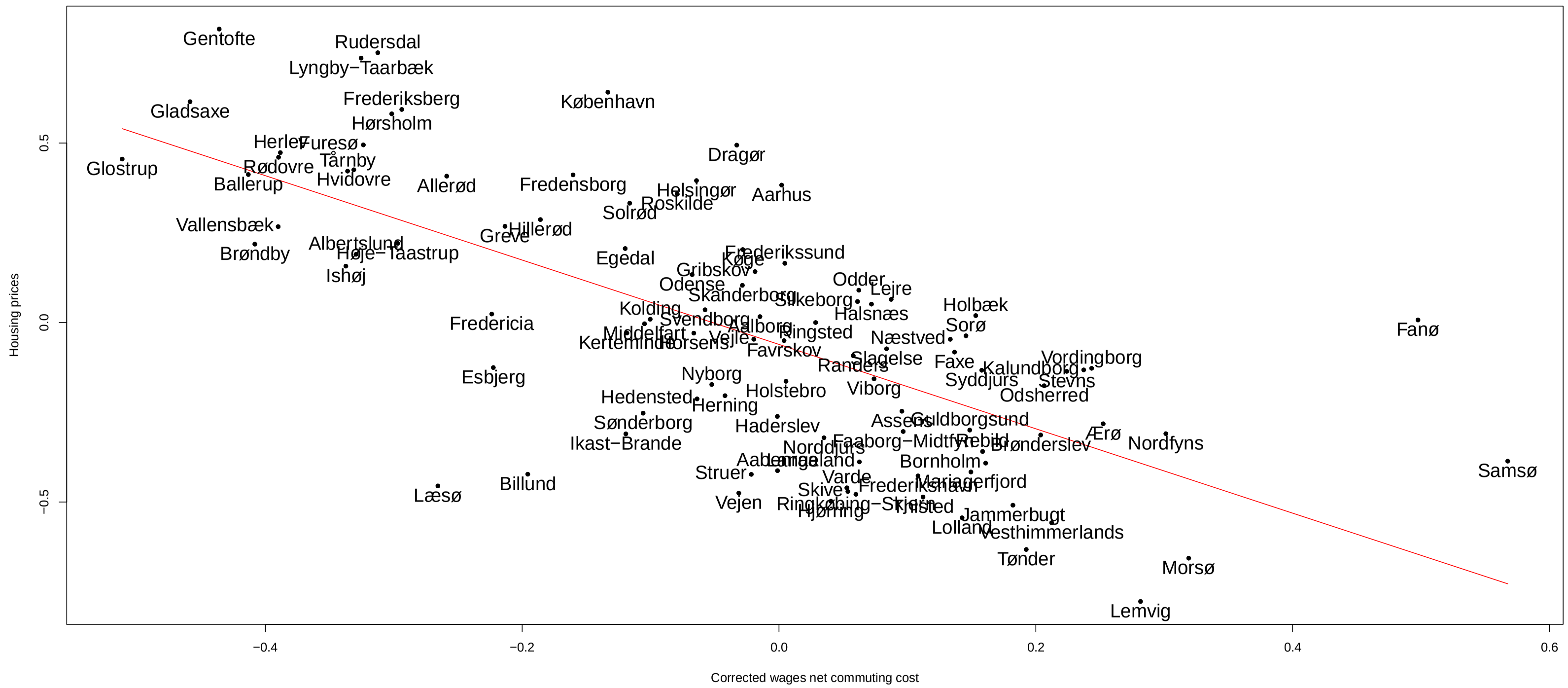
Rank	Municipality	$\hat{Q}_j$	$\hat{w}_j$	$\hat{p}_j$	$\hat{f}_j$
68	Fredericia	-0.06	0.03	0.02	-0.20
69	Rebild	-0.06	-0.02	-0.36	0.13
70	Faaborg-Midtfyn	-0.07	-0.03	-0.30	0.02
71	Nyborg	-0.07	-0.02	-0.17	-0.14
72	Bornholm	-0.07	-0.07	-0.39	-0.04
73	Herning	-0.08	-0.01	-0.20	-0.09
74	Haderslev	-0.08	-0.03	-0.26	-0.10
75	Mariagerfjord	-0.08	-0.02	-0.42	0.13
76	Hedensted	-0.09	-0.00	-0.21	-0.10
77	Norddjurs	-0.09	-0.02	-0.32	-0.02
78	Frederikshavn	-0.10	-0.02	-0.43	0.06
79	Langeland	-0.10	-0.03	-0.39	-0.01
80	Jammerbugt	-0.10	-0.03	-0.51	0.13
81	Morsø	-0.11	-0.03	-0.66	0.30
82	Vesthimmerlands	-0.11	-0.03	-0.56	0.18
83	Esbjerg	-0.11	0.02	-0.13	-0.23
84	Sønderborg	-0.11	-0.03	-0.25	-0.25
85	Thisted	-0.12	-0.03	-0.49	0.06
86	Lolland	-0.13	-0.06	-0.54	-0.01
87	Varde	-0.13	-0.01	-0.46	0.03
88	Aabenraa	-0.13	-0.01	-0.41	-0.03
89	Skive	-0.13	-0.03	-0.47	-0.03
90	Ringkøbing-Skjern	-0.13	0.00	-0.48	0.09
91	Ikast-Brande	-0.14	-0.00	-0.31	-0.17
92	Tønder	-0.14	-0.03	-0.63	0.14
93	Struer	-0.14	-0.03	-0.42	-0.14
94	Hjørring	-0.14	-0.03	-0.50	-0.05
95	Lemvig	-0.16	-0.02	-0.78	0.29
96	Vejen	-0.16	-0.02	-0.48	-0.11
97	Billund	-0.19	0.03	-0.42	-0.14
98	Læsø	-0.23	-0.06	-0.46	-0.53

Table A4: Descriptive statistic for amenity variables

	mean	std.dev	min	max
No. of publ. transp. departures per sqkm	178.27	498.65	0.09	3952
Log distance to the nearest highway ramp (km)	1.63	1.41	-1.83	4.95
Service level (municipality service expenses index)	1.00	0.04	0.93	1.14
Share of population with higher education (%)	23.38	8.44	13.70	51.20
Share of pupils in private schools (%)	13.84	6.12	0.00	29.40
Population density (people per sqkm)	557.52	1,362.04	17.00	11,028.00
Share of workers commuting from munic. (%)	44.58	20.05	5.20	83.50
Share of workers commuting to munic. (%)	39.11	20.56	3.30	87.10

Notes: Number of observations is 98. High education includes bachelor, long-cycle higher education and PhD-degree.

Figure A1: Housing price index and local wages corrected for commuting costs



B Appendix

We estimate models for three different types of households (workers) based on the highest education level obtained: low education, medium educated and high education. We estimate local wages by place of work for these three groups separately. Housing expenditures and the income share for housing (s_y), share of income spent on commuting (s_w) and income share from labour (s_c) are homogeneous across households.

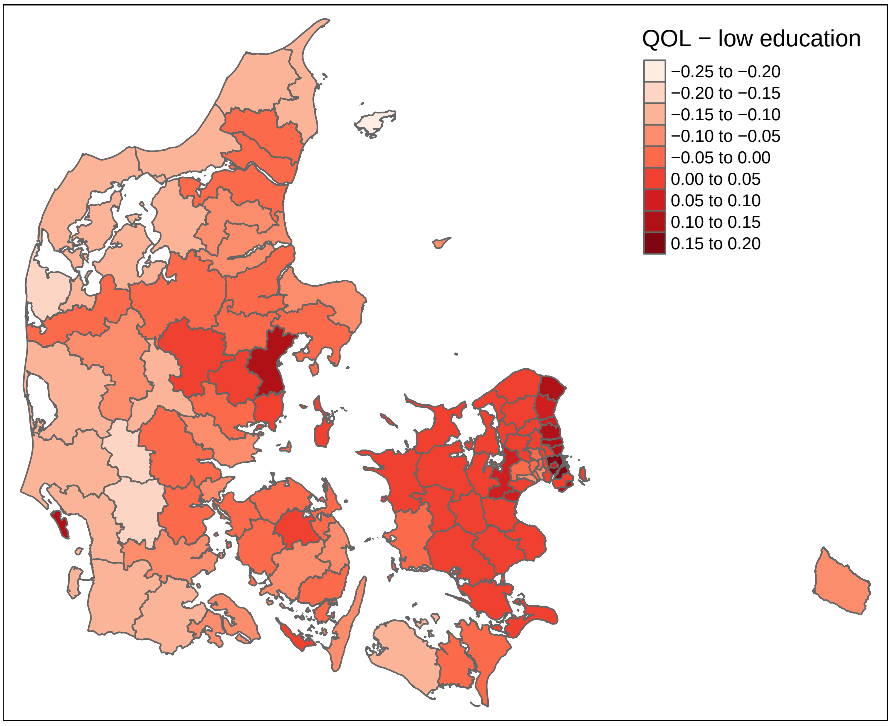
We find similar municipality rankings based on the QOL index for all three types of households, see Table B1. For example, for all three groups the highest QOL index is in the Municipality of Copenhagen and the lowest on the island Læsø. Figures B1-B3 show the $\hat{Q}_j$ for the three considered types of households.

Table B1: Top- and bottom-five municipalities in Denmark based on the QOL

Municipality	Rank based on $\hat{Q}_j$			
	representative household	low education	medium education	high education
	Top five			
København	1	1	1	1
Fanø	2	2	4	2
Dragør	3	5	2	4
Rudersdal	4	3	3	3
Lyngby-Taarbæk	5	4	6	6
	Bottom five			
Hjørring	94	94	92	96
Lemvig	95	95	94	90
Vejen	96	96	96	94
Billund	97	97	97	97
Læsø	98	98	98	98

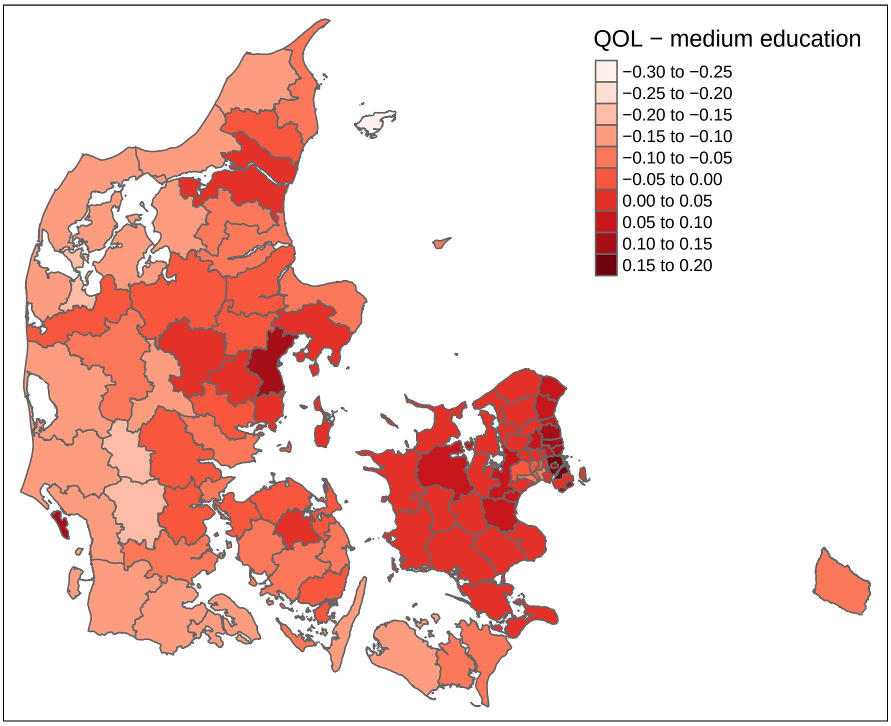
Notes: Low education includes: basic school, general upper secondary school, vocational upper secondary school and vocational education; medium education includes: short-cycle higher education and medium-cycle higher education; and high education includes: bachelor, long-cycle higher education and PhD-degree.

Figure B1: QOL index ($\hat{Q}_j$) for low educated



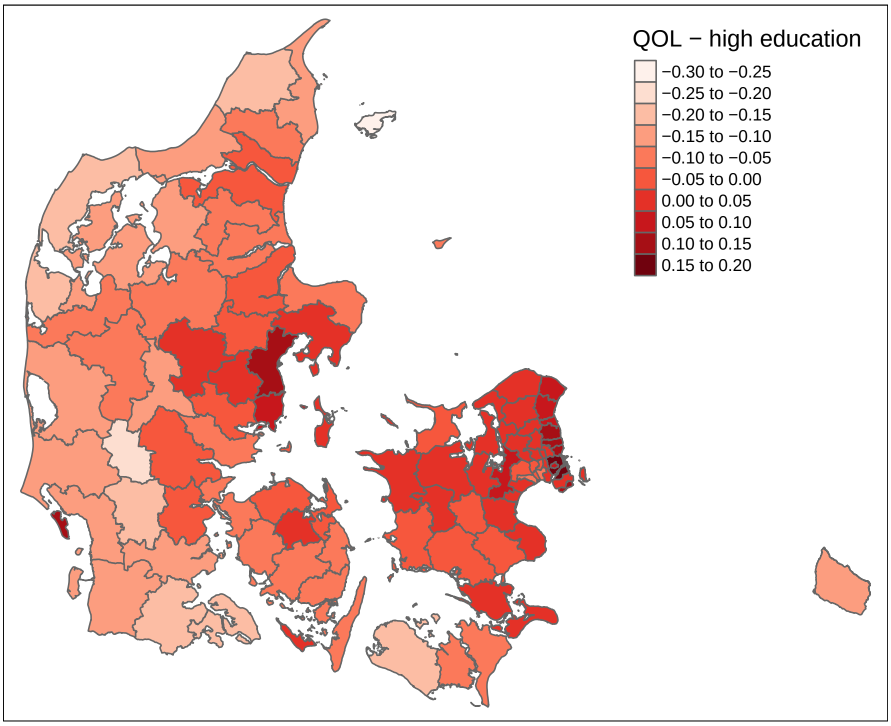
Notes: This QOL index represents the marginal willingness-to-pay for local amenities $\hat{Q}_j$. Low education includes: basic school, general upper secondary school, vocational upper secondary school and vocational education.

Figure B2: QOL index ($\hat{Q}_j$) for medium educated



Notes: This QOL index represents the marginal willingness-to-pay for local amenities $\hat{Q}_j$. Medium education includes: short-cycle higher education and medium-cycle higher education.

Figure B3: QOL index ($\hat{Q}_j$) for high educated



Notes: This QOL index represents the marginal willingness-to-pay for local amenities $\hat{Q}_j$. High education includes: bachelor, long-cycle higher education and PhD-degree.