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**Abstract**

This paper investigates how changes to the age distribution of cities' resident populations shape the growth rate of local house prices in different market segments. For estimation purposes, we combine city-level demographic information with detailed housing price data for 87 German cities over 1995-2014. We show that house prices and key demographic variables exhibit strong cross-section dependence but are panel stationary in first differences when this form of dependence is accounted for. Employing a mixed-regressive spatial panel model that incorporates spatial fixed effects as well as changes in city size, purchasing power and mortgage rates, we find that real urban house price appreciation tends to be substantially lower in cities that age more rapidly. Population aging has heterogeneous effects across housing segments: sales price growth of condominiums and single-family homes is negatively related to stronger growth of the old-age dependency ratio, while a positive association is found for aging and real rent growth.

**Keywords:** House prices · Demographic change · Urban areas · Germany

**JEL classification:** G12 · J11 · R31

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## 1 Introduction

Housing is a dominant asset in the household portfolio, and the major part of housing wealth in advanced economies is concentrated in urban areas. According to the most recent World Bank data, three out of four Germans, four out of five Americans, and nine out of ten Japanese live in cities.[1] Wealth formation in the household sector is therefore closely tied to the evolution of housing prices in the very same locations that lie at the heart of economic activity (Rosenthal and Strange 2004).

While a steady trend towards urbanization is expected to keep cities growing in terms of population, an often overlooked impact factor on urban housing wealth is a major shift to the age structure of residents. Many advanced countries are stepping into a rapid aging phase, and there is considerable concern about to what extent population aging will affect housing markets. Starting with Mankiw and Weil (1989), a long list of papers has argued that working age households tend to have greater demand for housing than retirement agers (see, e. g., Engelhardt and Poterba 1991, Pitkin and Myers 1994, Ermisch 1996, Ohtake and Shintani 1996, Eichholtz and Lindenthal 2014, and the references therein): in the absence of frictions, the consumption of housing services underlies a lifecycle, which implies that shifts to the age structure alter demand in the market for housing services. A similar argument can be made for the demand of housing as a durable capital good (as for retirement saving): urban house prices will be affected if households entering retirement age dissolve urban housing capital and move towards more remote locations. If demand changes related to aging are reflected in prices (which is plausible in the market for housing), theory suggests that permanent and major increases in the retirement-to-working age ratio of city residents should systematically affect the trajectory of urban housing prices.[2] An issue that has seen much less attention so far in the academic literature is that retirement-age city residents are expected to demand housing in market segments much different from working-age residents. Different segments of urban housing markets should therefore be heterogeneously affected by aging.

The aim of this paper is to examine empirically how historical changes to the age composition of city populations have been related to the trajectory of housing prices, spanning different types of owner-occupied as well as rental housing. In its scope and research design, the study draws upon recent research by Takáts (2012), who shows that changes to demography have substantially shaped real house price developments in OECD economies during the past 40 years. The cited and related papers are based

[1] See http://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS. Depending on national definitions, the term "urban area" can extend to cities, towns, as well as larger conurbations. In this paper, we refer to a sample of 87 administratively self-standing German cities as urban areas.

[2] Since a substantial part of urban housing capital is debt-financed, severe house price declines can pose a threat to household net wealth, which can in turn impair financial stability (Mian and Sufi 2011). The systemic relevance of urban house prices is further amplified by evidence that real house price changes in cities tend to "ripple" towards geographically adjacent regions (Meen 1999, Lee and Chien 2011).

on macroeconomic data, which is why they deal carefully with issues related to panel stationarity and model specification. However, a remaining concern with their results is *aggregation bias*. It is well established that housing markets are local by nature, being linked together in space through commuting, migration or common shocks (Meen 2012). Such factors are impossible to be appropriately captured by the analysis of non-spatial data. National analysis also uses to pool data on different (and possibly heterogeneous) segments, which precludes any statements on the effects of aging on different housing submarkets. In a recent contribution on segmented housing search, Piazzesi et al. (2015) find that search activity and inventory co-vary positively within but negatively across cities, a finding that strongly supports the analysis of different housing segments at the city level.[3]

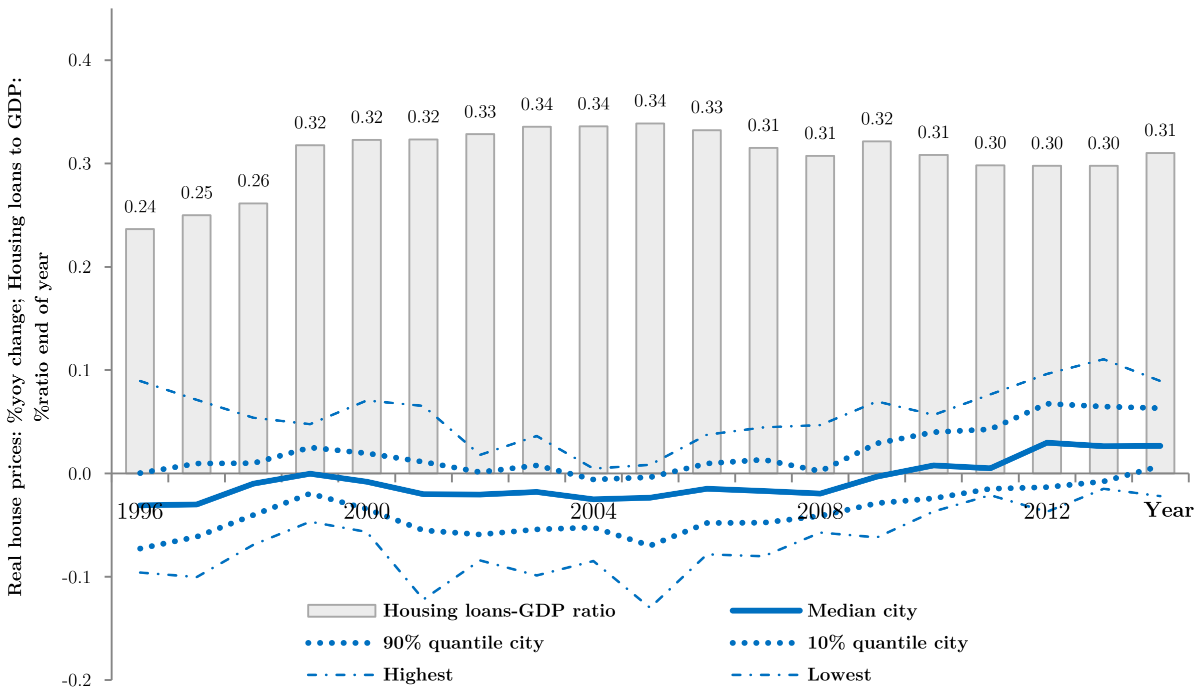
Collecting data from official and private sources, we construct an untapped panel data set that spans yearly observations on real house prices in different market segments and a broad range of demographic and socio-economic variables for 87 German cities over 1995-2014. We manage to make two major contributions to the literature by studying this data. Following recent work on spatial panel models by Lee and Yu (2010a, 2010b), we first derive possibly unbiased estimates for the aging-house price relationship at the city level within a mixed-regressive spatial panel framework. The framework explicitly accounts for cross-section dependence among urban housing markets as well as for spatially autocorrelated disturbances. Along with spatial dependence, we implicitly control for unobserved heterogeneity in the size of local housing supply elasticity by including city-level fixed effects. Secondly, we establish first-time empirical evidence regarding the heterogeneity in how population aging affects different major housing segments: condominiums, single-family homes and (unregulated) rental apartments. While not yet having been scrutinized in the literature, this heterogeneity carries important implications for urban housing policy and planning.

Cities in Germany lend their selves exceptionally useful for the analysis of the links between demography and housing prices. Due to historical circumstances – most notably, the political separation of East and West Germany between 1945 and 1990 – there has been considerable variation in demographic developments across urban areas over the last 25 years. This variation partly originates from differences in birth behavior and life expectancy, but also from large differences in net migration. At the same time, the German system of housing finance has been very stable over the sample period. For U.S. cities, differences in the development of subprime lending, mortgage securitization and home foreclosures have been well documented to considerably affect house price trajectories (Favara and Imbs 2015, Mian et al. 2015). Since the prevalence of subprime lending has been highly correlated with urban demographics such as minority or young working-age households, empirical estimates of the nexus between demographic changes and house prices based on US data may be severely biased.

[3] In related work, Genesove and Han (2012) document that changes to aggregate demand shape long-run city house price appreciation much more than shifts of relative demand between intra-city locations

The considerable amount of cross-city variation in real house price appreciation rates in German cities is illustrated by Figure 1. The figure combines a weighted average of inflation-corrected annual percentage changes of condominium prices, single-family home prices and apartment rents for different quantiles of the sample distribution (represented by solid, point and dashed lines) with information on the development of consumer housing credit relative to national GDP. The figure shows that house prices for the median city almost remained constant in real terms over the sample period (tracking aggregate national house prices). The level of heterogeneity in price changes across cities, measured by the absolute difference between the highest and lowest annual appreciation rate, ranges from 9.0 percentage points in 2004 to 18.7 points in 2001. No single city experienced a boom-bust cycle in real house prices over the sample period, which is indicated by a national volume of private housing loans that has remained flat relative to aggregate production.

**Figure 1.** Real housing price growth and housing loans relative to GDP, 1996-2014.




*Source: Authors' own illustration based on data by bulwiengesa AG (house prices), Bundesbank (housing loans) and German Federal Statistical Office (GDP, CPI inflation). Quantiles of the distribution of percentage year-over-year real housing price change across all cities refer to individual years.*

Our econometric results lend strong support to the hypothesis that the development of a city's age structure is a fundamental determinant of local house price evolutions. The effects of population aging are heterogeneous across segments: our favorite specification suggests that real sales price growth of existing condominiums and single-family homes is negatively related to stronger growth in the old-age dependence ratio (with condominium prices being more severely affected than home prices), whereas a positive association is found between increases in the old-age dependency ratio and real rent growth. A possible explanation for this asymmetry is that relative demand for condominiums and homes as a form of capital investment is declining with aging populations, whereas demand for housing services in the urban rental sector increases with growing population shares of the elderly. This interpretation is in line with recent micro data evidence that German households do not tend to substantially downsize housing consumption in old age.

The remainder of the paper is organized as follows. Section 2 reviews the economic theory on the effects of demography on housing demand and prices. It also discusses the existing empirical evidence at the macro and micro levels. Combining the national perspective with a view on individual cities, Section 3 presents stylized facts regarding the past and expected future developments of key demographic indicators in Germany. In Section 4 we present the data, discuss its cross-section dependence and panel stationarity properties and introduce a generic framework for the econometric analysis. Section 5 serves to present segment-wise regression results for spatial and non-spatial panel specifications of the housing price equations. We interpret direct and indirect spatial effects and discuss similarities and differences between housing segments. Section 6 concludes with implications for policy and further research.

## 2 Literature review

### 2.1 Demography and house prices: theory

Economic theory suggests at least three distinct channels through which changes in the age structure of a city's resident population can affect local house prices. The first channel is the effect of aging on the *demand for housing services*. Along with incomes and preferences, the total number of adult residents is a major driver of aggregate demand for housing services in a location (Mankiw and Weil 1989, DiPasquale and Wheaton 1994). Assuming that the long-run housing supply schedule is finitely elastic, house prices increase after a permanent positive shock to population size. A change in the house price level due to a population shift without any change to the age composition can be labelled as a *size effect*.

In addition to the size effect, the optimal path of individual housing services consumption underlies a life cycle (Flavin and Yamashita 2002): individual housing services consumption should be comparatively low during schooling years, increase with labor market entry, peak at starting and maintaining a family and decrease again in retirement age.[4] When the relative size of the retirement-age population experiences a permanent upward shift, the price of housing services should therefore decline. This can be labelled as an *age composition effect*, which is expected to act independently of the size effect (Takáts 2012).

[4] In the presence of borrowing constraints and other frictions, households face obstacles of smoothing housing services consumption over the life cycle and will purchase self-owned housing (which often requires a down payment and high levels of creditworthiness) in later stages in life.

A second channel is the effect of aging on *investment demand for housing* as a durable asset. In stylized models of savings behavior over the life cycle, young individuals purchase capital as a conduit of saving and retirement provision and dissolve (parts of) their assets in retirement age to move to peripheral locations or to rent again (Henderson and Ioannides 1983, Kraft and Munk 2011). Analogous to housing services demand, a permanent upward shift in the ratio between retirement-age and working-age individuals thus implies lower investment demand for housing. The magnitude of any price effects arising from such changes in housing investment demand will again depend on the local price elasticity of housing supply. Different from housing services demand, however, the price effects of aging on investment demand are inherently self-reinforcing: forward-looking home buyers may anticipate future price declines caused by forthcoming increases in the ratio of sellers to buyers in the market. Since lower expected real house price gains increase housing capital costs, this decreases housing investment demand and prices further today.

In addition to affecting the demand for housing services and capital, a more subtle third channel relates to the *supply side* of urban housing markets. While changes to local demography are unlikely to affect construction costs due to the high mobility of construction workers and other inputs, an essential housing production factor that is likely to be affected is the amount of land available for new construction. Anticipating population aging and decline, city planners typically tighten zoning laws in order to stabilize prices in the stock (Mayer and Somerville, 2000, Glaeser et al. 2006). Another possibility to stabilize prices is to remove excess housing through demolition.[5] Any reduced-form empirical estimate of a house price-demography relationship at the city level will pick up the combined effect of demography-related changes in demand and a possible planning-related change in local supply.

A major difference between a local versus a more aggregate view of the aging-house price link lies in the relative importance of migration. At the level of the nation, internal migration completely cancels out and external migration is typically negligible relative to total population. Demographic change is thus mainly driven by shocks to fertility and life expectancy. In a cross-section of cities, however, internal migration can contribute significantly to demographic shifts. Since the decision to move is not independent of age, a considerable part of the "age composition effect" may originate from net migration: wherever working-age migrants tend to go, the age composition will change towards higher shares of younger age cohorts, while housing demand and prices will tend to increase. Indeed, Arntz and Wilke (2009) show that internal migration in Germany is dominated by job-related moves of high-qualified workers. From a methodological viewpoint, internal migration may also give rise to spatial autocorrelation between individual units of observation.

[5] Both measures were realized at larger scale in eastern German cities since reunification (Bernt 2009).

## 2.2 Existing evidence at the micro and macro levels

Since a seminal paper by Mankiw and Weil (1989), housing market effects of demographic change have been an active area of empirical research in economics. Combining household data from the US census with time series on the age structure of the US population, Mankiw and Weil constructed a national time series of age-related housing demand and subsequently regressed the first difference in national real home prices against the first difference of this indicator. The regression indicated a strong inverse relationship, which led Mankiw and Weil to conclude that future house prices could decrease to considerably lower levels due to expected demographic headwinds.

While Mankiw and Weil's macro conclusions induced intense debate, their finding of an inverse microeconomic link between age and housing demand found general acceptance among researchers.[6] Unresolved questions, however, remain: one crucial aspect is the timing and effective amount to which the elderly downsize housing consumption. International comparisons have pointed towards considerable differences in age-related housing demand trajectories across countries, with housing demand being rather flat after retirement entry in central European countries (Chiuri and Japelli 2010). There is also a lack of consensus as to which demographic variables should optimally be used to explain aggregate house price evolutions. In their original paper, Mankiw and Weil state that their demand indicator derived from household survey data is "not very different from a time series on the adult population" (Mankiw and Weil 1989, p. 242).[7] Including only changes to the adult population in a housing price equation might produce flawed results, given that an independent and economically meaningful relationship between prices and the age *composition* of the adult population is ignored.[8] More recent studies have therefore used both overall population size as well as the age structure (in form of the old-age dependency ratio) as self-standing independent variables to explain changes in house prices (see, e.g. Takáts 2012).

Concerning more recent empirical findings from micro data, Ferndández-Villaverde and Krueger (2007) and Yang (2009) – both using US data – provide evidence that housing consumption in all income brackets first monotonically increases with age, before flattening out towards the end of the life cycle rather than decreasing substantially. This view partially refutes the classic idea of an inverse U-shaped life cycle pattern of housing consumption that easily arrives in the absence of borrowing constraints. For European countries, Eichholtz and Lindenthal (2014) show that cohort-corrected demand for housing services in England steadily increases with age for adult household

[6] There are few exceptions to this rule. For example, Green and Hendershott (1996) find that the quantity of housing demand does not decrease with age *per se*, but is determined by education and income.

[7] Poterba et al. (1991) even clarify that "Mankiw-Weil housing demand (…) is essentially the same as the adult population" (Poterba et al., 1991, p. 186).

[8] Technically, including only changes to the adult population in a house price regression is equivalent with the assumption that shifts to the age structure *within* the adult population do not matter for price determination in the housing market.

heads, peaking just before retirement (50-64 years). For retirees, housing consumption decreases only at slow pace and constantly remains above consumption levels in younger age. Examining data from the Dutch Housing Demand Survey, Clark and Deurloo (2006) also report evidence of housing over-consumption by elderly households.

For Germany, empirical evidence from micro data equally suggests a rather flat pattern of age-related housing demand after retirement. Based on data from different waves of the German Socio-Economic Panel (G-SOEP), Keese (2012) shows that many Germans do not seriously downsize housing consumption. This holds even in the case that children move out or the partner deceases. Also using data from the G-SOEP, Boehm and Schlottmann (2014) find a moderate probability that Germans who initially achieved homeownership return to rental tenure or move to smaller homes in old age. They also find local house price changes to have little effect on the demand for owner-occupied housing, which they interpret as evidence against a strong independent role of housing investment demand among German households.

While household survey data is regarded highly instructive for analyzing age-related patterns of individual housing consumption, due to limited sample size it has to be silent on the implications of local demographic shifts for wider house price developments in smaller geographic areas. For practical reasons, most studies using micro data focus entirely on the demand for housing services. Recent studies based on aggregate data suggest strong empirical links between demography and housing prices, both at the national and regional levels. Takáts (2012) finds that real house price growth across 22 OECD countries over 1970-2009 was promoted by population growth but heavily depressed by aging populations, *ceteris paribus*. His favorite specification produces an estimate of the partial elasticity of real house prices with respect to population size of 1.05, while the partial elasticity with respect to the old-age dependency ratio is estimated at -0.68. According to these findings, he projects that the major directional shift in demographics over the next decades should decrease house prices by an average of 80 basis points per annum in the analyzed countries. Saita et al. (2013) get comparable results based on data for Japanese prefectures and US states over 1976-2010 and 1975-2011, respectively. Their results point towards even stronger house price effects of demography: especially for Japanese prefectures, the coefficients estimated on the effects of population aging are larger, while those estimated on total population are comparable to those found by Takáts.

Given the local nature of housing markets, there is a striking paucity of studies that investigate the long-term housing price effects of demography using city data.[9] One of

[9] Many papers using local housing market data have concentrated on the short-run, cyclical behavior of metropolitan housing prices. Some studies focus on transitory metropolitan house price bubbles (Gallin 2008, Goodman and Thibodeau 2008, Glaeser et al. 2008). Others focus on the time series properties of city-level house price data (Capozza et al. 2002, Miller and Peng 2006). Another line of papers has concentrated on heterogeneity with regard to the reactions of city-level house prices to a monetary stimulus or shocks to aggregate macroeconomic variables (Himmelberg et al. 2005, Carlino and DeFina 2008). Yet

the few exceptions is Maennig and Dust (2008), who study the quantitative relationship between the 1992-2002 percentage change in population and 2002 single-family house prices across 98 German cities. Their analysis suggests no statistically significant relationship between house prices and past population increases, whereas population decline between 1992 and 2002 is associated with significantly lower price levels in 2002. Since their analysis draws alone on cross-sectional information on single-family home prices, they can neither trace back the effects of gradual changes in cities' age distributions on local house prices over time, nor the heterogeneity of such effects across different segments of the housing market.

## 3 National and city-wide demographic trends in Germany

Similar to other advanced economies like the US or Japan, Germany is expected to be severely affected by demographic change in upcoming decades. While the nation's total population remained roughly constant at 81 million over 1995-2014, the most recent 13th official demographic projection by the German Federal Statistical Office expects the population size to decline by five to ten per cent until the year of 2050 (Destatis 2015).[10] The main underlying cause of this expected decline is low overall fertility. Importantly, a higher balance of external migration may dampen future decline in population, but not stop or even reverse it.

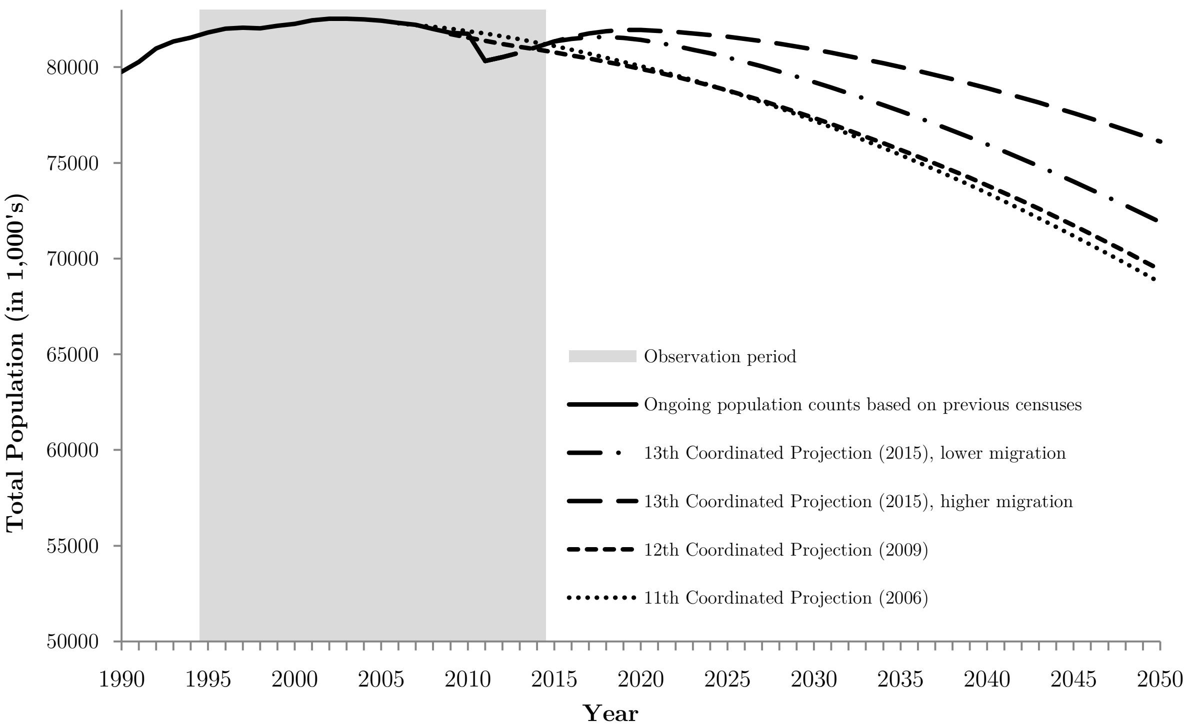
Combining data from ongoing population statistics with the "medium variant" of the official population projection, Figure 2 shows that even under the assumption of a high long-term average migration balance of +200,000 persons annually, total population will decrease by about over four million inhabitants between 2012 and 2050. In comparing the expected trajectories of the most recent projection with previous contemporary projections that were conducted by the same authority in 2009 and 2006, at the same time the figure illustrates the relatively high uncertainty of population projections.[11] While the most recent projection points towards a slower rate of shrinkage that starts later than projected by its predecessors, the big picture remains largely unchanged.

another strand investigates endogenous spatial contagion and co-cyclicity among metropolitan housing prices (Beenstock and Felsenstein 2010, Holly et al. 2010, Kuethe and Pede 2011, Brady 2011, Zhu et al. 2013).

[10] The German Statistical Office provides eight different projection scenarios, each of which differs by assumptions regarding the total rate of fertility (the number of live-births per woman), the life expectancy for males and females, and the net migration balance. We report data from two versions of the "medium variant", which assumes that fertility and life expectancy remain at their current levels and only differs with respect to assumptions on net migration.

[11] The 2011 Census revealed that continuous updates of population figures from previous censuses based on flow data (deaths, live-births, and new residents' registrations) led to an overestimation of the actual population by about 1.4 million or 1.7 per cent.

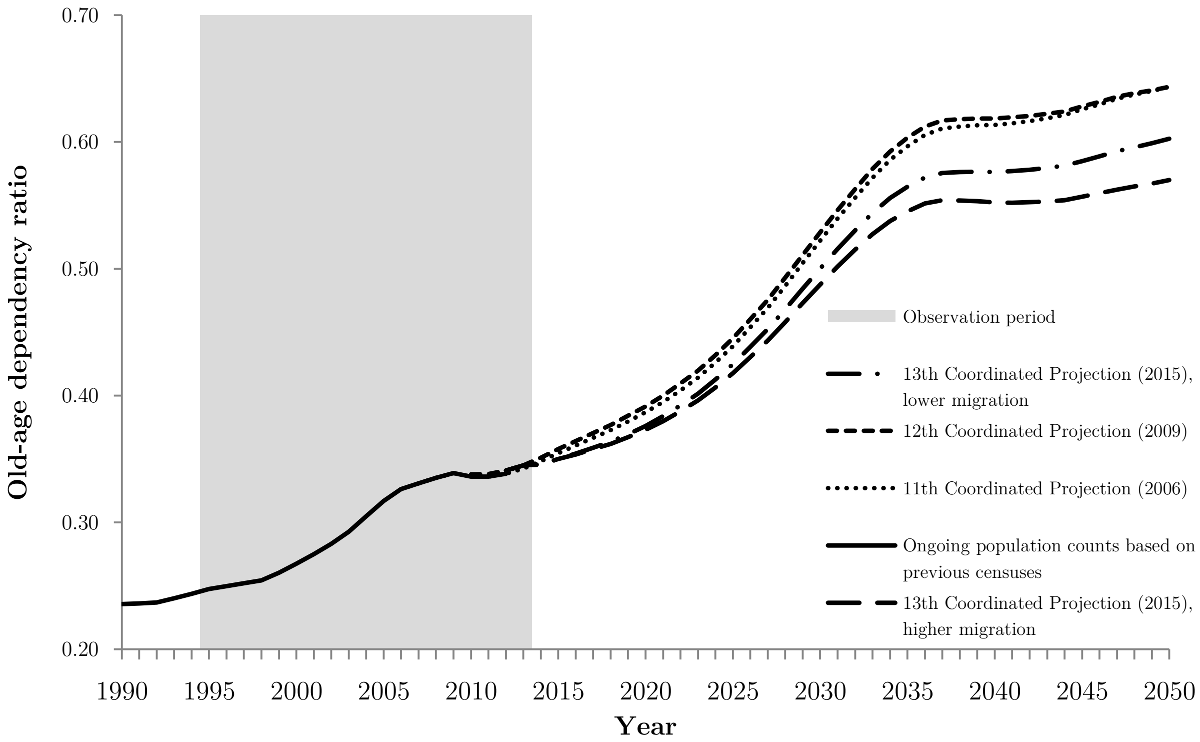
**Figure 2.** Projected development of the total population in Germany until 2050.




*Source: German Federal Statistical Office: Ongoing population counts based on previous censuses; 11th, 12th and 13th Coordinated Population Projection, Var. 1-W1/2*

Interconnected with overall decline, the future age profile of Germany's population is expected to look substantially different from today. Due to low fertility and increasing life expectancy, the national population share of elderly persons is expected to increase at a much higher pace than it did over the past two decades. Figure 3 illustrates this trend by displaying the expected development of the nationwide old-age dependency ratio, which we define as the percentage ratio of persons aged 65 years or older to persons aged between 20-64 years. Information from ongoing population counts is again combined with current and past contemporary projections by the German Federal Statistical Office to highlight uncertainty in demographic projections. Again referring to the "medium variant" of most recent official projection, Germany's nationwide old-age dependency ratio is expected to jump sharply from 0.35 in 2014 to a level of 0.5 in 2030, before growing at a slower pace until 2050. Compared with population decline, this trend is much more substantial and also much less sensitive to net migration: compared to a projected decrease in population size of five to ten per cent over 2014-2030, the projection implies an upward shift in the old-age dependency ratio of almost 50 per cent over the same time horizon.

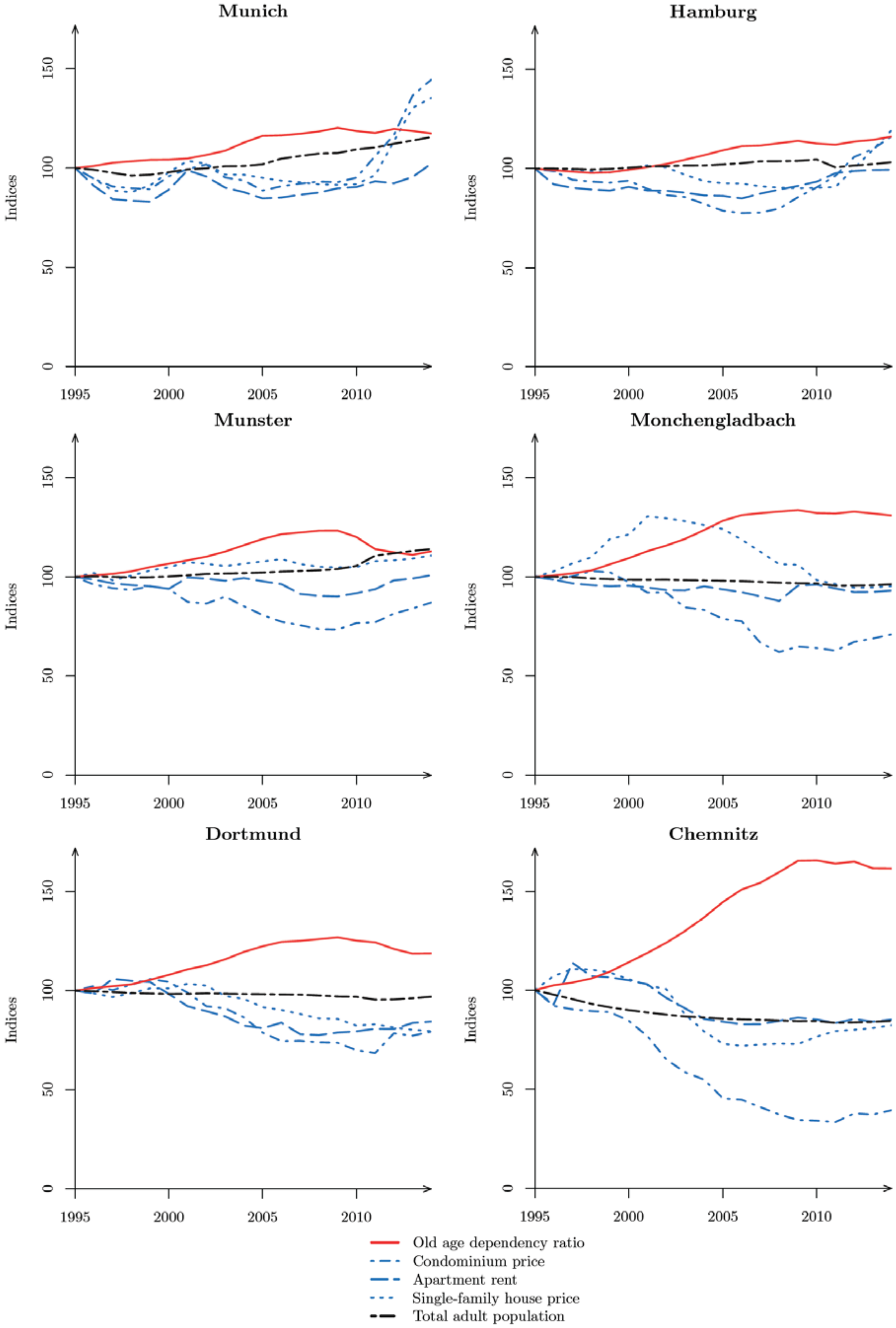
**Figure 3.** Projected development of the old-age dependency ratio in Germany until 2050.




*Source: German Federal Statistical Office, Ongoing population counts based on previous censuses; 11th, 12th and 13th Coordinated Population Projection, Var. 1-W1/2, authors' own calculations.*

National demographics disguise the high level of spatial diversity as a distinct feature of demographic change. Due to differences in natural population movements and net migration, individual cities can evolve very differently from the nation as a whole. Figure 4 illustrates that the variation of temporal developments of population size and age structures across cities was indeed substantial during the sample period. It displays six characteristic examples by plotting line charts for the total population, the old-age dependency ratio and the inflation-corrected house prices in the three covered segments over 1995-2014 (all series are indexed to 1995=100). Tentatively, less shrinkage and less rapid aging go along with better performing real house prices: Munich's (upper left panel) population displayed mainly positive growth, while its old-age dependency ratio increased only slightly by a cumulative 20 per cent. Real housing prices displayed largely positive growth rates except for rents. The Saxon city of Chemnitz (lower right panel) is an example of exactly contrary developments: due to a strong outflow of working-age persons, population growth was mostly negative, while the old-age dependency ratio increased steeply by a cumulative 67 per cent. Real housing prices in all segments declined considerably. The four other graphs depict examples of cities that lie somewhere between these two extreme cases. In what follows, we analyze this variation in more depth to identify the partial links between cross-city differences in the extent of population aging and segment-wise real house price appreciation.

**Figure 4.** Examples of city-wide real house price change and demographic change, 1995-2014.




*Source: Authors' own illustration based on data from bulwiengesa AG (housing prices) and the German Federal Statistical Office (CPI, population, old-age dependency ratio),*

## 4 Analytic framework and data

### 4.1 A generic model

Demographic change is a potentially important, but not exclusive factor affecting changes to housing demand and prices at the city level. Any reasonable empirical model must accommodate changes to other relevant factors that plausibly correlate with prices and the demographic variables. Along with potential non-stationarity of the individual panel time series, possible concerns are spatial dependence between local house prices as well as common shocks generating spatial correlation in the disturbances.

We specify a generic empirical model as follows:

$$\Delta p_{it} = \rho \sum_{j=1}^{N} w_{ij}\, \Delta p_{jt} + \beta_1 \Delta old_{it} + \beta_2 \Delta pop_{it} + \mathbf{x'}_{\mathbf{it}} \boldsymbol{\gamma}_{\boldsymbol{k}} + \mu_i + \varepsilon_{it} \tag{1}$$

$$\text{with} \qquad \varepsilon_{it} = \lambda \textstyle\sum_{j=1}^{N} w_{ij}\, \varepsilon_{jt} + u_{it}\,, \qquad u_{it} \sim (0, \sigma_i^2)$$

where $\Delta p_{it}$ denotes real house price growth in city $i$ between time period $t$ and $t-1$ (captured by the first differenced log house price corrected for CPI inflation), $\Delta old_{it}$ is percentage growth in the ratio of retirement age to working age residents (the old-age dependency ratio), $\Delta pop_{it}$ is percentage growth in total adult population, $\mathbf{x}_{\mathbf{it}}$ is a vector of further covariates, $\mu_i$ represents unobserved fixed effects (like local differences in supply elasticity, see Glaeser et al. 2008, Saiz 2010), $\varepsilon_{it}$ is a composite error term, and $u_{it}$ is a random disturbance with zero mean and heteroscedastic variance. The (vectors of) parameters to be estimated in this model are $\rho$, $\beta_{1,2}$, $\boldsymbol{\gamma}_{\mathbf{k}}$ and $\lambda$.

As proposed by Kapoor et al (2007), this mixed-autoregressive spatial panel specification accommodates cross-section dependence in housing prices by including a spatial lag the dependent variable, as well as spatially correlated common shocks by including a Cliff and Ord type spatial error process in the disturbances. This type of model has been labelled spatial simultaneous autocorrelation (SAC) model by LeSage and Pace (2009) and spatial autoregressive model with autoregressive disturbances (SARAR) by Kelejian and Prucha (1998). Spatial dependence in house prices may arise from interactions within socioeconomic networks, whereas spatial autocorrelation in the disturbances arises from unobserved shocks or simply from the use of administrative boundaries (Chudik and Pesaran 2014). Depending on the extent of spatial dependence and on whether the source of dependence is correlated with the included covariates, conventional panel estimators may result in misleading standard errors or even biased and inconsistent estimators (Sarafidis and Wansbeek 2012). Both spatial processes are governed by a non-stochastic, row-standardized $N$-dimensional spatial weight matrix $\mathbf{W}$. We choose the elements $w_{ij}$ to mirror the inverse physical distances between the geographic centroids of the individual cities.

The vector $\mathbf{x}_{\mathbf{it}}$ incorporates a set of time-varying covariates for statistical control. Given that changes to local demographics are expected to be correlated with changes to local productivity and labor supply, we include annual growth in real purchasing power per capita. In view of recent empirical evidence that individual education is a key determinant of housing demand (Eichholtz and Lindenthal 2014) and might also serve as a reasonable proxy for expected future income, we additionally include percentage growth in the ratio of workers with college-level education and workers without any educational degree, which we label the city's human capital ratio. Finally, we account for changes in national housing financing costs over time by including the average inflation-corrected effective interest rate on mortgages with initial interest rate fixation periods of 10 years or more in year $t$.[12]

It is important to note that the above specification nests the pooled OLS specification without spatial effects employed on OECD country data by Takáts (2012), including mortgage interest instead of time fixed effects and augmenting the model by an additional explanatory variable (the human capital ratio). We estimate the same generic equation separately for resale prices of existing condominiums, resale prices of existing single-family homes, and market rents of existing unregulated rental apartments (exclusive of heating and other additional utility costs).

The empirical evidence in favor or against statistically and economically relevant partial associations between real urban house price appreciation in different segments and changes to the old-age dependency ratio will be based on the statistical significance and magnitude of $\beta_1$. From theory, negative coefficients are expected for the change in the old-age dependency ratio and for the real mortgage interest rate. The partial elasticities of real house price growth with respect to growth in total population, real purchasing power and the human capital ratio are expected to be positive. For sake of comparison, we additionally report results on estimations of non-spatial versions of the same model by pooled OLS and conventional panel fixed effects.

## 4.2 Data definitions and sources

Our econometric analysis relies on a panel data set with 87 independent German cities (*"Kreisfreie Städte"*) on its cross-sectional dimension and 20 years (1995-2014) on its time period dimension. Figure 5 below illustrates the geographic locations of all cities included in the data set. According to the 2011 Census, the included cities cover 30.5 per cent of the overall German population.

Variable definitions and data sources are reported in Table 1. As representative measures of urban house prices in different market segments, we use average resale prices and rents for existing condominiums, single-family homes and apartments of predefined size, quality and location. The price information is provided by the private consulting firm bulwiengesa AG. It relies on standardized annual surveys among local

[12] Since the German mortgage market can be seen as highly integrated, we assume the interest rate to be the same for all cities. There may be some cross-city variation in other user cost components, such as property tax or maintenance. This variation tends to be very limited in practice and relatively stable over time, so we expect it to be picked up by city-level fixed effects.

appraisers, surveyors and brokers. The data is used for housing market analysis on a regular basis by the BIS, OECD and the German Bundesbank (Kajuth et al. 2013) and is widely respected as a valid indicator of spatially disaggregated house prices (for which no public source is available).[13] For a recent macroeconomic study using the data source, see Geiger et al. (2016).

**Figure 5.** Geographic locations of all 87 cities in the sample.


*Source: Authors' own visualization based on Google Maps.*

Annual data on city-level populations in different age brackets is obtained from the regional branches of the German Federal Statistical Office. We compute annual percentage changes in total adult population and the old-age dependency ratio, for which we use the same definition as outlined in Section 3.[14] Annual data on local purchasing

[13] The public national home price index, which is published by the Federal Statistical Office, is derived from disaggregated transaction data reported by public local boards of surveyors (*Lokale Gutachterausschüsse*). The index is not yet available for individual cities.

[14] Since we use annual percentage changes instead of absolute values for the demographic variables, our individual panel time series on city populations and age structures are robust to the structural break emerging from the 2011 German Census, which revealed that the total population of residents in Germany as a whole was about 1.8 per cent lower than assumed through statistical extrapolation of prior popu-

power per capita is obtained from the private research institution Gesellschaft für Konsumforschung (GfK). The corresponding information is compiled by evaluating publicly available data on local taxable income and consumer spending. We compute the annual changes of the corresponding time series and correct them by CPI inflation to arrive at a measure of the change of real current available income of local residents. Data on percentage changes in the proportion of workers with college degree to those without any formal labor market qualification in each city is obtained from the Federal Employment Agency. Data on average effective mortgage interest rates for residential mortgages are obtained from the German Bundesbank. Data on annual CPI inflation is obtained from the Federal Statistical office.

**Table 1.** Variable definitions and data sources.

| Variable | Definition | Data sources |
|---|---|---|
| Real condominium price | Inflation-corrected average resale price of existing condominiums [EUR/sqm] | bulwiengesa AG, Federal Statistical Office |
| Real single-family house price | Inflation-corrected average resale price of existing single-family homes [EUR] | bulwiengesa AG, Federal Statistical Office |
| Real apartment rent | Inflation-corrected average rental price of existing rental apartments [EUR/sqm] | bulwiengesa AG, Federal Statistical Office |
| Total adult population | Number of residents aged 20 years or older | Regional Statistical Offices |
| Old-age dependency ratio | Ratio of residents aged 65 years or older to residents aged 20-64 years | Regional Statistical Offices |
| Real purchasing power per capita | Inflation-corrected average available income per resident | Gesellschaft für Konsumforschung, Federal Statistical Office |
| Human capital ratio | Ratio of workers with college degree to workers without formal educational degree | Federal Employment Agency |
| Real mortgage interest rate | Inflation-corrected average effective annual interest on residential mortgages to private households with initial interest fixation of 10 years or more | Bundesbank, Federal Statistical Office |

### 4.3 Testing for cross-section dependence and panel unit root

Table 2 reports descriptive statistics for the entire set of variables, along with test statistics on cross-section dependence and panel stationarity. All individual panel time series are annual percentage growth rates.[15] The need for testing cross-section dependence arises from the assumption that cities pertaining to the same national housing market are highly unlikely to be economically independent. Since conventional tests for panel stationarity assume stochastic independence across units, an evolving literature

lation counts based on births, fatalities and local public registers. For the Census year of 2011, annual percentage changes are calculated based on pre-Census information on population levels.

[15] Table A1 in the Appendix provides an overview of average absolute values over the sample period.

on panel unit root testing in large panel models has pointed out that such tests may be seriously distorted in the presence of cross-section dependence (Chudik and Pesaran 2014). Appropriate stationarity testing needs tests that are robust against this possible source of distortion.

In order to first test for cross-section dependence, we implement the panel cross section dependence test by Pesaran (2004). Instead of imposing any dependence structure on the data in form of a particular spatial weight matrix, this test is based on pair-wise coefficients of correlation between the individual time series, which makes the test highly general. We secondly check for unit roots in the individual panel time series employing the Im-Pesaran-Shin panel unit root test in the presence of cross-section dependence (Pesaran, 2007).

Mean values and standard deviations for the three house price growth rate variables show that house prices in all segments displayed slightly negative average growth rates after correcting for consumer inflation, albeit with considerably large standard deviations that range between 3.7 and 5 percentage points. Concerning the explanatory variables, the annual percentage growth of city-wide old-age dependency ratios was positive on average with a moderate standard deviation, whereas average population and real purchasing power growth were both close to zero. The ratio of high- and low-qualified city workers displayed the highest average annual growth rate among all variables, indicating considerable gains in urban human capital over the sample period. According to the cross-section dependence tests, extensive cross-section dependence is clearly present in all variables. The individual panel time series throughout are panel-stationary under cross-section dependence.

**Table 2.** Descriptive statistics and tests on panel properties of the data.

| **Dependent variables** | **Mean** | **St. Dev.** | **Min.** | **Max.** | **CD test** | **CIPS test** | **NxT** |
|---|---|---|---|---|---|---|---|
| Pct. growth of real price: existing condominiums | -0.0028 | 0.0400 | -0.2036 | 0.2307 | 53.09*** | -4.259 | 87x19 |
| Pct. growth of real price: existing single-family homes | -0.0127 | 0.0509 | -0.2713 | 0.2031 | 97.5*** | -4.063 | 87x19 |
| Pct. growth of real rents: existing apartments | -0.0094 | 0.0372 | -0.2066 | 0.1623 | 84.01*** | -4.463 | 87x19 |
| **Independent variables** | | | | | | | |
| Pct. growth of old-age dependency ratio | 0.0132 | 0.0190 | -0.0607 | 0.0879 | 180.92*** | -3.39 | 87x19 |
| Pct. growth of total population | -0.0007 | 0.0084 | -0.0383 | 0.0437 | 119.24*** | -2.791 | 87x19 |
| Pct. growth of real purchasing power per capita | 0.0032 | 0.0155 | -0.0761 | 0.0983 | 87.52*** | -3.834 | 87x19 |
| Pct. growth of human capital ratio | 0.0674 | 0.0745 | -0.1886 | 0.5230 | 208.02*** | -4.308 | 87x19 |
| Real mortgage interest rate | 0.0356 | 0.0160 | 0.0105 | 0.0681 | N/A | N/A | 19 |

Summary statistics for the dependent and independent variables. CD rest refers to the Pesaran (2004) test statistic on cross-sectional dependence in panel time-series data. This test statistic is standard normally distributed under the null hypothesis of cross-section independence for large $N$. CIPS test refers to the Pesaran (2007) panel unit root test in the presence of cross-section dependence. Under the null hypothesis, the heterogeneous autoregressive term in a cross-sectionally augmented Dickey-Fuller panel regression is zero for all cities. All panel unit root tests are performed with city-specific intercepts, without linear trends, with a lag period of one year and with a serial correlation order of one. *,**,*** indicate statistical significance at the 10%-, 5%- and 1%-levels, respectively.

# 5 Spatial panel estimation results

## 5.1 Main findings

The main results of estimating the house price equation separately by segment with and without spatial effects are reported in Table 3. The coefficient estimates for the mixed-regressive spatial panel (SAC) model are reported in the left column of each coefficient bloc, followed by the ordinary panel fixed effects and pooled OLS estimates. Average total impacts are reported in the top part of the table for the spatial model instead of the original coefficients, while standard coefficient estimates are reported for the other models. All reported standard errors are of the Huber-White form and robust to heteroscedasticity. Since the ordinary fixed effects and pooled OLS models do not provide for any spatial spillovers, direct comparisons of the different models are necessarily of limited validity and must be treated with appropriate care (LeSage and Pace 2009). To improve interpretation, we also report the direct and indirect effects as well as the original estimates for the spatial panel models in the lower part of the table.

Mostly independent of the specification considered, the results lend strong support to our key hypothesis that cross-city heterogeneity in the speed of population aging (and other socio-demographics) is able to systematically explain differences in real house price appreciation. The effects of aging are heterogeneous across segments: for condominiums and single-family homes, we find the expected negative relationship, with sales price growth of existing condominiums being more heavily affected by aging than sales price growth of existing homes. For existing rental apartments, the mixed-regressive spatial panel model points towards a positive link between the rate of aging and the growth rate of real rents. The respective coefficient is negative but insignificant in the fixed effects and pooled OLS specifications.

The conjecture that a city's growth rate in real housing prices covaries systematically with house price growth among its geographical neighbors is strongly supported for the condominium and single-family house segments, where we obtain highly significant coefficients for the spatial lag parameter $\rho$ in the range of 0.8. In substantive terms, this implies that a city's expected real growth rate of condo and home prices would be around 0.8 percentage points higher if neighboring cities had an average growth rate of 1 percent compared with a neighbor average of 0 per cent (which is close to the sample mean over 1995-2014). In the case of single-family housing, we additionally obtain a significant parameter $\lambda$ for the spatial error process incorporated in the disturbances. For the rental housing segment, only the spatial error parameter is statistically different from zero, so there is no evidence in favor of systematic spatial dependence in rents.

Modelling spatial autocorrelation greatly reduces cross-section dependence, which we evaluate from applying the Pesaran (2004) cross-section dependence tests on the regression residuals of each panel specification. While still signaling weak but statistically significant dependence, the test statistics for the spatial panel models shrink by a factor of ten compared to the non-spatial models. At the same time, some coefficient estimates differ substantially, indicating the existence of omitted spatially correlated variables in the fixed effects and pooled OLS specifications. In view of this evidence, we clearly favor the coefficient estimates of the mixed-regressive spatial panel models over the respective non-spatial estimates.

**Table 3.** Regression results of different specifications: Panel SAC, panel FE and pooled OLS.

| | Condominium price | | | Single-family house price | | | Apartment rent | | |
|---|---|---|---|---|---|---|---|---|---|
| **Independent variables** | SAC | FE | Pooled OLS | SAC | FE | Pooled OLS | SAC | FE | Pooled OLS |
| Δ Log old age dependency ratio | **-0.7856** ** | **-0.7139** *** | **-0.6571** *** | **-0.5155** * | **-0.4370** *** | **-0.3912** *** | **0.2218** ** | -0.0464 | -0.0788 |
| | (0.3290) | (0.0767) | (0.0657) | (0.2782) | (0.0633) | (-0.3912) | (0.0926) | (0.0560) | (0.0532) |
| Δ Log total adult population | -0.3684 | **-0.3839** * | 0.1236 | -0.1536 | -0.1414 | 0.0901 | 0.1021 | 0.0466 | **0.4148** *** |
| | (0.6920) | (0.2154) | (0.1724) | (0.8881) | (0.2279) | (0.0901) | (0.1956) | (0.2483) | (0.1522) |
| Δ Log real income per capita | **0.8648** *** | **0.2936** *** | **0.3260** *** | **0.6334** ** | **0.3293** *** | **0.3303** *** | -0.0053 | **0.1753** *** | **0.2076** *** |
| | (0.3290) | (0.0743) | (0.0714) | (0.2716) | (0.0618) | (0.3303) | (0.0599) | (0.0588) | (0.0678) |
| Δ Log human capital ratio | **0.2179** ** | **0.1642** *** | **0.1609** *** | **0.1857** *** | **0.1126** *** | **0.1066** *** | 0.0222 | 0.0257 | **0.0323** ** |
| | (0.0853) | (0.0183) | (0.0185) | (0.0666) | (0.0151) | (0.1066) | (0.0288) | (0.0159) | (0.0158) |
| Log real mortgage interest rate | **-0.9041** * | **-0.6575** *** | **-0.6061** *** | -0.4069 | **-0.2767** *** | **-0.2680** *** | **-0.8000** ** | **-0.6386** *** | **-0.5630** *** |
| | (0.4707) | (0.1071) | (0.0782) | (0.3141) | (0.0730) | (-0.2680) | (0.3478) | (0.0908) | (0.0858) |
| ***Regression diagnostics*** | | | | | | | | | |
| $R^2$ (within) | 0.2859 | 0.2477 | 0.2500 | 0.2159 | 0.1706 | 0.1668 | 0.0771 | 0.0916 | 0.0970 |
| Pesaran (2004) CD test on residuals | **-2.21** ** | **22.92** *** | **24.71** *** | **-2.70** *** | **32.10** *** | **33.85** *** | **-2.16** ** | **28.32** *** | **27.66** *** |
| ***Direct effects*** | | | | | | | | | |
| Δ Log old age dependency ratio | **-0.1610** ** | | | **-0.1006** * | | | **0.2368** ** | | |
| | (0.0701) | | | (0.0537) | | | (0.0975) | | |
| Δ Log total adult population | -0.0742 | | | -0.0320 | | | 0.1069 | | |
| | (0.1428) | | | (0.1739) | | | (0.2121) | | |
| Δ Log real income per capita | **0.1755** *** | | | **0.1230** ** | | | -0.0079 | | |
| | (0.0651) | | | (0.0504) | | | (0.0630) | | |
| Δ Log human capital ratio | **0.0437** *** | | | **0.0363** *** | | | 0.0247 | | |
| | (0.0146) | | | (0.0121) | | | (0.0284) | | |
| Log real mortgage interest rate | **-0.1856** * | | | -0.0797 | | | **-0.8899** ** | | |
| | (0.0966) | | | (0.0582) | | | (0.4417) | | |
| ***Indirect effects*** | | | | | | | | | |
| Δ Log old age dependency ratio | **-0.6246** ** | | | **-0.4149** * | | | -0.0149 | | |
| | (0.2630) | | | (0.2279) | | | (0.0517) | | |
| Δ Log total adult population | -0.2941 | | | -0.1216 | | | -0.0048 | | |
| | (0.5505) | | | (0.7164) | | | (0.0473) | | |
| Δ Log real income per capita | **0.6894** *** | | | **0.5105** ** | | | 0.0026 | | |
| | (0.2693) | | | (0.2259) | | | (0.0101) | | |
| Δ Log human capital ratio | **0.1742** ** | | | **0.1494** *** | | | -0.0025 | | |
| | (0.0719) | | | (0.0562) | | | (0.0083) | | |
| Log real mortgage interest rate | **-0.7185** * | | | -0.3272 | | | 0.0898 | | |
| | (0.3771) | | | (0.2578) | | | (0.1692) | | |
| ***Coefficients*** | | | | | | | | | |
| Δ Log old age dependency ratio | **-0.1535** ** | | | **-0.0956** * | | | **0.2360** ** | | |
| | (0.0668) | | | (0.0510) | | | (0.0970) | | |
| Δ Log total adult population | -0.0541 | | | -0.0122 | | | 0.1322 | | |
| | (0.1604) | | | (0.1901) | | | (0.2496) | | |
| Δ Log real income per capita | **0.1637** *** | | | **0.1150** ** | | | -0.0122 | | |
| | (0.0599) | | | (0.0465) | | | (0.0584) | | |
| Δ Log human capital ratio | **0.0402** *** | | | **0.0331** *** | | | 0.0227 | | |
| | (0.0128) | | | (0.0109) | | | (0.0261) | | |
| Log real mortgage interest rate | **-0.1628** ** | | | -0.0662 | | | **-0.8183** ** | | |
| | (0.0799) | | | (0.0485) | | | (0.3766) | | |
| ***Spatial diagnostics*** | | | | | | | | | |
| $\rho$ | **0.8062** *** | | | **0.8141** *** | | | -0.0633 | | |
| $\lambda$ | -0.2067 | | | **-0.3216** *** | | | **0.7498** *** | | |
| $\sigma^2$ | **0.0016** *** | | | **0.0009** *** | | | **0.0013** *** | | |

The table displays alternative regression results with and without spatial effects. The results are presented separately by segment. Huber-White heteroscedasticity-robust standard errors are presented in brackets. The spatial weight matrix used to model the spatial processes in the mixed-regressive panel (SAC) model is row-standardized inverse distance matrix. ***,**,* denote statistical significance at the 1%,5%,10% levels, respectively.

Since they account for feedback effects among cities, the spatial panel results are considerably richer than the ordinary fixed effects and pooled OLS results. In particular, the expanded set of estimators allows discriminating between the direct, indirect and total effects of a change in explanatory variables.[16] Following the average total impact to an observation viewpoint pioneered by LeSage and Pace (2009), we focus the interpretation of coefficients on the average total effects. Based on the estimates of the average total impact of a global change in old-age dependency ratio growth in the entire sample of cities, a one percentage point increase in the speed of aging in every city would on average imply a 0.8 percentage points lower growth rate of inflation-corrected condominium prices, a 0.5 percentage points lower growth rate of single-family home prices, and a 0.2 percentage point higher growth rate of real rents. These estimates incorporate the complete chain of feedback effects that arise before the system settles to a new long-run equilibrium. For condos and homes, the indirect effects carry the same sign as the direct effects, but are of larger magnitudes. This is explained by the fact that the cumulative indirect effect estimates represent the sum over a large number of partitioned individual effects spreading over first-order, second-order and higher-order neighboring cities. For rental housing, the indirect effects for all variables are statistically insignificant from zero.

Along with statistical significance, the estimates for the average total effects of aging are economically meaningful: with the sample standard deviation of annual old-age dependency growth being 0.0190, increasing the speed of aging in the whole group of cities by one standard deviation in a thought experiment implies that real condo and single-family home prices would have appreciated 1-1.5 percentage points less on average after accounting for the chain of feedback effects through the entire system of cities. Since the sample mean appreciation rate ranges from -0.0028 for condominiums to -0.0127 per annum for single-family homes, this suggests that average price growth in the condo and home segments would have been positive over the sample period if the extent of population aging in German cities had been by one standard deviation less pronounced.

The result of a positive association between the speed of aging and real rent growth appears to be difficult to reconcile with the findings for the other two housing segments and requires further explanation. A possible explanation for the asymmetric effect is that prices in the condo and home markets simultaneously reflect the relative demand for housing services and capital investment in those segments, while prices in the market for rental housing alone reflect relative demand for housing services in this particular segment. It seems perfectly possible that demand for condominiums or single-family homes as investment vehicles decreases with an aging population, whereas demand for housing services in urban rental sectors increases with higher population shares of the

[16] Because the magnitude of feedback effects depends critically on the spatial weight matrix $\mathbf{W}$, which has to be defined a priori, we ran all spatial panel estimations with three alternative, row-standardized binary contiguity matrices with cut-off distances of 150km, 200km and 250 km between the geographical centroids of individual cities as alternative measures of spatial relatedness. These modifications did not lead to a qualitative change the estimates for the direct, indirect and total effects. The according results are provided in Table A2 in the Appendix.

elderly. Since German individuals tend to not substantially scale down housing consumption in old age (Keese 2012), downward pressure on prices in the condo and home segments with simultaneous upward pressure on rental prices may be best explained by substitution effects between different types of housing. For this interpretation to be valid, it is necessary that rental apartments, condos and homes form relatively autonomous segments that are separated by institutional barriers and populated by heterogeneous clienteles. Otherwise, simple asset pricing theory would need the reaction of prices in those different segments to always be positively correlated.

The coefficients estimated on the partial relationships between real urban house prices and further demographic and economic fundamentals by and large meet with theoretical expectations. We find that the temporal development of a city's economic productivity, measured by changes to real purchasing power per capita and the qualification of its workforce, act as a positive driver of real price appreciation, at least for the condominium and single-family home segments. We neither find a consistent positive statistical association between rent growth and purchasing power nor between rent growth and changes to human capital. This could be explained by the fact that renting is generally less common among the high-qualified, who have benefited disproportionally from real income gains over the sample period. After controlling for spatial dependence, we do not find any significant partial association between house price growth and population growth (in the fixed effects regression for single-family home prices, the coefficient for population is significant, but carries an implausible negative sign, whereas in pooled OLS for rents it is significant and positive).[17] In line with expectations, real house prices appreciate more strongly in the presence of lower real mortgage rates at the national level, a finding that holds across all models (with the only exception of single-family home prices in the spatial panel model, where the effect is negative but insignificant).[18] Consistent with this, Geiger et al. (2016) recently provide evidence that national German house prices are well explained by an inverse demand model in which the mortgage interest rate plays a dominant role.

While evidence in favor of real income growth spurring demand for housing (a normal good) and thereby house prices has been present in the literature for long, evidence that an increasing shares of academic workers in urban labor forces result in more positive trajectories of urban house prices (at least for the upper-tier market segments) is more recent. Our results here are in line with seminal work by Shapiro (2006), who argued that local human capital accumulation increases house prices by affecting both

[17] Temporal changes in household formation behavior, especially a steady trend towards smaller households, may be a reasonable explanation for the missing house price-population link.

[18] According to the spatial panel estimates for condominiums, a global increase in the national real mortgage interest rate by one percentage point decreases the average rate of real price appreciation in the sample of cities by 0.9 percentage points. A coefficient of this size suggests that the European Central Bank's low interest rate policy in response to the financial crisis plays an important role in explaining the substantial increase in real housing prices in many German cities since the year of 2009.

local productivity and quality of life. Gyourko et al. (2013) recently show that the growing spatial skewness in U.S. metro house prices is related to inelastic supply of land in attractive locations combined with an increasing number of high-income workers. Eichholtz and Lindenthal (2014) have added microeconometric evidence on this subject, focusing on the link between individual human capital and housing demand.

## 5.2 How do the results compare to the existing literature?

In order to illustrate how our results relate to recent studies on the subject, Table 4 lists the regression coefficients for three main variables of interest (old-age dependency, population, and income) derived from the favorite specification together with the results of two recent relevant studies by Takáts (2012) and Saita et al. (2013).[19]

While the validity of any comparison of results across studies must be limited due to differences in the estimation technique employed, the data used and housing segments covered, the table illustrates striking qualitative and quantitative similarities between the results. All three studies find the partial elasticity of real house prices with respect to changes in real per capita incomes to be positive and less than one. While both Saita et al. and Takáts find positive elasticities. our estimates for the partial elasticity of real house prices with respect to changes in overall population size are not different from zero. Most notably, the econometric results of all three studies yield strong support to the conjecture that changes in age distributions act as strong drivers of real capital gains in housing markets. In absolute numbers, the average total impact estimates for the negative sensitivity of real condo and home prices to a global change in the old-age dependency ratio in the present study (-0.8 for condos and -0.5 for homes) is in the range of the partial elasticities that Saita et al. find for all housing in US states (-0.54) and Takáts finds for all housing in OECD countries (-0.68). They are considerably lower than the partial elasticity that Saita et al. report for real land prices in Japanase prefectures (-1.73). The positive statistical assocation that we report for rental prices in the unregulated apartment segment is new to the literature and could motivate further research.

In summary, while there is still only a few number of empirical studies that exploit the rich temporal information coming from long (spatial) panel data sets, there is now a growing body of evidence in favor of economically meaningful effects of population aging on house prices at the local, the regional and the national levels.

[19] Takáts uses housing price data from the Bank of International Settlements International Property Price Database, which includes data on different forms of housing. Saita et al. (2013) use US housing price data from the Federal Housing Finance Agency (all transactions indexes). The statistical definition of the old-age dependency ratio complies with the one used in the present paper.

**Table 4**. Comparison of estimation results in different studies

| This paper | | Saita et al. (2013) | | | Takáts (2012) | |
|---|---|---|---|---|---|---|
| Spatial Panel Autocorrelation Model | | Panel Error Correction Model | | | Pooled OLS | |
| | **Germany** | | **Japan** | **U.S.** | | **OECD** |
| Panel units (N) | 87 cities | Panel units (N) | 47 prefectures | 50 states | Panel units (N) | 22 countries |
| Time periods (T) | 20 years | Time periods (T) | 34 years | 36 years | Time periods (T) | 40 years |
| **ΔLog real condominium prices** | | **Log real land/ housing prices** | | | **ΔLog real house prices** | |
| ΔLog old-age dependency ratio | -0.7856 | Log old-age dependency ratio | -1.7280 | -0.5363 | ΔLog old-age dependency ratio | -0.6818 |
| ΔLog total adult population | not sign. | Log total population | 2.0220 | 1.8079 | ΔLog total population | 1.0547 |
| ΔLog real income per capita | 0.8648 | Log real GDP per capita | 0.2302 | 0.4525 | ΔLog real GDP per capita | 0.8842 |
| **ΔLog single-family home prices** | | | | | | |
| ΔLog old-age dependency ratio | -0.5155 | | | | | |
| ΔLog total adult population | not sign. | | | | | |
| ΔLog real income per capita | 0.6334 | | | | | |
| **ΔLog apartment rents** | | | | | | |
| ΔLog old-age dependency ratio | 0.2218 | | | | | |
| ΔLog total adult population | not sign. | | | | | |
| ΔLog real income per capita | not sign. | | | | | |

The table displays the regression coefficients found in the present study with evidence from previous research. The results for the present study refer to the average total effect estimates of the baseline specification of a mixed-regressive spatial panel model including the annual mortgage rate and spatial fixed effects. The results of Saita et al. (2013) refer to the long-run coefficients of their baseline specification of a panel error correction model including regional fixed effects. The results of Tákats (2012) refer to his baseline specification of a pooled OLS model including time fixed effects.

## 6 Conclusions

How house price developments are affected by long-run demographic change in industrialized countries is of critical relevance for home owners, investors and policy makers alike. In addition to the risk of population decrease, an often overlooked risk factor for housing wealth consists in a gradual but pronounced shift to the age structure of residents. Due to the age dependency of private demand for different forms of housing, population aging can unfold heterogeneous impacts across different housing market segments, an issue that has so far been largely ignored by the literature.

Estimating a mixed-regressive spatial panel housing price model with city-level data for different housing segments from the German market, the results of this paper demonstrate evidence of negative and economically meaningful effects of population aging on real sales prices of condominiums and single-family homes. This holds after controlling for cross-section dependence, spatial fixed effects and possibly confounding time-varying factors. Sales prices in the condo segment are found to be more heavily affected by aging than sales prices in the single-family home segment. We additionally show that real rent growth is positively associated with faster increases in city-level old-age dependency ratios, a finding that might be explained by increasing relative demand for types of housing that provide only housing services.

Concerning the economic magnitude of the results, our estimates suggest that real average price growth in the more investment-oriented segments of condominiums and homes would probably have been positive if the old-age dependency ratio had grown by about one standard deviation less in German cities over the past two decades. If the magnitude of these historical relationships continues to hold, projected severe population aging will be a huge hampering factor to real house price growth in almost any urban housing market in Germany over the next decades. As with any study employing demographic relationships, it is evident that the estimates on the aging-housing price relationship have to be treated with the appropriate care. The causal mechanisms underlying the empirical links between these variables can and do change with changes in household preferences, housing finance institutions and the elasticity of housing supply.

The most obvious implications of these findings for policy are related to the field of urban housing policy and planning: the most successful cities of in aging societies will be those that best manage to supply to the housing needs of their elderly residents. In view of our results, promoting a well-functioning urban rental sector might gain even higher importance in this area. Another application concerns policies related to private old-age provision, which occurs strongly in direct investment in residential real estate (often promoted by tax benefits or direct transfers). In view of our results, governments in countries with rapidly aging societies may reassess policies related to wealth creation in the household sector. An objective of such policy could be to prevent households from holding wealth portfolios that are heavily skewed towards highly illiquid assets that face low or even negative expected real future returns.

A question open to further investigation is to what extent shifts to the age structure of cities are plausibly exogenous to urban house price growth. As adverse price effects related to aging make urban housing in certain segments more affordable, this could in principle render younger households to invest in an aging city. Existing research at the micro level points out that migration decisions in different age brackets are at least partially sensitive to intercity house price differentials in their levels, while they appear to be insensitive to differentials in *changes* in house prices (Rabe and Taylor, 2012). Future research could take our findings as a starting point to think more deeply about possibilities to disentangle first- from potential second-round effects in the relationship between aging and urban house prices. To do so, it appears promising to account for the distribution of urban amenities and their evolution over time within a dynamic spatial equilibrium framework, such as the one proposed recently by Glaeser et al (2014).

## References

M. Arntz, R. A. Wilke. Unemployment Duration in Germany: Individual and Regional Determinants of Local Job Finding, Migration and Subsidized Employment. *Regional Studies*, 43(1): 43-61, 2009.

M. Beenstock, D. Felsenstein. Spatial error correction and cointegration in nonstationary panel data: regional house prices in Israel. *Journal of Geographic Systems*, 12(2): 189-206, 2010.

M. Bernt. Partnerships for Demolition: The Governance of Urban Renewal in East Germany's Shrinking Cities. *International Journal of Urban and Regional Research*, 33(3): 754-769, 2009.

T. P Boehm, A. M. Schlottmann. The dynamics of housing tenure choice: Lessons from Ger many and the United States. *Journal of Housing Economics*, 25: 1-19, 2014.

R. R. Brady. Measuring the diffusion of housing prices across space and over time. *Journal of Applied Econometrics*, 26(2): 213-231, 2011.

D. R. Capozza, P. H. Hendershott, C. Mack, C. J. Mayer. Determinants of real house price dynamics. *NBER Working Paper* No. 9262, 2002.

G. A. Carlino, R. H. DeFina. Macroeconomic analysis using regional data: An application to monetary policy. In: R. J. Arnott and D. P. McMillen (Eds.) *A Companion to Urban Economics*, 440-459, Blackwell Publishing Ltd, Oxford, UK, 2008.

M. C. Chiuri, T. Jappelli. Do the elderly reduce housing equity? An international comparison, *Journal of Population Economics,* 23: 643-663, 2010.

A. Chudik., M. H. Pesaran. Large Panel Data Models with Cross-Sectional Dependence: A Survey. In: B. Baltagi (Ed.), *The Oxford Handbook on Panel Data*, Oxford University Press, 2014.

W. A. V. Clark, M. C. Deurloo. Aging in place and housing over-consumption. *Journal of Housing and the Built Environment,* 21: 257-270, 2006.

Destatis. Germany's population by 2060 - Results of the 13$^{th}$ coordinated population projection. *German Federal Statistical Office*, Wiesbaden, https://www.destatis.de/EN/Publications/Specialized/Population/GermanyPopulation2060.pdf?___blob=publicationFile, 2015.

D. DiPasquale, W. C. Wheaton. Housing Market Dynamics and the Future of Housing Prices. *Journal of Urban Economics*, 35(1): 1-27, 1994.

P. Eichholtz, T. Lindenthal. Demographics, human capital, and the demand for housing. *Journal of Housing Economics*, 26(1): 19-32, 2014.

G. Engelhardt, J. Poterba. Demographics and house prices: the Canadian evidence. *Regional Science and Urban Economics,* 21: 539-546, 1991.

J. Ermisch. The demand for housing in Britain and population ageing: Microeconometric evidence. *Economica*, 63(251): 383-404, 1996.

G. Favara, J. Imbs. Credit Supply and the Price of Housing. *American Economic Review,* 105(3): 958-992, 2015.

J. Ferndández-Villaverde, D. Krueger. Consumption over the life cycle: Facts from consumer expenditure survey data. *The Review of Economics and Statistics,* 89(3): 552-565. 2007.

M. Flavin, T. Yamashita. Owner-Occupied Housing and the Composition of the Household Portfolio. *American Economic Review*, 92(1): 345-362, 2002.

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

F. Geiger, J. Muellbauer, M. Rupprecht. The housing market, household portfolios and the German consumer. *European Central Bank Working Paper* No. 1904, 2016.

D. Genesove, L. Han. Search and matching in the housing market. *Journal of Urban Economics,* 72(1): 31-45, 2012.

A. C. Goodman, T. G. Thibodeau. Where are the speculative bubbles in US housing markets? *Journal of Housing Economics*, 17(2): 117-137, 2008.

E. L. Glaeser, J. Gyourko, A. Saiz. Housing supply and housing bubbles. *Journal of Urban Economics*, 64(2): 198-217, 2008

E. L. Glaeser, J. Gyourko, R. Saks. Urban growth and housing supply. *Journal of Economic Geography,* 6(1): 71-89, 2006.

E. L. Glaeser, J. Gyourko, E. Morales, C. G. Nathanson. House Price Dynamics: An Urban Approach. *Journal of Urban Economics* 81: 45-56, 2014.

R. Green, P. H. Hendershott. Age, housing demand, and real house prices. *Regional Science and Urban Economics*, 26(5): 465-480, 1996.

J. Gyourko, C. Mayer, T. Sinai. Superstar Cities. *American Economic Journal: Economic Policy*, 5(4): 167-199, 2013.

J. V. Henderson, Y. M. Ioannides. A Model of Housing Tenure Choice. *American Economic Review*, 73(1): 98-113, 1983.

C. Himmelberg, C. Mayer, T. Sinai. Assessing high house prices: Bubbles, fundamentals and misperceptions. *The Journal of Economic Perspectives*, 19(4): 67-92, 2005.

S. Holly, M. H. Pesaran, and T. Yamagata. A spatio-temporal model of house prices in the USA. *Journal of Econometrics*, 158(1): 160-173, 2010.

F. Kajuth, T. A. Knetsch, N. Pinkwart. Assessing house prices in Germany: evidence from an estimated stock-flow model using regional data. *Deutsche Bundesbank Discussion Paper* No. 46, 2013.

M. Kapoor, H. H. Kelejian, I. R. Prucha. Panel data models with spatially correlated error components. *Journal of Econometrics*, 140: 97-130, 2007.

M. Keese. Downsize, Undermaintain, or Leave it as it is: Housing Choices of Elder Germans. *CESifo Economic Studies,* 58(3): 570-598, 2012.

H. H. Kelejian, I. Prucha. A generalized spatial two-stage least squares procedure for estimateing a spatial autoregressive model with autoregressive disturbances. *Journal of Real Estate Finance and Economics* 17(1): 99-121, 1998.

H. Kraft, C. Munk. Optimal Housing Consumption and Investment Decisions over the Life Cycle. *Management Science*, 57(6): 1025-1041, 2011.

T. H. Kuethe, V. O. Pede. Regional Housing Price Cycles: A Spatio-temporal Analysis Using US State-level Data. *Regional Studies*, 45(5): 563-574, 2011.

C. C. Lee, M. S. Chien. Empirical modelling of regional house prices and the ripple effect. *Urban Studies*, 48(10): 2029-2047, 2011.

L. Lee, J. Yu. Estimation of spatial autoregressive panel data models with fixed effects. *Journal of Econometrics*, 154(2): 165-185, 2010a.

L. Lee, J. Yu, Some recent developments in spatial panel data models. *Regional Science and Urban Economics*, 40: 255-271, 2010b.

O. Lerbs. House prices, housing development costs, and the supply of new single-family housing in German counties and cities. *Journal of Property Research*, 31(3): 183-210, 2014.

J. LeSage, R. K. Pace. *Introduction to Spatial Econometrics.* Taylor & Francis, Boca Raton, FL, 2009.

N. G. Mankiw, D. N. Weil. The baby boom, the baby bust, and the housing market. *Regional Science and Urban Economics*, 19(2): 235-258, 1989.

W. Maennig, L. Dust. Shrinking and growing metropolitan areas asymmetric real estate price reactions? The case of German single-family houses. *Regional Science and Urban Economics*, 38(1): 63-69, 2008.

C. J. Mayer, T. Somerville. Land use regulation and new construction. *Regional Science and Urban Economics*, 30(6): 639-662, 2000.

G. Meen. Regional house prices and the ripple effect: a new interpretation. *Housing Studies*, 14(6): 733-753, 1999.

G. Meen. *Modelling Spatial Housing Markets – Theory, Analysis and Policy.* Kluwer Academic Publishers, 2012.

A. R. Mian, A. Sufi. House Prices, Home Equity-Based Borrowing, and the US Household Leverage Crisis. *American Economic Review,* 101(5): 2132-2156, 2011.

A. R. Mian, A. Sufi, F. Trebbi. Foreclosures, House Prices, and the Real Economy. *Journal of Finance,* 70(6): 2587-2634, 2015.

N. Miller, L. Peng. Exploring Metropolitan Housing Price Volatility. *Journal of Real Estate Finance and Economics*, 33: 5-18, 2006.

F. Ohtake, M. Shintani. The effect of demographics on the Japanese housing market. *Regional Science and Urban Economics,* 26(2): 189-201, 1996.

M. H. Pesaran. General Diagnostic Tests for Cross Section Dependence in Panels, *IZA Discussion Paper* No. 1240, 2004.

M. H. Pesaran. A Simple Panel Unit Root Test In The Presence Of Cross-section Dependence, *Journal of Applied Econometrics,* 22: 265-312, 2007.

M. Piazzesi, M. Schneider, J. Stroebel. Segmented Housing Search. *NBER Working Paper,* No. 20823, 2015.

J. R. Pitkin, D. Myers. The Specification of Demographic Effects on Housing Demand: Avoid ing the Age-Cohort Fallacy. *Journal of Housing Economics*, 3(3): 240-250, 1994.

J. Poterba, D. N. Weil, R. Shiller. House Price Dynamics: The Role of Tax Policy and Demography. *Brookings Papers on Economic Activity,* 1991(2): 143-203, 1991.

B. Rabe, M. P. Taylor. Differences in Opportunities? Wage, Employment and House-Price Effects on Migration. *Oxford Bulletin of Economics and Statistics*, 74(6): 831-855, 2012.

S. S. Rosenthal, W. C. Strange. Evidence on the nature and sources of agglomeration economies. In: J.V. Henderson, J.-F. Thisse (Eds.) *Handbook of Regional and Urban Economics*, Vol. 4, 2119-2171, Elsevier, Amsterdam, 2004.

Y. Saita, C. Shimizu, T. Watanabe. Aging and Real Estate Prices: Evidence from Japanese and US Regional Data, *Tokyo Center for Economic Research (TCER), Paper No. E-68*, 2013.

A. Saiz. The Geographic Determinants of Housing Supply. *Quarterly Journal of Economics,* 125(3): 1253-1296, 2010.

V. Sarafidis, T. Wansbeek. Cross-section dependence in panel data analysis. *Econometric Reviews,* 31: 483-531, 2012.

J. Shapiro. Smart Cities: Quality of Life, Productivity, and the Growth Effects of Human Capital. *The Review of Economics and Statistics,* 88(2): 324-335, 2006.

E. Takáts. Aging and house prices. *Journal of Housing Economics*, 21(2): 131-141, 2012.

F. Yang. Consumption over the life cycle: How different is housing? *Review of Economic Dynamics,* 12(3): 423-443, 2009.

B. Zhu, R. Füss, N. Rottke. Spatial Linkages in Returns and Volatilities among U.S. Regional Housing Markets. *Real Estate Economics*, 41(1): 29-64, 2013.

# Appendix

**Table A1**. Panel averages of all variables in levels over 1995-2014 (std. dev. in parentheses)

| No. | City | Condominium prices | Single-family house prices | Apartment rents | Total adult population | Old age dependency ratio | Real income per capita | Human capital ratio |
|---|---|---|---|---|---|---|---|---|
| 1 | Flensburg | 1152 (184) | 203274 (26286) | 5,2 (0,6) | 69653 (1653) | 0,3 (0,02) | 17844 (278) | 0,43 (0,2) |
| 2 | Kiel | 1537 (262) | 278552 (41834) | 6,7 (0,4) | 197354 (3904) | 0,27 (0,02) | 17565 (277) | 0,82 (0,25) |
| 3 | Lubeck | 1511 (200) | 266425 (34612) | 6,4 (0,4) | 174319 (1712) | 0,35 (0,03) | 17858 (433) | 0,57 (0,21) |
| 4 | Neumunster | 1342 (249) | 209974 (34721) | 5,6 (0,4) | 62500 (1076) | 0,34 (0,04) | 17141 (246) | 0,31 (0,07) |
| 5 | Hamburg | 2332 (266) | 421952 (30310) | 8,7 (0,5) | 1428764 (25355) | 0,28 (0,02) | 21498 (791) | 0,97 (0,4) |
| 6 | Brunswick | 1329 (234) | 261086 (33027) | 5,7 (0,5) | 204800 (1900) | 0,32 (0,02) | 20744 (243) | 1,24 (0,63) |
| 7 | Salzgitter | 1172 (221) | 224866 (49397) | 5 (0,5) | 85969 (3912) | 0,36 (0,05) | 17727 (383) | 0,29 (0,1) |
| 8 | Wolfsburg | 1294 (218) | 258254 (44746) | 5,8 (0,3) | 99249 (1232) | 0,35 (0,05) | 21148 (610) | 0,7 (0,58) |
| 9 | Oldenburg | 1383 (237) | 240449 (44187) | 6,2 (0,5) | 128294 (3038) | 0,27 (0,02) | 18970 (639) | 0,99 (0,47) |
| 10 | Osnabruck | 1470 (207) | 267353 (23629) | 5,9 (0,5) | 134269 (2511) | 0,29 (0,02) | 18452 (571) | 0,77 (0,36) |
| 11 | Wilhelmshaven | 1002 (232) | 176872 (22090) | 4,6 (0,3) | 68442 (2720) | 0,37 (0,05) | 17705 (284) | 0,39 (0,1) |
| 12 | Bremen | 1440 (172) | 312118 (35430) | 6,5 (0,5) | 448967 (5015) | 0,32 (0,03) | 18526 (493) | 0,89 (0,32) |
| 13 | Bremerhaven | 1002 (183) | 183436 (27741) | 5 (0,3) | 94437 (4125) | 0,34 (0,03) | 16263 (671) | 0,31 (0,1) |
| 14 | Dusseldorf | 2259 (238) | 553131 (27015) | 8,1 (0,3) | 481457 (9098) | 0,29 (0,02) | 23128 (476) | 1,08 (0,49) |
| 15 | Duisburg | 1442 (230) | 306852 (19253) | 5,6 (0,5) | 405422 (9688) | 0,33 (0,03) | 16864 (243) | 0,34 (0,1) |
| 16 | Essen | 1671 (325) | 426182 (36017) | 6,2 (0,4) | 480276 (8595) | 0,34 (0,02) | 20067 (368) | 0,77 (0,26) |
| 17 | Krefeld | 1443 (220) | 323160 (17062) | 6,3 (0,5) | 190318 (5153) | 0,32 (0,04) | 19573 (166) | 0,55 (0,19) |
| 18 | Monchengladbach | 1405 (254) | 338650 (37720) | 6 (0,2) | 208228 (1379) | 0,31 (0,03) | 18928 (225) | 0,42 (0,16) |
| 19 | Mulheim (Ruhr) | 1797 (206) | 385827 (28008) | 6,3 (0,3) | 140015 (2130) | 0,37 (0,04) | 21772 (387) | 0,69 (0,25) |
| 20 | Oberhausen | 1384 (150) | 276351 (23343) | 5,8 (0,5) | 175284 (1875) | 0,32 (0,03) | 17601 (309) | 0,4 (0,11) |
| 21 | Remscheid | 1451 (191) | 318538 (24894) | 5,5 (0,7) | 91509 (2221) | 0,34 (0,04) | 20132 (262) | 0,31 (0,11) |
| 22 | Solingen | 1515 (225) | 345153 (44149) | 6 (0,6) | 129492 (1944) | 0,33 (0,04) | 19752 (521) | 0,32 (0,14) |
| 23 | Wuppertal | 1371 (223) | 342364 (29838) | 5,8 (0,4) | 290089 (7453) | 0,33 (0,03) | 19697 (335) | 0,43 (0,14) |
| 24 | Bonn | 1825 (107) | 386114 (21492) | 8,1 (0,4) | 250812 (6175) | 0,28 (0,01) | 22228 (352) | 1,39 (0,53) |
| 25 | Cologne | 2046 (165) | 463762 (20676) | 8,4 (0,2) | 808447 (25388) | 0,26 (0,02) | 21292 (433) | 0,96 (0,38) |
| 26 | Leverkusen | 1764 (264) | 340879 (10979) | 6,1 (0,4) | 129652 (769) | 0,33 (0,05) | 20640 (421) | 0,54 (0,18) |
| 27 | Bottrop | 1454 (188) | 314000 (39135) | 5,8 (0,3) | 95375 (248) | 0,32 (0,03) | 18185 (476) | 0,45 (0,19) |
| 28 | Gelsenkirchen | 1224 (283) | 337594 (45593) | 4,8 (0,5) | 216736 (7319) | 0,34 (0,02) | 16685 (269) | 0,33 (0,1) |
| 29 | Munster | 2117 (199) | 401997 (12204) | 7,3 (0,3) | 225240 (11605) | 0,25 (0,02) | 20336 (832) | 1,31 (0,54) |
| 30 | Bielefeld | 1457 (195) | 302142 (36825) | 5,9 (0,2) | 260686 (3187) | 0,32 (0,02) | 18501 (436) | 0,59 (0,22) |
| 31 | Bochum | 1534 (230) | 390173 (30889) | 5,6 (0,2) | 316435 (7106) | 0,32 (0,03) | 18959 (376) | 0,76 (0,28) |
| 32 | Dortmund | 1486 (219) | 380643 (33289) | 5,9 (0,6) | 475483 (2754) | 0,32 (0,02) | 18145 (180) | 0,71 (0,23) |
| 33 | Hagen | 1443 (193) | 311721 (27374) | 5,2 (0,3) | 157834 (5296) | 0,35 (0,04) | 18564 (210) | 0,33 (0,1) |
| 34 | Hamm | 1249 (198) | 248333 (33684) | 5,4 (0,3) | 142433 (1516) | 0,3 (0,03) | 16915 (182) | 0,31 (0,11) |
| 35 | Herne | 1356 (283) | 307059 (41130) | 4,9 (0,6) | 136858 (5581) | 0,34 (0,03) | 17109 (293) | 0,38 (0,1) |
| 36 | Darmstadt | 2073 (189) | 408849 (17673) | 7,9 (0,6) | 116708 (3400) | 0,28 (0,01) | 21533 (687) | 1,3 (0,44) |
| 37 | Frankfurt (Main) | 2693 (102) | 590104 (42341) | 9,4 (0,6) | 548095 (15588) | 0,25 (0,01) | 22548 (531) | 1,19 (0,42) |
| 38 | Offenbach (Main) | 1778 (173) | 435823 (72650) | 6,7 (0,3) | 94740 (1185) | 0,26 (0,02) | 18934 (534) | 0,48 (0,12) |
| 39 | Wiesbaden | 2302 (318) | 549663 (19500) | 8,4 (0,5) | 221428 (2548) | 0,3 (0,02) | 22369 (413) | 0,91 (0,32) |
| 40 | Kassel | 1227 (272) | 262746 (34577) | 5,2 (0,4) | 160139 (1760) | 0,31 (0,01) | 17861 (426) | 0,86 (0,33) |
| 41 | Koblenz | 1534 (186) | 317527 (44170) | 6 (0,2) | 88641 (1769) | 0,34 (0,03) | 19185 (511) | 0,59 (0,26) |
| 42 | Trier | 1628 (197) | 278809 (14250) | 6,4 (0,7) | 84672 (3436) | 0,29 (0,01) | 16751 (881) | 0,64 (0,22) |
| 43 | Kaiserslautern | 1268 (208) | 247279 (24621) | 5,2 (0,3) | 81360 (688) | 0,3 (0,02) | 17221 (345) | 0,53 (0,22) |
| 44 | Ludwigshafen (Rhein) | 1532 (243) | 340866 (21782) | 6,1 (0,3) | 131146 (1533) | 0,3 (0,03) | 19911 (316) | 0,41 (0,15) |
| 45 | Mainz | 1723 (167) | 435931 (19261) | 7,6 (0,5) | 159056 (8164) | 0,25 (0,02) | 20995 (498) | 1,19 (0,43) |
| 46 | Stuttgart | 2218 (157) | 604187 (22917) | 8,7 (0,3) | 490748 (8622) | 0,27 (0,02) | 22731 (562) | 1,09 (0,43) |
| 47 | Heilbronn | 1793 (189) | 390192 (28894) | 5,8 (0,4) | 96548 (1393) | 0,31 (0,03) | 17484 (4693) | 0,38 (0,16) |
| 48 | Karlsruhe | 1847 (175) | 439432 (22383) | 7 (0,4) | 236802 (7663) | 0,29 (0,01) | 20901 (377) | 1,03 (0,44) |
| 49 | Heidelberg | 2485 (195) | 569274 (38074) | 8,9 (0,6) | 121071 (4044) | 0,23 (0,01) | 19919 (688) | 1,7 (0,75) |
| 50 | Mannheim | 1792 (291) | 427481 (23164) | 6,6 (0,3) | 251846 (4664) | 0,28 (0,02) | 19331 (648) | 0,71 (0,3) |

The table displays variable-specific average values and corresponding standard deviations for each individual panel and the sample period of 1995-2014. Condominium prices and monthly apartment rents are in constant 2010 euros per square meter of living space. Single-family home prices and real annual income per capita are in constant 2010 euros.

**Table A1**. (Continued)

| No. | City | Condominium price | Single-family house price | Apartment rent | Total adult population | Old age dependency ratio | Real income per capita | Human capital ratio |
|---|---|---|---|---|---|---|---|---|
| 46 | Stuttgart | 2218 (157) | 604187 (22917) | 8.7 (0.3) | 490748 (8622) | 0.27 (0.02) | 22731 (562) | 1.09 (0.43) |
| 47 | Heilbronn | 1793 (189) | 390192 (28894) | 5.8 (0.4) | 96548 (1393) | 0.31 (0.03) | 17484 (4693) | 0.38 (0.16) |
| 48 | Karlsruhe | 1847 (175) | 439432 (22383) | 7 (0.4) | 236802 (7663) | 0.29 (0.01) | 20901 (377) | 1.03 (0.44) |
| 49 | Heidelberg | 2485 (195) | 569274 (38074) | 8.9 (0.6) | 121071 (4044) | 0.23 (0.01) | 19919 (688) | 1.7 (0.75) |
| 50 | Mannheim | 1792 (291) | 427481 (23164) | 6.6 (0.3) | 251846 (4664) | 0.28 (0.02) | 19331 (648) | 0.71 (0.3) |
| 51 | Pforzheim | 1705 (149) | 354912 (18381) | 6 (0.2) | 94725 (1283) | 0.32 (0.03) | 20243 (626) | 1.08 (0.61) |
| 52 | Freiburg (Breisgau) | 2261 (231) | 495342 (21670) | 8.1 (0.4) | 175018 (7159) | 0.23 (0.01) | 18699 (509) | 0.38 (0.16) |
| 53 | Ulm | 1863 (221) | 362621 (20074) | 6.8 (0.9) | 96056 (2833) | 0.27 (0.02) | 21004 (1060) | 0.88 (0.41) |
| 54 | Ingolstadt | 1920 (260) | 402516 (32394) | 7.1 (0.9) | 96289 (5731) | 0.28 (0.02) | 21020 (715) | 0.7 (0.42) |
| 55 | Munich | 3059 (455) | 758930 (95053) | 11.2 (0.7) | 1072151 (61757) | 0.25 (0.02) | 26233 (522) | 1.39 (0.59) |
| 56 | Rosenheim | 2161 (241) | 464854 (32939) | 7.3 (0.3) | 48741 (774) | 0.29 (0.03) | 20785 (1182) | 0.56 (0.26) |
| 57 | Landshut | 1780 (294) | 438607 (36649) | 6.1 (0.6) | 50744 (2379) | 0.34 (0.02) | 22522 (526) | 0.62 (0.31) |
| 58 | Passau | 1460 (155) | 320514 (10699) | 6 (0.7) | 42224 (495) | 0.32 (0.03) | 19717 (511) | 0.72 (0.37) |
| 59 | Regensburg | 2177 (296) | 414855 (65292) | 7.2 (0.7) | 109436 (4800) | 0.28 (0.01) | 21627 (435) | 1.12 (0.54) |
| 60 | Bamberg | 1740 (229) | 355156 (27223) | 5.6 (0.5) | 57720 (1168) | 0.34 (0.01) | 20010 (324) | 0.76 (0.42) |
| 61 | Bayreuth | 1345 (183) | 298599 (44039) | 6.1 (0.5) | 60841 (623) | 0.31 (0.02) | 19160 (560) | 0.67 (0.33) |
| 62 | Coburg | 1445 (219) | 255491 (40153) | 5.3 (0.5) | 34496 (488) | 0.37 (0.02) | 20253 (710) | 0.65 (0.34) |
| 63 | Erlangen | 2063 (217) | 452789 (36106) | 7.4 (0.4) | 84233 (2149) | 0.28 (0.02) | 23762 (460) | 1.56 (0.49) |
| 64 | Furth | 1552 (153) | 385616 (31196) | 5.9 (0.5) | 90924 (3971) | 0.28 (0.02) | 21001 (869) | 0.54 (0.26) |
| 65 | Nuremberg | 1730 (229) | 428930 (43469) | 6.6 (0.5) | 410055 (6313) | 0.31 (0.02) | 20707 (290) | 0.65 (0.3) |
| 66 | Aschaffenburg | 1719 (202) | 398845 (62129) | 6 (0.4) | 54661 (1256) | 0.31 (0.02) | 19902 (956) | 0.53 (0.29) |
| 67 | Schweinfurt | 1168 (69) | 255575 (46571) | 5 (0.2) | 43766 (494) | 0.39 (0.02) | 18643 (445) | 0.38 (0.16) |
| 68 | Wurzburg | 1895 (176) | 394800 (33103) | 6.5 (0.4) | 109781 (3859) | 0.29 (0.01) | 20008 (333) | 1.02 (0.51) |
| 69 | Augsburg | 1593 (184) | 406676 (20202) | 6.3 (0.4) | 215000 (7493) | 0.32 (0.01) | 19048 (238) | 0.58 (0.26) |
| 70 | Kempten (Allgau) | 1586 (181) | 391851 (39202) | 5.9 (0.3) | 50283 (1713) | 0.35 (0.03) | 19651 (641) | 0.39 (0.19) |
| 71 | Berlin | 2075 (284) | 334283 (19111) | 6.8 (0.4) | 2803344 (50058) | 0.26 (0.04) | 18383 (421) | 1.2 (0.46) |
| 72 | Brandenburg (Havel) | 1105 (250) | 182782 (43461) | 4.9 (0.4) | 63476 (1768) | 0.35 (0.08) | 15911 (467) | 0.98 (0.4) |
| 73 | Cottbus | 1275 (161) | 181779 (36060) | 5.5 (0.7) | 89636 (3020) | 0.29 (0.07) | 16423 (667) | 1.9 (0.5) |
| 74 | Frankfurt (Oder) | 1279 (283) | 188325 (21297) | 5.7 (0.9) | 54584 (3502) | 0.29 (0.08) | 16383 (417) | 1.48 (0.54) |
| 75 | Potsdam | 1999 (156) | 307618 (33841) | 6.9 (0.5) | 121823 (8351) | 0.27 (0.04) | 17763 (1267) | 2.05 (0.8) |
| 76 | Rostock | 1466 (230) | 217970 (26925) | 6.4 (0.7) | 169999 (4355) | 0.3 (0.07) | 16586 (527) | 1.64 (0.7) |
| 77 | Schwerin | 1430 (245) | 204246 (21563) | 5.8 (0.5) | 81231 (2385) | 0.32 (0.08) | 17244 (410) | 1.32 (0.73) |
| 78 | Chemnitz | 1129 (446) | 197213 (32340) | 5 (0.5) | 213735 (6583) | 0.38 (0.07) | 16487 (815) | 2.14 (0.87) |
| 79 | Dresden | 1822 (230) | 266992 (18825) | 6.3 (0.5) | 413905 (22307) | 0.31 (0.04) | 17436 (549) | 2.74 (1) |
| 80 | Leipzig | 1576 (421) | 259615 (35040) | 5.9 (1) | 427137 (15507) | 0.31 (0.04) | 16289 (547) | 2.11 (0.88) |
| 81 | Halle (Saale) | 1282 (338) | 203881 (32527) | 5.4 (0.6) | 201791 (7073) | 0.32 (0.06) | 16101 (360) | 1.7 (0.64) |
| 82 | Magdeburg | 1175 (375) | 191267 (28955) | 5.5 (0.7) | 195188 (3882) | 0.32 (0.06) | 16358 (619) | 1.61 (0.68) |
| 83 | Erfurt | 1628 (389) | 251997 (29618) | 6.3 (0.6) | 167529 (4518) | 0.28 (0.04) | 17246 (629) | 1.88 (0.71) |
| 84 | Gera | 1135 (419) | 190949 (17745) | 4.9 (0.4) | 88736 (4098) | 0.35 (0.08) | 16617 (475) | 1.47 (0.57) |
| 85 | Jena | 1711 (255) | 238969 (24368) | 6.6 (0.3) | 85232 (4633) | 0.27 (0.04) | 16686 (637) | 3.79 (1.9) |
| 86 | Suhl | 1284 (332) | 176876 (28881) | 5.4 (0.5) | 36498 (3085) | 0.33 (0.1) | 17415 (1025) | 1.88 (0.78) |
| 87 | Weimar | 1417 (257) | 233960 (29260) | 6.1 (1) | 52265 (2112) | 0.3 (0.04) | 16714 (538) | 2.66 (1.09) |

The table displays variable-specific average values and corresponding standard deviations for each individual panel and the sample period of 1995-2014. Condominium prices and apartment rents are in constant 2010 euros per square meter of living space. Single-family home prices and real annual income per capita are in constant 2010 euros.

**Table A2**. Results of SAC panel model specification with alternative spatial weight matrices.

| | **Condominium price** | | | **Single-family house price** | | | **Apartment rent** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Independent variables** | 150 km | 200 km | 250 km | 150 km | 200 km | 250 km | 150 km | 200 km | 250 km |
| Δ Log old age dependency ratio | **-0.8607 ***** | **-0.8434 ***** | **-0.8181 ***** | **-0.4335 **** | **-0.5079 **** | **0.6994 *** | **0.1082 **** | **0.1150 ***** | **0.1205 ***** |
| | (0.1872) | (0.2383) | (0.2584) | (0.1951) | (0.2268) | (0.2459) | (0.0437) | (0.0411) | (0.0360) |
| Δ Log total adult population | -0.9123 | -1.0205 | -1.1063 | 0.6981 | 0.8171 | -0.4526 | -0.0971 | (-0.0829) | -0.0316 |
| | (0.8156) | (0.9911) | (1.0219) | (0.9855) | (1.1507) | (0.2484) | (0.1950) | (0.1682) | (0.1315) |
| Δ Log real income per capita | **0.5343 ***** | **0.7372 ***** | **0.7370 ***** | **0.5878 ***** | **0.6887 ***** | **0.9406 ***** | -0.0004 | -0.0159 | -0.0207 |
| | (0.2068) | (0.2734) | (0.2846) | (0.2053) | (0.2380) | (1.2031) | (-0.0003) | (0.0335) | (0.0275) |
| Δ Log human capital ratio | **0.2251 ***** | **0.2391 ***** | **0.2393 ***** | **0.1251 **** | **0.1464 **** | **0.1502 **** | 0.0173 | 0.0164 | 0.0141 |
| | (0.0510) | (0.0665) | (0.0732) | (0.0557) | (0.0641) | (0.0693) | (0.0165) | (0.0161) | (0.0136) |
| Log real mortgage interest rate | **-0.6704 **** | **-0.6108 *** | **-0.6427 *** | -0.1123 | -0.1308 | -0.1556 | **-0.7543 ***** | **-0.7508 ***** | **-0.7656 **** |
| | (0.2726) | (0.3519) | (0.3850) | (0.2346) | (0.2711) | (0.2927) | (0.2166) | (0.2740) | (0.3419) |
| ***Regression diagnostics*** | | | | | | | | | |
| $R^2$ (within) | 0.2947 | 0.3017 | 0.3008 | 0.2263 | 0.2304 | 0.2241 | 0.0844 | 0.0832 | 0.0836 |
| Pesaran (2004) CD test on residuals | **-1.96 *** | **-2.68 ***** | **-2.52 **** | **32.32 ***** | **31.28 ***** | **29.84 ***** | **66.93 ***** | **66.56 ***** | **66.63 ***** |
| ***Direct effects*** | | | | | | | | | |
| Δ Log old age dependency ratio | **-0.1965 ***** | **-0.1554 ***** | **-0.1548 ***** | **-0.1026 ***** | **-0.0743 **** | **-0.0679 *** | **0.1870 **** | **0.2183 ***** | **0.2689 ***** |
| | (0.0464) | (0.0465) | (0.0481) | (0.0345) | (0.0339) | (0.0367) | (0.0806) | (0.0824) | (0.0826) |
| Δ Log total adult population | -0.2029 | -.01841 | -0.2076 | 0.1125 | 0.1189 | 0.1448 | -.16076 | -0.1636 | -0.0783 |
| | (0.1805) | (0.1782) | (0.1910) | (0.1711) | (0.1671) | (0.1831) | (0.3308) | (0.3186) | (0.2929) |
| Δ Log real income per capita | **0.1217 ***** | **0.1346 ***** | **0.1394 ***** | **0.1226 ***** | **0.1009 ***** | **0.1067 ***** | -0.0008 | -0.0306 | -0.0465 |
| | (0.0471) | (0.0480) | (0.0522) | (0.0345) | (0.0360) | (0.0395) | (0.0644) | (0.0635) | (0.0615) |
| Δ Log human capital ratio | **0.0514 ***** | **0.0440 ***** | **0.0454 ***** | **0.0267 ***** | **0.0213 **** | **0.0227 **** | 0.0293 | 0.0309 | 0.0314 |
| | (0.0121) | (0.0122) | (0.0134) | (0.0091) | (0.0089) | (0.0100) | (0.0270) | (0.0296) | (0.0295) |
| Log real mortgage interest rate | **-0.1524 **** | **-0.1112 *** | **-0.1213 *** | -0.0270 | -0.0185 | -0.0226 | **-1.2917 ***** | **-1.4324 ***** | **-1.7102 **** |
| | (0.0596) | (0.0600) | (0.0685) | (0.0377) | (0.0369) | (0.0409) | (0.3946) | (0.5538) | (0.7613) |
| ***Indirect effects*** | | | | | | | | | |
| Δ Log old age dependency ratio | **-0.6641 ***** | **-0.6880 ***** | **-0.6633 ***** | **-0.4227 ***** | **-0.4335 **** | **-0.3846 *** | **-0.0787 **** | **-0.1034 **** | **-0.1484 ***** |
| | (0.1482) | (0.1972) | (0.2163) | (0.1368) | (0.1951) | (0.2140) | (0.0391) | (0.0444) | (0.0499) |
| Δ Log total adult population | -0.7094 | -0.6880 | -0.8987 | 0.4586 | 0.6981 | 0.7958 | 0.0636 | 0.0807 | 0.0467 |
| | (0.6377) | (0.1972) | (0.8345) | (0.7043) | (0.9855) | (1.0227) | (0.1372) | (0.1519) | (0.1624) |
| Δ Log real income per capita | **0.4126 **** | **0.6026 ***** | **0.5976 ***** | **0.5071 ***** | **0.5878 ***** | **0.5928 ***** | 0.0004 | 0.0147 | 0.0258 |
| | (0.1624) | (0.2289) | (0.2368) | (0.1434) | (0.2053) | (0.2105) | (0.0272) | (0.0304) | (0.0344) |
| Δ Log human capital ratio | **.17375 ***** | **0.1952 ***** | **0.1938 ***** | **0.1113 ***** | **0.1251 **** | **0.1275 **** | -0.0120 | -0.0145 | -0.0174 |
| | (0.0405) | (0.0557) | (0.0615) | (0.0410) | (0.0557) | (0.0599) | (0.0109) | (0.0139) | (0.0162) |
| Log real mortgage interest rate | **-0.5180 **** | **-0.4996 *** | -0.5214 | -0.1123 | -0.1123 | -0.1330 | **0.5404 ***** | **0.6816 **** | **0.9445 **** |
| | (0.2156) | (0.2936) | (0.3188) | (0.1647) | (0.2346) | (0.2524) | (0.1951) | (0.2936) | (0.4311) |
| ***Coefficients*** | | | | | | | | | |
| Δ Log old age dependency ratio | **-0.1673 ***** | **-0.1359 ***** | **-0.1392 ***** | **-0.0840 **** | **-0.0621 *** | -0.0581 | **0.1910 **** | **0.2228 **** | **0.2710 ***** |
| | (0.0496) | (0.0507) | (0.0535) | (0.0354) | (0.0357) | (0.0398) | (0.0915) | (0.0943) | (0.0943) |
| Δ Log total adult population | -0.1887 | -0.1787 | -0.2062 | 0.0920 | 0.1020 | 0.1292 | -0.1789 | -0.1845 | -0.0995 |
| | (0.1430) | (0.1470) | (0.1631) | (0.1355) | (0.1379) | (0.1568) | (0.2972) | (0.2856) | (0.2614) |
| Δ Log real income per capita | **0.1065 ***** | **0.1219 ***** | **0.1301 ***** | **0.1045 ***** | **0.0891 ***** | **0.0976 ***** | -0.0012 | -0.0301 | -0.0455 |
| | (0.0415) | (0.0436) | (0.0489) | (0.0299) | (0.0322) | (0.0366) | (0.0623) | (0.0618) | (0.0595) |
| Δ Log human capital ratio | **0.0445 ***** | **0.0394 ***** | **0.0420 ***** | **0.0224 ***** | **0.0185 **** | **0.0204 **** | 0.0268 | 0.0284 | 0.0291 |
| | (0.0099) | (0.0102) | (0.0113) | (0.0071) | (0.0072) | (0.0084) | (0.0241) | (0.0266) | (0.0264) |
| Log real mortgage interest rate | **-0.1265 ***** | **-0.0948 **** | **-0.1067 *** | -0.0198 | -0.0132 | -0.0169 | **-1.1982 ***** | **-1.3109 ***** | **-1.5337 **** |
| | (0.0451) | (0.0471) | (0.0557) | (0.0280) | (0.0285) | (0.0326) | (0.3250) | (0.4580) | (0.6307) |
| ***Spatial diagnostics*** | | | | | | | | | |
| $\rho$ | **0.8023 ***** | **.8340 ***** | **.8220 ***** | **0.8340 ***** | **0.8701 ***** | **.8600 ***** | **-.6675 ***** | **-.8507 ***** | **-1.1797 ***** |
| $\lambda$ | **-0.8247 ***** | **-.7956 ***** | **-.5871 ***** | **-1.0411 ***** | **-1.1079 ***** | **-.8708 ***** | **.7672 ***** | **.8319 ***** | **.8843 ***** |
| $\sigma^2$ | **0.0015 ***** | **0.0015 ***** | **.0016 ***** | **0.0008 ***** | **0.0009 ***** | **.0009 ***** | **.0012 ***** | **.0012 ***** | **.0012 ***** |

The table displays alternative regression results for the mixed-regressive spatial panel model. We employ three different row-standardized binary contiguity matrices with alternative cut-off distances of 150 km, 200 km and 250 km between the geographical centroids of the individual cities. Huber-White heteroscedasticity-robust standard errors are presented in brackets. ***,**,* denote statistical significance at the 1%,5%,10% levels, respectively.