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Sorting in an urban housing market—is there a response to demographic change?

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Abstract Using Dortmund as a case study we analyse whether rents and housing prices responded to local demographic change in a German city between 2007 and 2016. In a two-step analysis based on a spatial autoregressive hedonic pricing model and a discrete choice model of housing location we find that during the study period as a whole, higher local mortality induced a negative effect on apartment prices and rents. Yet, the neighbourhood effects of local ageing vary across sub-city districts.

Availability of data and material (data transparency) This study uses data from the following sources:

1. dortmunderstatistik (2018); this data is available for download at: <https://www.dortmund.de>
2. RWI-GEO-GRID (2018) Socio-economic data on grid level, provided by Micromarketing-Systeme und Consult GmbH (microm). Population by age and gender, <https://doi.org/10.7807/microm:einwGeA1:v5>; Share of foreigners, <https://doi.org/10.7807/microm:auslaender:V5>
3. RWI-GEO-RED (2018) Real estate offers (purchase and rent) including object characteristics gathered by the internet platform ImmobilienScout24. Apartments for rent, <https://doi.org/10.7807/immo:red:wm:suf:v1>; Apartments for sale, <https://doi.org/10.7807/immo:red:wk:v1>; Houses for sale, <https://doi.org/10.7807/immo:red:hk:suf:v1>
4. IT.NRW Information und Technik Nordrhein-Westfalen (Statistics North Rhine-Westphalia) (2020) Bevölkerungsstand nach Altersjahren (90) – Gemeinden – Stichtag, Fortschreibung des Bevölkerungsstandes, 31.12.2019. 12411–09iz; this data is available for download at <https://www.landesdatenbank.nrw.de>
5. KOSTAT (2018) Municipal statistical data for sub-city districts, provided by KOSIS Association KOSTAT, Bremen; this data is distributed to RWI under a contract and cannot be distributed further; the data can be obtained from KOSTAT.

Code availability The computer code underlying the analysis was programmed using the Stata statistical software package. The corresponding do-files are available from the authors upon request.

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Most prominently, the study period was characterised by a strong and rising desire to purchase or rent housing in the vicinity of the city centre. Furthermore, prices for owner-occupied apartments and houses increased rapidly in the more well-off southern part of the city and particularly in a previously declining community, where a large-scale urban regeneration and environmental upgrading project has been implemented since 2011. The characteristics of households likely to move to this neighbourhood switched from low to high income.

Keywords Demographic segregation · Hedonic analysis · Spatial autocorrelation · Discrete choice · Urban policy

JEL Classification R21 · R23 · R31 · R58 · J61

1 Introduction

Residential segregation by demographic characteristics is a well-known feature of cities. In ageing societies, considerable changes on local housing and service markets may abound, because the demand for housing varies across the individual life cycle. Housing prices may decline in neighbourhoods, for example, which are not favoured by younger generations and where—as a consequence of a low inflow of mobile households—ageing thus proceeds more rapidly. While it may be a goal of urban policy to address the local consequences of demographic change, any evidence on the outcomes of such policy so far is scarce.

This can be explained partly by the methodical challenges confronting empirical analysis of neighbourhood sorting, but another reason is that segregation by age has remained out of the main focus of urban research and policy so far. Over the past decades, an expanding range of studies has developed approaches designed to overcome the most severe empirical challenges arising for segregation analysis. Up to now, most research using recent methodical approaches designed to isolate the causal effect of an individual household characteristic (e.g. its age composition) on the likelihood of this household to choose a particular residential location or to isolate the effect of this household characteristic on the household's willingness-to-pay for a specified neighbourhood amenity have usually drawn on data from the United States (Kuminoff et al. 2013).

Sager's (2012) study on migrant sorting in Germany refers to this methodical framework. As a whole, however, studies on the determinants of location choice in Europe are still comparatively scarce. Due to methodical challenges, so far it has been very difficult to isolate the effect of a specific household characteristic on the likelihood of this household to choose a location or on the willingness-to-pay of this household for a particular neighbourhood amenity. A European perspective is of interest also for many reasons, however, since demographic ageing is more advanced and the weighting among the various individual and neighbourhood-related determinants responsible for segregation is likely to differ from that in the States (Haase et al. 2010). Europe's largest national economy, Germany, should be in the focus not least due to this country's rapid ageing process. In the US, the age group 60

and over currently (in 2019) comprises 22.9% of the population, in Germany 28.5% (US Census Bureau 2020; Destatis 2020).

During the past decade, ageing in Germany was put to a halt temporarily by a strong inflow of immigrants. Whereas discussion of the consequences of this influx has been very dominant in the public debate, ageing has never been a prominent issue. Yet, continuing immigration to Germany at a rate that would compensate for population ageing and shrinking would need to be relatively high. According to current population projections for Germany as a whole, an annual average migration surplus of 311,000 would be required to maintain a total population of around 83 million (which represents the population of 2018) until 2060 (Destatis 2019). It is not a completely unrealistic scenario, which would be in accordance with average annual migration to Germany since 1990. Yet, this period comprises phases of previously unprecedented immigration to Germany in the early 1990s and in the past decade. More moderate variants of the current population projection would expect a lower net migration to Germany, which would most likely result in considerable ageing and population decline.

In the course of this demographic change, regional and intra-urban disparities can be expected to continue to widen. For purposes of studying residential sorting within urban areas, housing prices offer an opportunity to measure the attractiveness assigned to specific features of neighbourhood surroundings. Specifically, it is expected that prices may decrease in regions and neighbourhoods, where ageing advances more rapidly (Hiller and Lerbs 2016).

Many of the regional consequences of demographic change can be studied among the large urban regions of North Rhine-Westphalia. In particular, ageing is far advanced in the Ruhr area (Klemmer 2001) Due to job-related out-migration of working-age residents in the course of industrial decline, the Ruhr area population began to shrink in the 1960s. Today (in 2019), the share of the population aged 60 and over comprises 24.9% in Düsseldorf, but 28.3% in Essen and 26.9% in Dortmund, i.e., the two largest cities in the Ruhr area (IT.NRW 2020).

Throughout the past decades many industrial sites have been regenerated by publicly-funded regeneration programmes. Among these, the Emscher Conversion Scheme focusses on environmental upgrading alongside the Emscher River in the northern part of the urban core zone of the Ruhr area (Frank and Greiwe 2012). In Dortmund, since 2011 as part of the Emscher Conversion a high-quality housing estate has been developed in the vicinity of a newly constructed water expanse (“Phoenix-See”) on parts of an old industrial site in the Hörde district. Having required an initial public investment amounting to around 230 million euro, it has become one of the most favoured housing locations in Dortmund (Stadt Dortmund 2017).

Using Dortmund as a case study, we compile a comprehensive data set, which combines micro-level information on housing prices and housing characteristics with municipal statistics on demographic neighbourhood features. We examine

- whether housing prices were affected by neighbourhood-level ageing between 2007 and 2016, and

- whether the Phoenix-See urban regeneration scheme implemented from 2011 onwards affected local prices and choice probabilities among sub-city districts.

Following a literature review and an outline of the empirical approach in the following sections and a brief characterisation of Dortmund residential communities in the fourth section, we present our analysis in the fifth section and conclude in the final section.

The analysis comprises three steps focussing on different territorial levels at the sub-city scale drawing on different methodical approaches. Since we employ microdata on housing in combination with neighbourhood-level population statistics, variation in the spatial scale represented by aggregate statistics serves as a robustness check with respect to any neighbourhood effects we may identify.

2 Literature review

Analysis of the regional dimensions of ageing needs to be concerned, among other things, with the location decisions of households, as far as they correlate with age. The following section reviews the relevant literature on household location theory, residential sorting and the effects of demographic ageing on housing prices.

Apparently, over the past decades ageing in Germany coincided with an increase in regional and intra-urban disparities, driven to a large extent by regional mobility of high-skilled and younger individuals (Gregory and Patuelli 2015). From the view of land use theory, household location decisions derive mainly from the strength of two forces, the demand for space and the costs of commuting. When they consider how to maximise their utility by choosing a residential location, they will thus trade off how far they are prepared to commute against their desire to occupy a larger dwelling. Distance to jobs and amenities is assumed to represent a disutility, since commuting reduces leisure time (Alonso 1964).

As the price of housing varies in line with mean preferences concerning dwellings and neighbourhoods, prices for land and housing are highest in urban centres, where jobs and amenities agglomerate. In general, residential segregation by income and preferences concerning the characteristics of housing and distance to amenities is a likely outcome. Since it has been found that younger individuals seek to co-agglomerate (Couture and Handbury 2017; Haase et al. 2010), in ageing societies the characteristics of neighbourhood populations may become more important among local surroundings, which have been described by Schelling (1971) as important determinants of location choice. After all, as mobility decreases among age groups beyond 50, the location choices of individuals below 50 comprise the main “driving force” resulting in residential segregation by age.

A literature concerned with examining these tastes was initiated by Tiebout (1956), who argues that the willingness-to-pay for local government services will result in sorting by demographic characteristics (and preferences regarding local public goods). If it is assumed that the level of public goods supplied by each community is determined by the income of the community’s households, the general demand for a public good can be estimated by regressing actual public expenditures

related to the services of interest on mean demographic characteristics of the residential population. This work has inspired a very comprehensive range of studies on “Tiebout sorting” (Kuminoff et al. 2013, see below).

The empirical framework has since been applied to a variety of specific issues, e.g. school quality (Ferreyra 2007) and environmental improvement (Tra 2010), the quality of which may be measured in terms of the public spending allocated to the specific service, but also by outcome indicators or other quality classifications. Gibbons and Machin (2003), for example, provide evidence on the effect of primary school performance on property prices in the UK. Luttik (2000) demonstrates considerable effects of environmental amenities on housing prices in the Netherlands.

In any case it is problematic to utilise data on local public spending as evidence on the general willingness-to-pay for a specific public good. After all, people are assumed to have moved to a specific location at least partly due to their preference for the public goods on offer locally. Local residents thus hardly qualify as a representative sample concerning the desirability of specific local amenities among the total population. Goldstein and Pauly (1981) label this identification problem “Tiebout bias”, which has become the focus of a specific literature on “Tiebout sorting” (Kuminoff et al. 2013). Similarly, when investigating the way in which local ageing affects mobility inflows it will be difficult to disentangle the role of population characteristics from other features that may affect neighbourhood sorting.

Hedonic price functions provide one way to characterise sorting equilibria, maintaining that under mild restrictions on preferences, the equilibrium price of an individual dwelling can be expressed as a function of its characteristics and the amenities it provides (Ebertz 2013). Rosen (1974) observes that the hedonic price function reflects equilibrium stratification patterns that mirror those described by Tiebout (1956), i.e., they measure the willingness-to-pay for specific assets characterising the quality of housing.

Epple and Sieg (1999) apply a hedonic pricing approach to residential sorting analysis by estimating the price of housing in each municipality within the Boston area as a community-specific fixed effect measured in terms of a local public goods index. Thus, utilising the hedonic approach for sorting analysis, they observe a significant stratification of prices along this index. Given that the hedonic pricing approach controls for a wide range of housing-specific characteristics determining the willingness-to-pay for a unit of housing, it can thus be demonstrated how far, in addition, local amenities affect the price.

Bayer et al. (2004) adopt a probabilistic view by allowing for the likelihood of households to differ in their relative preferences for housing and local amenities. Whereas hedonic pricing models examine the way in which housing characteristics and amenities affect pricing—and thereby the mean willingness-to-pay for specific amenities, the discrete choice model investigates the likelihood of a household to locate in a specific area, given both individual household and neighbourhood characteristics. Using Census microdata for the San Francisco Bay area, they find a strong preference by college-educated individuals to dwell close to neighbours with a similar education and by all households for neighbours from the same race. Tra (2010) draws on this approach to analyse the effects of environmental improvement policy on household location choice in the Los Angeles region. He finds a considerable

increase in the desirability (and price) of housing in neighbourhoods where air pollution was reduced considerably between 1990 and 2000.

Mankiw and Weil (1989) argue that as the demand for housing varies over the individual life cycle, demographic ageing may result in a considerable decrease in the price of housing altogether. Their work has initiated a controversial discussion about methodical issues that arise for the measurement of the impact of demographic change on housing markets. Subsequent studies corroborate that population ageing is likely to exert downward pressure on house prices (Hiller and Lerbs 2016; Levin et al. 2009; Maenning and Dust 2008; Takáts 2012). Nevertheless, as Hartt and Hackworth (2018) point out, in the US population loss in shrinking cities combines with a considerable decrease in household sizes. In a given city, an overall loss in population thus will not necessarily result in a corresponding decline in the demand for residential housing space altogether. Since an “urban revival” has been observed in the US and Germany (Couture and Handbury 2017; Haase et al. 2010) the desire of younger individuals to co-agglomerate in favourable neighbourhoods of large cities may nevertheless result in an even greater relative widening of the differences in price levels between these central city locations and other urban areas than in countries where ageing is less advanced.

3 Data and methods

Our dataset combines data from three sources representing neighbourhood-level population characteristics and micro-level information on the prices and properties of housing that enters the market for rent and for sale:

1. The first data base, RWI-GEO-RED (2018), offers micro-level information on prices for apartments (for rent and for sale) and residential houses (one- and two-family homes), as advertised on the internet platform ImmobilienScout24. The data includes information about a variety of housing characteristics such as living space, type and condition of the building, and features like having a garden, balcony or cellar. All offerings posted on the platform between 2007 and 2016 are included¹. Georeference is provided with respect to 1 km²-spatial grids, and 5-digit postal code zones.
2. The second source comprises municipal statistics (Stadt Dortmund 2015, dortmunderstatistik 2018 and KOSTAT 2018), i.e., annual data providing information about the residential population (age, nationality, fertility and mortality), aggregated at the level of 5-digit postal code zones in Dortmund.
3. The third source, RWI-GEO-GRID (2018), comprises data on the residential population, compiled at the level of 1 km²-grids, as compiled by microm Micromarketing-Systeme und Consult GmbH, a market research firm specialising in territorial analysis (microm 2017).

¹ The RWI-GEO-RED (2018) data was cleared from duplicates. In case an object was advertised more than once during the study period, only the last advertisement was kept. From the monthly observations, only the last offering per object was kept in the research dataset. It is assumed to represent the transaction price most closely.

Although our data source includes no information about final housing transaction prices or dates, there are several reasons to assume that it is suitable for the analysis of segregation dynamics. ImmobilienScout24 is the biggest internet platform for real estate offerings in Germany. Its self-reported market share amounts to around 50% of all offered dwellings for sale or rent in Germany (Georgi and Barkow 2010; an de Meulen et al. 2014). Dinkel and Kurzrock (2012) investigate asking prices and transaction prices for owner-occupied dwellings in six districts (Landkreise) of Rhineland-Palatinate based on data provided by ImmobilienScout24. They find that advertised prices are significantly higher than final transaction prices, but do not vary systematically among different property types. Bauer et al. (2017) use this data base in order to analyse the effects of the Fukushima Daiichi accident in Japan in March 2011 on housing prices near nuclear power plants in Germany. Winke (2017) draws on data from ImmobilienScout and another source (IDN ImmoDaten GmbH) in order to examine the impact of aircraft noise on apartment prices in Frankfurt. Frondel et al. (2019) employ the data in an analysis of the effect of disclosing energy information on the asking prices of houses, Breidenbach and Schaffner (2020) describe the data set.

Kholodilin et al. (2017) provide a comprehensive discussion of the issues arising for the study of housing markets based on offers from internet platforms such as ImmoScout24. Their review confirms that concerning the gap between offers and transaction prices there is no systematic effect attributable to housing characteristics.

Furthermore, one possible way to control for the accuracy of asking prices is to add the advertisement duration to the estimation model. Presumably the longer the duration, the higher will be the difference between advertised and transaction price and vice versa (Zuehlke 1987; Mense and Kholodilin 2014). To avoid measurement errors that may be connected to long durations, we exclude all offers beyond the 95th percentile in duration from each of our three categories (rented accommodation, apartments and housing for sale) in each year. On average, rented accommodation is on offer for less than a month, houses and apartments for sale for a duration of between one and three months in 2008 and 2015 (Table 2, see below). We expect the vast majority of offers to represent transactions, since vacancy rates in Dortmund are low (1.7% in 2016) and have been decreasing over the past years (Stadt Dortmund 2017).

First, the overall valuation of housing and neighbourhood features is examined according to the hedonic pricing model (1),

$$\log(P_{i,jkt}) = \beta_x X_{i,t} + \beta_N N_{j,t} + \mu_k + T_t + \gamma_{t,k} T_t \mu_k + \varepsilon_{i,jkt} \quad (1)$$

in which P is the price (or rent without heating) of object i per unit of residential dwelling space (in m^2) in year $t = 2007, 2008, \dots, 2016$. X is a vector of object-specific characteristics such as the year of construction, living space, the number of rooms and the state and quality of the dwelling. Neighbourhood characteristics in postal code zone $j = 1, 2, \dots, 27$ are described by vector N including the total population, mortality rates and the share of foreigners. In our model two selected indicators represent demographic features. They refer to basic dimensions of urban

neighbourhood populations as identified by research on urban social geography (Knox and Pinch 2010, p. 70–72): age/household size and ethnicity.

In Dortmund, a third dimension, income or socioeconomic status, is represented by a distinctive intra-urban division separating households with higher incomes in the southern from households with lower incomes in the northern parts of the city. This spatial subdivision of the urban territory according to the socioeconomic status is accounted for by dummies μ_k , which identify $k = 1, 2, \dots, 7$ residential communities and thus control for locational fixed effects at a broader district level. Residential communities are defined by the Dortmund municipal administration for purposes of urban planning (Stadt Dortmund 2017). T are year dummies for 2008 to 2016 (with reference group 2007). The coefficients γ display the variation of price changes for the seven communities, identified by the interaction of time- and community-dummies.

Individual apartments and houses are assumed to be sufficiently small such as not to affect the prices of other objects. Common locational characteristics determining prices are captured via neighbourhood characteristics N and community fixed effects μ_k^2 .

The basic specification (1) operates without spatial weights. However, as measurement problems due to spatial autocorrelation may arise (Anselin 1988), our analysis applies a spatial autoregressive (SARAR) model according to Eq. 2 and 3, allowing for spatial effects among the dependent variable and the error term,

$$\log(P_{i,jkt}) = \lambda \sum_{l=1}^n w_{ij} \log(P_{l,jkt}) + \sum_{p=1}^q x_{i,jkt} \beta_{pt} + u_{it} \quad (2)$$

$$u_{it} = \rho \sum_{p=1}^q m_{ilt} u_{lt} + \varepsilon_{it} \quad (3)$$

in which w_{il} and m_{il} represent spatial weights, which are inversely related to the distance (in kilometres) between objects i and l , x is a set of q independent variables comprising object-specific characteristics, neighbourhood characteristics and community and time fixed effects as in Eq. 1. z comprises the corresponding parameters, u_i is a spatial autoregressive error term, such that disturbances ε_{it} are assumed to be independent and identically distributed, the parameter λ measures the extent of spatial interaction in the outcomes of the dependent variable and ρ measures spatial dependence in the error term. The spatial-autoregressive model implemented in this analysis uses a generalised spatial two-stage least-squares (GS2SLS) estimator (Arraiz et al. 2010).

In a second step, we estimate separate hedonic pricing models by residential community, by which we examine neighbourhood effects at the level of 1 km²-grids (Eq. 4). We assume that the broad residential communities represent local housing environments, which differ considerably in basic aspects (comprising central city locations, declining inner city areas, large-scale urban regeneration areas and lower-density residential zones of the northern and southern parts of Dortmund).

² Fig. 1 shows a basic outline of postal code zones and residential communities in Dortmund (see below).

Households seeking to maximise their overall utility by locating in any of these communities will not be as likely to settle in one of the other communities. We therefore examine the following separate pricing models for each community:

$$\log(P_{i,jt}) = \beta_X X_{i,t} + \beta_N N_{j,t} + T_t + \varepsilon_{i,jkt} \quad (4)$$

X is a vector of object-specific characteristics (cf. Eq. 1), neighbourhood characteristics at the level of $j = 1, 2, \dots, 254$ grids are described by vector N including the (log) total number of population and the population shares of the age group > 60 and foreign nationals. They refer to the basic dimensions of urban neighbourhood populations as defined in the context of Eq. 1 (see above). In regional analysis, statistics on the population with a foreign passport is often referred to, since in German statistics, information about this group is more readily available and more precise than data on the total population with a migrant background. In addition, we include a control for the number of offerings in relation to the existing stock of buildings per grid in order to account for potential “shocks” to local housing markets in case larger housing developments enter the market, e.g. in the course of urban regeneration.

Again, we will apply spatial autoregressive models according to Eq. 2 and 3 as robustness checks. In the following, we will report on the results of the spatial autoregressive models for Dortmund as a whole (Sect. 5.1) and for residential districts (Sect. 5.2).

In addition, it is of interest to study the effects of demographic change and urban policy on intra-urban sorting by household characteristics. Since our analysis is concerned primarily with housing markets and no similarly comprehensive and precise data on German households has been made available for research purposes so far, we will derive broad household characteristics from our data on housing. Our approach adopts its basic assumptions from the equilibrium sorting framework utilised for housing market analysis by Bayer *et al.* (2004). In their model of residential location choice, each household chooses a residence in neighbourhood h to maximise its indirect utility

$$V_h^i = \alpha_{0X} X_h + \alpha_{0Z} Z_h - \alpha_{0p} p_h + \lambda_h^i + \xi_h + \varepsilon_h^i \quad (5)$$

in which the indirect utility of location choice, V_h^i , divides into household-specific parameters λ_h^i and mean indirect utilities, which are disentangled in terms of parameters α_0 . These are common to all households. As denoted by Eq. 5, mean indirect utilities are expected to relate to the observable characteristics of housing choice X_h (e.g., the size of dwelling), neighbourhood attributes Z_h and the price of housing choice, p_h , which is a disutility, i.e. households would prefer a lower price for the same amount of housing with the same housing and neighbourhood attributes. ξ_h comprises the location-specific proportion of unobserved preferences for hous-

ing and neighbourhood and ε_h^i represents idiosyncratic preferences. We examine household-specific choice probabilities according to equation Eq. 6.

$$V_{h,t}^i = a_{0h,t} + \log a_1 \lambda_{1h,t}^i + \log a_2 \lambda_{2h,t}^i + \varepsilon_h^i \quad (6)$$

in which $V_{h,t}^i$ is represented by a categorical variable corresponding to residential location choice h in one of $k = 1, 2, \dots, 7$ communities in each year $t = 2007, 2008, \dots, 2016$. We estimate a multinomial logit (MNL) model³ to predict the probability of location choice h in year t , given any combination of the household-specific parameters $a_1 \lambda_{1h,t}^i$, $a_2 \lambda_{2h,t}^i$ and a community-specific parameter $a_{0h,t}$. The community-specific utility $a_{0h,t}$ is estimated in the form of $k - 1$ (i.e., 6) alternative constants per year.

In order to extract the parameter $a_{0h,t}$ housing-specific characteristics in the model are constructed such that the value zero represents the annual mean of each variable. The constant for the base category in each year is set to zero. The parameter $a_1 \lambda_{1h,t}^i$ is measured as a proxy for household size, determined by the size of a dwelling's residential floorspace in m², divided by the average residential housing floorspace per person in each of the seven Dortmund communities (Stadt Dortmund 2015, p. 97)⁴. The parameter $a_2 \lambda_{2h,t}^i$ enters as the (logarithmised) total monthly rent (without heating) or the total price of the dwelling on offer, divided by the average monthly (in case of rented accommodation) or annual household-level purchasing power within the 1 km² grid surrounding the dwelling, serving as a proxy for household income⁵.

4 Basic features of Dortmund residential communities

Dortmund is currently the largest city in terms of population (603,609 in 2019)⁶ in the Ruhr area and the third largest in North Rhine-Westphalia (following Cologne and Düsseldorf). In line with regional population ageing, in Dortmund the total number of citizens declined from 589,114 in 1998 to 576,824 in 2009. Ageing is more advanced in Dortmund than in other large German cities, e.g., according to municipal data from KOSTAT (2018), the population share of over 60-year-olds in Dortmund in 2015 was 26%, in Cologne 22.7% and in Düsseldorf 24.7%. Subsequent

³ In the MNL model, the “independence of irrelevant alternatives” (IIA) property implies that the unmeasured attributes of alternative choices are uncorrelated. In the literature on housing choice, a variety of studies have found the MNL model to be an appropriate empirical framework (Gabriel and Rosenthal 1999). Table 4 describes all variables entering the two-stage sorting analysis (see below).

⁴ The average residential floorspace per person in Dortmund varies by below 1% during the period under investigation. The average floorspace per person by Dortmund community is held constant at the value of 2013 in our analysis.

⁵ In the literature on real estate economics, the price-to-income ratio is a common measure of housing market characteristics. While there is no consensus in explaining the precise mechanisms of this ratio, various studies have found a correlation (Tu et al. 2018). We use the price (rent) in relation to the annual(monthly) purchasing power per household at the level of 1 km² grids as proxy.

⁶ Population statistics reported here refer to Dortmund municipal statistics (dortmunderstatistik 2018).

Table 1 Demographic characteristics of Dortmund residential communities

	2008	Total	Of which, in %			2015	Total	Of which, in %		
	Pop./km ²	POP	<18	>59	Foreign	Inh./km ²	POP	<18	>59	Foreign
City Centre	5276	71,623	11.4	25.2	12.2	5601	75,094	11.6	24.1	13.8
Nordstadt	3815	54,182	19.7	17.5	39.6	4239	60,609	20.2	15.3	46.7
DO-West	2064	138,248	17.8	24.3	10.2	2066	138,559	16.8	25.6	13.5
DO-North	1780	73,641	18.6	26.5	12.6	1843	75,843	18.1	26.6	17.8
DO-East	2229	137,822	15.5	29.4	6.4	2247	139,504	14.8	30.3	8.6
DO-South	1537	81,988	15.1	29.2	6.2	1549	82,858	14.4	30.5	8.0
Hörde	3190	22,975	15.9	25.0	17.8	3343	24,108	15.2	24.5	20.5
Dortmund	2619	580,479	16.3	25.9	12.6	2718	596,575	15.8	26.0	16.3

Authors' calculation based on KOSTAT (2018) and Stadt Dortmund (2015)
pop population

to the preceding downward slope, since 2010 Dortmund's population has increased due to migration gains, mainly driven by immigration from abroad. In our analysis as explained the seven residential communities represent a wider and postal code zones (and 1 km²-grids) a more local context.

Even among the relatively broad residential communities defined for purposes of municipal planning, considerable differentials among population characteristics outline demographic segregation. A much higher population density, for example, distinguishes the City Centre, Nordstadt and Hörde from the peripheral Dortmund-East, North, West and South districts (Table 1). Nordstadt represents a high-density worker's outskirt from the late 19th and early 20th century that became a deprived neighbourhood in the course of the decline of the nearby large-scale industrial plants.

The Hörde history since the mid-19th century was related closely to the local Phoenix steelworks. Following plant closure and dismantling of most industrial remains, a completely new neighbourhood comprising around 2000 dwelling units was constructed on part of the industrial site (Phoenix East) over the past two decades. As an infrastructure project within the large-scale Emscher Conversion Scheme (Frank and Greiwe 2012), part of the site was flooded in 2011, now comprising a 24 ha water expanse called "Phoenix-See". Construction of housing in the new quarter surrounding the lake began in 2012. It has since become one of the most favoured housing locations in Dortmund (Stadt Dortmund 2017), albeit having required a public investment amounting to around 230 million euro (NRW.BANK 2020).

The shares of children (aged <18 years) in particular and seniors (aged 60 and over) remain below the Dortmund average in the City Centre, which is obviously favoured by working-age residents (Table 1). In the adjacent Nordstadt community, on the contrary, the share of children is highest and the share of seniors lowest. In Nordstadt the share of seniors declined between 2008 and 2015, whereas the share of foreign nationals increased from 39.6 to 46.7%. During the past decade, immigration to Germany has increased considerably, culminating in a large number of refugees escaping from the war in Syria since 2015. The number of residents with a foreign

Table 2 Selected housing market characteristics (mean advertising price in Euro m²)

	2008			2015		
	Apartment/ Rent	Apartment/ Sale	House/ Sale	Apartment/ Rent	Apartment/ Sale	House/ Sale
<i>Floorspace in m²</i>						
<50	5.34	984.00	–	6.68	1017.61	–
50–70	5.01	1101.22	–	6.11	1185.54	–
70–90	5.08	1301.43	–	5.95	1443.21	–
90–120	5.70	1451.05	–	6.76	1846.54	–
>120	5.83	1546.00	–	7.78	1789.15	–
<i>Year of construction</i>						
<1950	5.18	1039.96	1318.86	6.16	866.43	1390.57
1950–1969	5.17	1075.74	1592.96	6.11	1083.10	1805.10
1970–1989	5.34	1202.78	1579.22	5.52	1303.89	1939.70
1990–1999	6.29	1612.56	1703.11	6.09	1767.56	2066.71
Since 2000	5.09	1465.22	2046.66	7.08	2036.45	2193.43
<i>Residential community</i>						
City Centre	5.70	1424.95	1540.71	7.31	1819.54	2232.57
Nordstadt	4.83	797.81	858.14	5.82	686.05	763.52
DO-West	4.85	1095.35	1668.67	5.68	1085.24	1778.95
DO-North	4.71	1143.13	1576.20	5.53	1235.73	1723.59
DO-East	5.26	1262.20	1869.89	6.04	1436.93	1929.62
DO-South	5.78	1571.20	2062.03	6.51	1837.01	2379.88
Hörde	4.97	1055.90	1295.42	6.93	2162.84	2202.83
All	5.15	1237.07	1700.84	6.28	1440.09	1764.95
Duration of offer (days), (mean)	22.8	68.8	47.4	27.2	49.3	78.4
Offers in relation to existing stock of buildings (mean) ^a	0.18	0.13	0.11	0.23	0.07	0.09
Observations	12,927	3027	2500	12,856	2778	1740

Authors' calculation based on RWI-GEO-RED (2018)

^aoffers in relation to existing buildings: 2009 and 2015

(and no German) passport has increased in all Dortmund communities, particularly since 2012.

The population with a foreign nationality represents only part of the migrant population, which is commonly defined as the population comprising the first and subsequent generations of immigrants, who came to Germany since the Second World War. While immigration has put ageing to a temporary halt in Germany as a whole, striking local variation reveals that ageing continues to proceed rapidly in districts with a low migrant inflow. In 2015, over 30% of the population in Dortmund East and South were older than 60, in Nordstadt only 15% (Table 1).

As in the City Centre and Nordstadt, population growth in Hörde combined with a rising share of foreigners (from 17.8 to 20.5%) and a slight decrease in the share of seniors. Ageing is most advanced in the Dortmund-East and South communities, while families with children prevail more in the North and West.

During the study period, the share of immigrants increased most rapidly in the outer districts (especially in Dortmund-North, East and South). It is, however, still considerably lower in the southern part of Dortmund (Dortmund-East and South) than in the Centre and North.

From 2008 to 2015 rents in Dortmund (in current prices) increased from 5.15 up to 6.28 € per m² of residential floorspace (+22%) on average, prices for owner-occupied apartments from 1237 to 1440 € per m² (+16.4%) and for one- and two-family homes from 1701 to 1765 (+3.7%) (Table 2).

As expected by land use theory, rents and prices for housing are highest in the City Centre. They are lowest in the West and North communities, where population density is comparatively low. Prices are higher in the South, however, where density is lowest among all districts. In line with a well-known North-South divide characterising the Ruhr area due to its specific settlement history (Wehling 2003), intra-urban price differentials reveal that the ageing southern part of the city is nevertheless preferred as location of residence.

Rents and prices in Hörde, where a large-scale urban regeneration programme was carried out (see above), were below the Dortmund average in 2008, i.e., before the upgrading came into effect. By 2015, prices had increased remarkably in this community. Rents per m² and prices for 1-/2-family homes now were second only to those in the City Centre and apartments on offer for sale cost more than in any other community. Rents in Hörde on average increased from 4.97 to 6.93 € per m² (+39.4%), prices for apartments from 1056 to 2163 (+105%) and for houses from 1295 to 2203 (+70%).

5 Neighbourhood stratification

5.1 Hedonic price functions for Dortmund

Estimation of hedonic price functions for rented and owner-occupied accommodation reveal considerable spatial autocorrelation among the dependent variable (as denoted by the λ statistics in Table 3) and the residuals (cf. ρ statistics). The analysis reveals a certain “size discount” on the rental market, as rents per m² decrease in line with an increase in total floorspace. No such “discount” characterises the markets for accommodation for sale.

Regarding the characteristics of neighbourhood populations, we find that across the complete survey period the price per m² for apartments on offer for sale was reduced by around 4% and rents by 1% in case *ceteris paribus* mortality in the surrounding postal code district (Figs. 1 and 2) was 1% (1 death per 100 inhabitants) higher. This may appear surprising, since prices are relatively high in the ageing south of Dortmund. However, prices increased much more and are highest in the “younger” City Centre and Hörde (see above). Rents and prices per m² for apartments were slightly lower (−0.2% and 0.6% respectively) in line with a 1% increase in the share of foreign nationals among the residents at the level of postal codes. Whereas local ageing corresponds to housing environments lacking the attributes of central city quarters preferred by the younger population, apparently in Dortmund very high

Table 3 Estimates of hedonic price function, 2007–2016, GS2SLS

	(1)	(2)	(3)
	Rent	Purchase: Apartments	Purchase: 1-/2-Family Homes
<i>Housing characteristics</i>			
Age categories	Yes	Yes	Yes
Age	-0.005*** (0.001)	-0.008*** (0.001)	-0.005*** (0.001)
Age ²	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)
Floor space (log)	-0.106*** (0.008)	0.097*** (0.014)	0.671*** (0.013)
No of rooms	0.014*** (0.003)	0.007 (0.004)	-0.014*** (0.002)
Multi-family housing	-0.008***	-0.018***	-
Floor level	(0.001)	(0.002)	-
Multi-family housing: further characteristics	Yes	Yes	-
Good state of house	0.071*** (0.004)	0.083*** (0.006)	0.038*** (0.006)
Bad state of house	-0.023*** (0.004)	-0.105*** (0.006)	-0.085*** (0.005)
Further characteristics of housing standard	Yes	Yes	Yes
Duration of offer	0.000*** (0.000)	-0.000 (0.000)	0.000 (0.000)
<i>Annual district characteristics at 5 digits postcode level</i>			
Population (log)	0.009 (0.007)	0.033** (0.017)	0.059*** (0.014)
Mortality (deaths per 100 inhabitants)	-0.013** (0.006)	-0.036*** (0.011)	0.006 (0.012)
Foreigners (in %)	-0.002*** (0.000)	-0.006*** (0.001)	-0.002 (0.002)
<i>Residential communities: time effects (reference category 2007)</i>			
Year community fixed effects 2007–2010	Yes	Yes	Yes
2011_City Centre	0.061*** (0.014)	0.103*** (0.020)	0.276 (0.072)
2011_Nordstadt	0.003 (0.015)	-0.251*** (0.060)	-0.176** (0.084)
2011_DO-West	-0.076*** (0.012)	-0.041*** (0.015)	-0.077 (0.064)
2011_DO-North	0.012 (0.011)	-0.058** (0.027)	-0.116* (0.063)
2011_DO-East	0.035*** (0.010)	0.007 (0.013)	-0.021 (0.066)

Table 3 (Continued)

	(1) Rent	(2) Purchase: Apartments	(3) Purchase: 1-/2-Family Homes
2011_DO-South	0.073*** (0.013)	0.033** (0.016)	0.053 (0.065)
2011_Hörde	-0.010 (0.016)	-0.032 (0.029)	0.008 (0.073)
Year community fixed effects 2012–2014	Yes	Yes	Yes
2015_City Centre	0.221*** (0.011)	0.234*** (0.030)	0.429*** (0.069)
2015_Nordstadt	0.146*** (0.016)	-0.020 (0.060)	0.057 (0.094)
2015_DO-West	0.132*** (0.010)	0.003 (0.022)	0.038 (0.064)
2015_DO-North	0.157*** (0.011)	0.050* (0.028)	-0.003 (0.064)
2015_DO-East	0.147*** (0.010)	0.120*** (0.018)	0.087 (0.065)
2015_DO-South	0.166*** (0.012)	0.133*** (0.020)	0.216*** (0.065)
2015_Hörde	0.154*** (0.017)	0.151*** (0.044)	0.152** (0.069)
2016_City Centre	0.240*** (0.012)	0.371*** (0.026)	- -
2016_Nordstadt	0.181*** (0.020)	0.077 (0.063)	- -
2016_DO-West	0.143*** (0.011)	0.075*** (0.019)	- -
2016_DO-North	0.170*** (0.013)	0.099*** (0.029)	- -
2016_DO-East	0.144*** (0.012)	0.159*** (0.018)	- -
2016_DO-South	0.156*** (0.013)	0.227*** (0.019)	- -
2016_Hörde	0.187*** (0.019)	0.267*** (0.037)	- -
Further char. of plot	No	No	Yes
Year fixed effects 2008–2016	Yes	Yes	Yes
Constant	0.008 (0.137)	1.437*** (0.529)	4.707*** (0.462)

Table 3 (Continued)

	(1)	(2)	(3)
	Rent	Purchase: Apartments	Purchase: 1-/2-Family Homes
Observations	16,004	15,786	25,347
λ	1.271*** (0.062)	0.743*** (0.068)	0.244*** (0.036)
ρ	1.176*** (0.073)	1.392*** (0.173)	1.447*** (0.186)

Authors' calculation based on RWI-GEO-RED (2018) (excluding observations representing the annual top 5% of offer durations per category (rent, apartments/houses for sale)), KOSTAT (2018) and dortmunderstatistik (2018). Sample of 1-/2-family homes comprises period 2008–2015 (reference category 2008). Accommodation on offer for rent represented by a 30% random sample. Standard errors allowing for heteroscedasticity in parentheses.

***/**/* = significant at 0.01/0.05/0.1-level

λ : spatial autocorrelation among dependent variable; ρ : spatial autocorrelation in error term; dependent variable: (logarithmised) price/rent in Euro/m² dwelling space (current prices, monthly observations, latest observation per object); age categories: pre-1905, 1905–1930, 1930–1944, 1944–1960, 1960–1970, 1970–1980, 1980–1990, 1990–2000, reference category: post-2000; further characteristics of dwellings in multi-family housing: cellar, lift, garden, balcony, fitted kitchen; further characteristics of 1-/2-family-homes: size of plot in m², terraced housing, building of new house is projected

shares of residents with a migrant background do not correspond to the most desired features of urbanism.

By 2015 and 2016 rents and prices had increased in all communities. Between 2007 and 2015, apartments for sale had experienced the strongest increase in prices per m² in the City Centre (+23%) and in Hörde (+15%). In 2016 the upswing accelerated even more, amounting to a 37% increase compared to 2007 in the City Centre and to a 27% increase in Hörde. Prices increased considerably also in Dortmund South (+22%) and East (+16%), but below 10% in the North and West (Table 3 and Fig. 1).

It is very likely that prices in parts of Hörde had been affected by the anticipated improvements even before new housing at the Phoenix-See entered the market. Yet, the main increase in prices took place after 2011.

Rents increased most strongly in the City Centre also (+24%), followed by Hörde (+18%), yet differentials across the Dortmund residential communities in the increase of rents were less distinct than the increase in prices for apartments on offer for sale. Increases in rents per m² were lowest in the East and West communities, but still amounted to 14% in these communities (Table 3 and Fig. 2).

Between 2008 and 2015, prices per m² of residential floorspace increased even more concerning houses on offer for sale in the City Centre (+43%) than for apartments. Prices per m² for houses increased significantly also in the South (+22%) and in Hörde (+15%).

5.2 Hedonic price functions for Dortmund residential communities

In the hedonic pricing estimations for Dortmund as a whole, neighbourhood-level price effects with respect to demographic characteristics measured at the level of postcode zones were found to be significant concerning rented accommodation and

Fig. 1 Price change 2007–2016 per unit (Euro per m² in current prices) for apartments on offer for sale in Dortmund residential communities (in %); hedonic price function (Table 3); ***/** = regression coefficients, significant at 0.01/0.05-level, spatial autoregressive model. (Authors’ illustration. Map data: GeoBasis-DE/BKG, Google. Data sources: RWI-GEO-RED (2018), KOSTAT (2018) and dortmunderstatistik (2018); lines display the boundaries of 5-digit postal code zones)

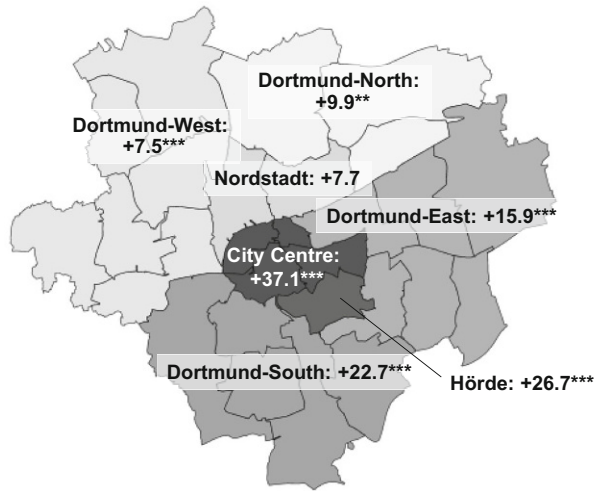


Fig. 2 Price change 2007–2016 per unit (Euro per m² in current prices) for rented accommodation in Dortmund residential communities (in %); hedonic price function (Table 3); ***/** = regression coefficients, significant at 0.01/0.05-level, spatial autoregressive model. (Authors’ illustration. Map data: GeoBasis-DE/BKG, Google. Data sources: RWI-GEO-RED (2018), KOSTAT (2018) and dortmunderstatistik (2018); lines display the boundaries of 5-digit postal code zones)



apartments and houses for sale. It is not surprising that across the complete study period prices were higher in more densely populated districts, since apparently prices per m² are highest and increased most considerably in the City Centre. Further, prices and rents were found to be reduced in line with a higher local mortality and (slightly) by a higher share of foreigners among the local population.

As expected, hedonic price estimations for separate residential communities confirm that considerable spatial autocorrelation needs to be accounted for in the measurement of housing prices. Regarding demographic characteristics measured at the smaller 1 km²-grid scale for each housing category, the analysis suggests that local ageing affects prices for houses on offer for sale in a different way than prices for apartments and rents (Table 4). In the estimations for Dortmund as a whole the coefficients assigned to district-level mortality were significant and negative among rents

Table 4 Estimates of hedonic price function for residential districts, 2007–2016, GS2SLS

	(1)	(2)	(3)
	Rent	Purchase: Apartments	1-/2-Family Homes
<i>Annual district characteristics at 1 km grid level</i>			
Community 1 (City Centre)			
Population (log)	Yes	Yes	Yes
Population aged >60 (in %)	-0.003 (0.003)	0.000 (0.006)	0.027*** (0.008)
Foreigners (in %)	-0.003** (0.001)	-0.009*** (0.003)	-0.002 (0.005)
New stock ^a	0.185 (0.159)	0.209*** (0.061)	0.451 (0.644)
Observations	1839	2118	670
λ	0.944***	0.585***	0.506***
ρ	0.874***	0.973***	1.079***
Community 2 (Nordstadt)			
Population (log)	Yes	Yes	Yes
Population aged >60 (in %)	0.001 (0.004)	0.003 (0.014)	0.011 (0.023)
Foreigners (in %)	-0.000 (0.002)	-0.002 (0.005)	-0.004 (0.008)
New stock ^a	-0.360 (0.254)	0.158 (0.182)	0.292 (0.204)
Observations	1149	820	404
λ	1.063***	0.674***	0.186
ρ	0.627***	0.389**	0.923***
Community 3 (Dortmund West)			
Population (log)	Yes	Yes	Yes
Population aged >60 (in %)	0.006*** (0.002)	0.000 (0.002)	0.003 (0.002)
Foreigners (in %)	0.003*** (0.001)	-0.003 (0.003)	-0.002 (0.002)
New stock ^a	-0.631*** (0.094)	0.047 (0.118)	0.156*** (0.058)
Observations	3997	2767	5279
λ	0.390***	0.552***	0.407***
ρ	0.939***	0.976***	1.366***
Community 4 (Dortmund North)			
Population (log)	Yes	Yes	Yes
Population aged >60 (in %)	0.003 (0.002)	0.009** (0.004)	0.002 (0.003)
Foreigners (in %)	-0.001 (0.001)	0.001 (0.002)	-0.003 (0.002)
New stock ^a	-0.091 (0.074)	0.176 (0.167)	0.073 (0.055)

Table 4 (Continued)

	(1)	(2)	(3)
	Rent	Purchase: Apartments	1-/2-Family Homes
Observations	1935	687	3321
λ	0.869***	0.669***	0.176*
ρ	0.660***	0.311**	1.107***
Community 5 (Dortmund East)			
Population (log)	Yes	Yes	Yes
Population aged >60 (in %)	0.001 (0.001)	-0.000 (0.002)	0.003*** (0.001)
Foreigners (in %)	-0.002* (0.001)	-0.006** (0.003)	-0.000 (0.001)
New stock ^a	-0.354*** (0.94)	0.025 (0.096)	0.009 (0.020)
Observations	3205	3288	6806
λ	0.973***	1.064***	0.171**
ρ	0.849***	0.526***	1.314***
Community 6 (Dortmund South)			
Population (log)	Yes	Yes	Yes
Population aged >60 (in %)	0.001 (0.001)	0.003 (0.003)	0.007*** (0.002)
Foreigners (in %)	-0.000 (0.001)	-0.003 (0.003)	0.000 (0.002)
New stock ^a	0.060 (0.125)	-0.083 (0.076)	0.050 (0.076)
Observations	1594	2433	4957
λ	0.701***	0.575***	0.437***
ρ	0.688***	0.973***	1.433***
Community 7 (Hörde)			
Population (log)	Yes	Yes	Yes
Population aged >60 (in %)	-0.003 (0.006)	-0.012 (0.013)	0.018 (0.016)
Foreigners (in %)	-0.004 (0.006)	-0.014 (0.009)	0.000 (0.008)

and apartments for sale, but insignificant for houses (see above). In the separate estimations for prices per m² in one- or two-family houses in residential communities the coefficients assigned to the share of the population aged over 60 are significant and positive in three communities (City Centre, East and South) and insignificant in the other communities.

Within the ageing East and South communities, neighbourhoods with a high share of seniors obviously represent surroundings deemed attractive for one- and two-family homes. Regarding apartments for sale, a high share of the population aged over 60 is assigned a positive price effect in Dortmund North, while the respective

Table 4 (Continued)

	(1)	(2)	(3)
	Rent	Purchase: Apartments	1-/2-Family Homes
New offers ^a	-0.143 (0.226)	-0.377 (0.278)	-0.796 (0.574)
Observations	626	646	475
λ	0.760***	0.518***	0.182
ρ	0.017	0.740***	0.918***
Housing characteristics	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Constants	Yes	Yes	Yes

Authors' calculation based on RWI-GEO-RED (2018) (excluding observations representing the annual top 5% of offer durations per category (rent, apartments/houses for sale)) and RWI-GEO-GRID (2018). Sample of 1-/2-family homes comprises period 2008–2015 (reference category 2008). Accommodation on offer for rent is represented by a 30% random sample. Standard errors allowing for heteroscedasticity in parentheses

***/**/* = significant at 0.01/0.05/0.1-level

Dependent variable: (logarithmised) price/rent in Euro/m² dwelling space (current prices, monthly observations, latest observation per object); housing characteristics cf. Table 3

^aAnnual offerings in relation to the existing stock of residential buildings

coefficients turn out insignificant in all other districts. Rents are affected (positively) only in Dortmund West (Table 4).

Rents and prices for apartments were affected (slightly) negatively by higher local shares of foreigners in the City Centre and Dortmund East, but rents were affected (slightly) positively by a higher share of foreigners among the local neighbourhoods of Dortmund West. Whereas local ageing and migrant agglomeration at the level of larger districts (representing around 20,000 inhabitants on average) tend to be regarded as disadvantageous, at the level of 1 km² grids both characteristics may affect local housing environments in the opposite direction. A larger share of senior citizens, for example, may be attributed to a safe neighbourhood at the very local level. Within a suburban district, on the other hand, a comparatively higher share of migrants may correspond to more central locations where prices are higher.

In the City Centre and in the East and West communities, housing prices apparently were affected to a significant extent by the volume of housing units entering the market in a specific year. In the Centre, average prices for apartments were even higher in case a larger number of apartments were on offer for sale in the respective neighbourhood. Rents were affected in the East and West communities, where a large local volume of rental offers coincided with a price reduction.

5.3 Community-level variation in location choice probabilities

The third step of our analysis examines the likelihood of households to have chosen accommodation in one of the seven Dortmund residential communities in each year during the period from 2009 to 2016.

In 2009, the mean sizes of households likely to move into rented accommodation were smaller than in Dortmund-West (which was the base category) in all

Table 5 Location choice probabilities, by Dortmund residential community (Multinomial logit estimation, selected results for 2009 and 2015/2016)

	City Centre	Nordstadt	DO-West	DO-North	DO-East	DO-South	Hörde
2009							
<i>Rent</i>							
Est. household size (log)	-1.106*** (0.060)	-0.458*** (0.072)	-	1.074*** (0.071)	0.023 (0.058)	-0.459*** (0.067)	-0.693*** (0.110)
Total rent/pp (log)	1.164*** (0.062)	1.144*** (0.070)	-	-0.892*** (0.069)	-0.070 (0.059)	0.398*** (0.069)	0.803*** (0.103)
$\alpha_{0h,t}$	-0.396*** (0.036)	-0.910*** (0.043)	-	-0.718*** (0.041)	-0.037 (0.032)	-0.663*** (0.038)	-1.817*** (0.060)
Observations	9524						
Pseudo-R ²	0.046						
<i>Apartments for sale</i>							
Est. household size (log)	-	2.038*** (0.102)	0.634*** (0.089)	2.136*** (0.132)	0.621*** (0.091)	0.302*** (0.087)	0.195 (0.150)
Total price/pp (log)	-	-2.685*** (0.115)	-0.820*** (0.102)	-1.871*** (0.137)	-0.706*** (0.103)	-0.031 (0.090)	-0.589*** (0.176)
$\alpha_{0h,t}$	-	-0.667*** (0.070)	-0.002 (0.055)	-1.513*** (0.096)	-0.055 (0.056)	-0.501*** (0.063)	-1.605*** (0.096)
Observations	3656						
Pseudo-R ²	0.082						
<i>Houses for sale</i>							
Est. household size (log)	0.589*** (0.131)	1.841*** (0.160)	-	0.671*** (0.098)	0.149 (0.093)	-0.116*** (0.098)	1.066*** (0.154)
Total price/pp (log)	-0.137 (0.137)	-0.967*** (0.164)	-	-0.911*** (0.098)	-0.677*** (0.086)	-0.195*** (0.089)	-0.683*** (0.172)
$\alpha_{0h,t}$	-1.767*** (0.117)	-3.617*** (0.273)	-	-0.674*** (0.080)	-0.007 (0.063)	-0.155** (0.065)	-2.608*** (0.172)

Table 5 (Continued)

	City Centre	Nordstadt	DO-West	DO-North	DO-East	DO-South	Hörde
Observations	2114						
Pseudo-R ²	0.057						
2016							
<i>Rent</i>							
Est. household size	-1.955*** (0.055)	0.868*** (0.0965)	-	1.555*** (0.072)	-0.790*** (0.048)	-0.609*** (0.053)	-0.619*** (0.062)
Total rent/pp (log)	3.005*** (0.064)	-0.212*** (0.085)	-	-1.550*** (0.082)	1.333*** (0.055)	1.034*** (0.060)	1.864*** (0.069)
$\alpha_{0h,t}$	-0.570*** (0.041)	-1.631*** (0.060)	-	-1.892*** (0.067)	-0.044 (0.033)	-0.405*** (0.0036)	-0.983*** (0.044)
Observations	11,143						
Pseudo-R ²	0.144						
<i>Apartments for sale</i>							
Est. household size	-0.417*** (0.115)	2.509*** (0.142)	0.921*** (0.103)	2.352*** (0.152)	-	-0.041 (0.113)	-0.206 (0.140)
Total price/pp (log)	1.080*** (0.133)	-4.092*** (0.193)	-1.370*** (0.124)	-2.705*** (0.186)	-	0.490*** (0.129)	2.009*** (0.173)
$\alpha_{0h,t}$	-1.114*** (0.089)	-2.349*** (0.145)	-0.252*** (0.064)	-1.942*** (0.125)	-	-0.866*** (0.079)	-2.249*** (0.151)
Observations	2512						
Pseudo-R ²	0.196						
<i>Houses for sale (2015)</i>							
Est. household size	-0.255 (0.186)	3.102*** (0.394)	-	0.274*** (0.092)	-0.593*** (0.100)	-0.668*** (0.110)	-0.509*** (0.226)

Table 5 (Continued)

	City Centre	Nordstadt	DO-West	DO-North	DO-East	DO-South	Hörde
Total price/pp (log)	1.764*** (0.181)	-0.816*** (0.256)	-	-0.437*** (0.105)	0.767*** (0.103)	1.161*** (0.113)	1.262*** (0.219)
$\alpha_{0h,t}$	-2.600*** (0.197)	-6.213*** (0.757)	-	-0.343*** (0.080)	-0.054 (0.072)	-0.422*** (0.081)	-2.477*** (0.187)
Observations	1651						
Pseudo-R ²	0.107						

Authors' calculation based on RWI-GEO-RED (2018), excluding observations representing the annual top 5% of offer durations per category (rent, apartments/houses for sale). Robust standard errors in parentheses
 ***/**/* = significant at 0.01/0.05/0.1-level
 est. household size = floorspace of dwelling in m², divided by the average floorspace per person in 2013 in corresponding residential community (Stadt Dortmund 2017); total rent/pp: total rent, divided by the average monthly purchasing power per household at the level of 1 km grids; total price/pp: total price, divided by the average annual purchasing power per household; $\alpha_{0h,t}$ = annual choice probability among households with mean characteristics

districts except for Dortmund North and East. Total rents in relation to household income were higher in all districts than in Dortmund-West, except for North and East (Table 5).

In general, considering housing on offer for rent or sale mean and household-specific probabilities characterising the likelihood to choose among six out of seven Dortmund residential communities remained relatively stable over the study period, e.g., one- and two-person-households being likely to move to the City Centre and low-income households prone to choose Nordstadt. A considerable change in the choice probabilities relating to household characteristics, however, took place with respect to Hörde. This change corresponds to a considerable upswing in prices for apartments and houses on offer for sale, which is likely to result at least partly from the environmental upgrading due to the Emscher Conversion and Phoenix-See development. In 2009, households moving into purchased accommodation in Hörde were likely to earn a comparatively low income (as denoted by negative coefficients assigned to the total price of the apartment or house in relation to local income). In 2016, they were likely to be well-off and—in case they were moving into apartments—to pay higher total prices even than households moving to the City Centre (Table 5).

For households with mean characteristics (as denoted by the coefficients for $a_{0h,t}$), however, it remained improbable to choose accommodation for rent or sale in Hörde. Regarding rented accommodation and one- or two-family homes for sale, the Dortmund West community represented mean preferences most accurately in 2009 and 2015/16. With respect to owner-occupied apartments, mean preferences shifted from the City Centre (2009) to the Dortmund East community. Whereas total prices in relation to local income differed only insignificantly between the Centre and East in 2009, in 2016 total prices for apartments in the Centre had become considerably (i.e. over one standard deviation, Table 5) higher than in the East.

While both the Centre and Hörde experienced an upswing of local housing prices, Nordstadt was affected by a continuing downturn, specifically concerning owner-occupied apartments. While the size of households likely to move in remained comparatively large, total prices remained considerably below those in the other districts and the gap between Nordstadt and the other districts in this respect has widened. In 2009, Nordstadt prices in relation to local income were 2.69 standard deviations below those in the reference category (which was the City Centre), in 2016 they were over 4 standard deviations below the reference category (Dortmund East).

6 Conclusions

We analyse whether housing prices and location choice probabilities in Dortmund over the period from 2007 to 2016 indicate a response to local demographic change at the level of different neighbourhood scales. It is difficult to isolate the effects of local ageing from other determinants of residential sorting in empirical analysis. We therefore apply different methods and incorporate neighbourhood-level statistics at varying spatial scales in order to evaluate the robustness of our results.

Hedonic price analysis drawing on spatial autoregressive models reveals that rents and prices for owner-occupied apartments are higher in neighbourhoods (i.e., 5-digit postal code zones representing around 20,000 inhabitants on average) where population ageing so far has proceeded less rapidly, which outlines a high popularity of accommodation at central city locations where the population is younger on average.

Further, the analysis finds significant effects for demographic characteristics measured at the 1 km²-grid scale, which vary among seven residential communities subdividing the Dortmund territory into broad local housing markets. The effects of ageing (measured in terms of the population share of over 60-year-olds) on the prices of one- or two-family homes are significant and positive in several communities, thus differing from those determining rents and prices for apartments.

In Hörde, fundamental environmental upgrading has been implemented due to construction of the Phoenix-See since 2011. The housing market effects demonstrate that considerable economic potentials are connected to such schemes, albeit having been initiated by a public investment of over 200 mio. euro. Rents and prices per m² have increased at impressive rates since 2011 and the average characteristics of housing that enters the market in this community changed from relatively low in total price before 2011 to small and high in price after 2011. Yet, in Hörde regeneration met with an overall desire of well-off households to reside in the southern part of the city. Prior to the Phoenix-See scheme, due to its previous vicinity to a huge steelworks site, Hörde had represented a declining lower-income enclave within the otherwise more well-off southern part of the city. The Phoenix-See scheme itself has not been designed with a view to specific age categories. The attributes of this high-quality urban housing development, however, make it likely to attract predominantly high-income working-age residents. Conversion of an industrial site in this case contributes to an urban regeneration strategy designed to overcome, among other things, some of the challenges connected to shrinking city populations.

High-income households may not be as willing to settle in other neighbourhoods in the vicinity of the Emscher conversion scheme, where the regeneration of the river will be implemented in years to come. In Hörde, an overall increase in prices was attributable mainly to the construction of a new quarter surrounding an artificial water expanse on a previously derelict industrial site located in the generally more popular southern part of Dortmund. To the west of Hörde, the Emscher swings north before crossing the border to neighbouring Castrop-Rauxel at the north-western edge of the Dortmund municipal territory. Downstream of Dortmund, the river flows through the northern parts of the Ruhr area (also known collectively as Emscher-Lippe region), which are deemed to be much less attractive as a place to live by higher-income households. In the vicinity of the Phoenix-See, on the contrary, it will be likely even for surrounding neighbourhoods located in some distance to the lake to experience gentrification.

If immigration to Germany should decrease, rapid ageing will become a prominent issue once again. As far as local migration is concerned it appears that there has been no explicit aversion by mobile households to choose residence in ageing neighbourhoods so far. Of course, while it is acceptable for cities to compete over mobile investment and population to some extent—after all, in regional economic theory

migration between regions is assumed to foster regional convergence—attracting households can only be part of an urban policy designed to overcome the local challenges of demographic change. It will be much more important to cope with ageing at a broader policy level, comprising a multitude of fields, e.g. (continuing) education, integration, health and support of entrepreneurship. Urban policy can help to adjust such policy to local variability in population ageing.

At the moment, it is uncertain whether and to what extent household location preferences will be affected by the experiences resulting from the Corona Pandemic. If workers who switch to telecommuting decided to move to more peripheral locations, this might change the ranking among the desirability of different types of residential location (Delventhal et al. 2021). Yet, even if less densely populated surroundings gain in popularity once again, it is likely that urban housing providing high-quality environmental amenities will continue to remain among the most attractive categories achieving comparatively high prices.

Apparently, the study period from 2009 to 2016 was characterised by an overwhelming dominance of the desirability to be close to central city amenities, indicated by the highest rents and prices per m² and the strongest price increases among the Dortmund residential communities. Successful implementation of the Phoenix-See regeneration scheme in Hörde confirmed that the dominating preference of central locations provided considerable potentials concerning an upgrading of inner urban neighbourhoods, in spite of a previously declining population. The experience from lockdowns during the pandemic suggests that it remains highly desirable for many people to benefit from the amenities offered by cities and that the lack of possibilities, e.g. to go shopping and to visit restaurants, cinemas or museums has been perceived as a dramatic impact on the quality of life. Perhaps more people will decide to seek accommodation in some distance to urban centres, but so far there are no indications of a beginning disurbanisation.

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Declarations

Conflict of interest U. Neumann and L. Taruttis declare that they have no competing interests.

Ethical standards This article is the authors own contribution. The authors are responsible for the study conception and design. Material preparation and analysis were performed by the authors.

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