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## Article

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ORIGINAL ARTICLE

Open Access



# Inequality of earnings and housing costs – developments between and within regions

Philipp Breidenbach<sup>1</sup> and Sandra Schaffner<sup>1,2\*</sup>

## Abstract

Household well-being is strongly influenced by changes in income – but real income is strongly determined by housing costs. The evolution of inequalities in both variables largely determines the development of living conditions between households. In this paper, we look at inequality trends between 2008 and 2017 from a regional perspective – between and within regions. While neighborhood earnings inequality has generally declined slightly, it is rising within Germany's largest cities. On the other hand, inequality in rents has less declined within those cities than in the rest of Germany, corresponding to price increases in poorer neighborhoods, too. Households in these poor neighborhoods thus suffer from a below-average earnings development, while it seems that the main costs caused by new rentals increase similar to the rest of the city.

**Keywords** Regional disparities, Inequality of earnings and housing costs

**JEL classification** J31, R23, R31

## 1 Introduction

Economic inequality and its development over time are receiving increasing attention in the economic and political debate. Alongside measures of purely effective economic processes (e.g. GDP growth), measures of the equitable distribution of growth and social participation in prosperity are becoming increasingly important. In this sense, individual earnings inequality serves as a suitable indicator for observing distributional developments in the economy.

After decades of low inequality, several authors diagnosed rising wage inequality for Germany in the early 2000s (e.g. Bluedorn et al. 2019; Dustmann et al. 2014; Card et al. 2013; Biewen and Juhasz 2012; Dustmann et al. 2009). Their findings suggest that the lower tail wage

inequality has increased in Germany since the 1990s. There are several explanations for the increasing inequality in the lower tail of the distribution (for an overview see Biewen et al. 2018). Some studies see the change in composition of workers as one explanation (Dustmann et al. 2009; Card et al. 2013). Further, there is some evidence that union coverage and/or collective bargaining (Dustmann et al. 2009; Felbermayr et al. 2014; Biewen and Seckler 2019) drives inequality. Card et al. (2013) show that heterogeneity of firm wage premiums and assortative matching between firms and workers explain rise of inequality while Biewen et al. (2018) show the impact of interruptions in full-time employment on the increase in inequality. More recent studies find evidence that wage inequality has remained stable or even declined after 2010 (Bossler and Schank 2023; Biewen et al. 2019; Brüll and Gathmann 2020; Möller 2016). Most of these studies focus on wage or earnings inequality as an important measure of inequality.

Our approach presented in this paper goes beyond the focus on earnings. We also take housing costs into

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account to get a sense of real wage or purchasing power inequality. Regions within a country face different price levels especially in terms of housing costs (e.g. Moretti 2013). Therefore, the evolution of regional purchasing power inequality is not per se clearly indicated by inequality in nominal-based pure earnings. Literature on income inequality respective housing costs is scarce in Germany. Dustmann et al. (2018) detected that the lower income quintile and younger population are disproportionately burdened by increasing housing costs in their study between 1993 and 2013 leading to an increase in inequality for lower income groups.

Our focus is on decomposing the temporal dynamics of inequality into components within and between the German regions. The data sources used – the GridAB and the RWI-GEO-RED data, allow the analysis of regional entities below the administrative level of German counties. The GridAB data which comprise earning information from the IEB (Integrated Employment Biographies) covers earnings on the level of  $1 \times 1$  km grid cells from all employees who are subject to the social security system in Germany. The RWI-GEO-RED data comprise apartments for rent offered on the largest online platform (ImmobilienScout24) in Germany. The information on rent prices is aggregated on the zip-code level. Earnings and prices are analyzed separately as the concrete location of GridAB grid cells within a county cannot be linked to the housing data.

In general, the overall inequality of neighborhoods earnings decreases by about 7% in Germany observing a period from 2008 to 2017. Decomposing the overall effect into the between county inequality and the within county (between neighborhoods) inequality reveals that both components decrease. Herein, the between component decreases much stronger by about 31%. Within the counties (and cities) of Germany, the inequality decreases by about 5%.

However, this general picture for all German regions does not reflect the situation in Germany's largest cities, where we find a growing within inequality. Within the largest four, and respectively 15 cities, the inequality of earnings is on a rise. Within the largest four cities (Berlin, München, Hamburg and Cologne) the inequality increased by 15%. The development is slightly lower in the top 15 cities, indicating an increase of 6%.

The inequality in neighborhood housing prices (reflected by offering prices for rental apartments) sharply increases in this same time frame by 66%. The main driver of the increase is the within inequality: The inequality of rental prices within a county (between neighborhoods) sharply rises. Thus, for the entire country, households in poor neighborhoods benefit from below-average rent price increases. The rise in inequality

is lower in cities. Housing cost inequality is even decreasing in the largest cities by 27%.

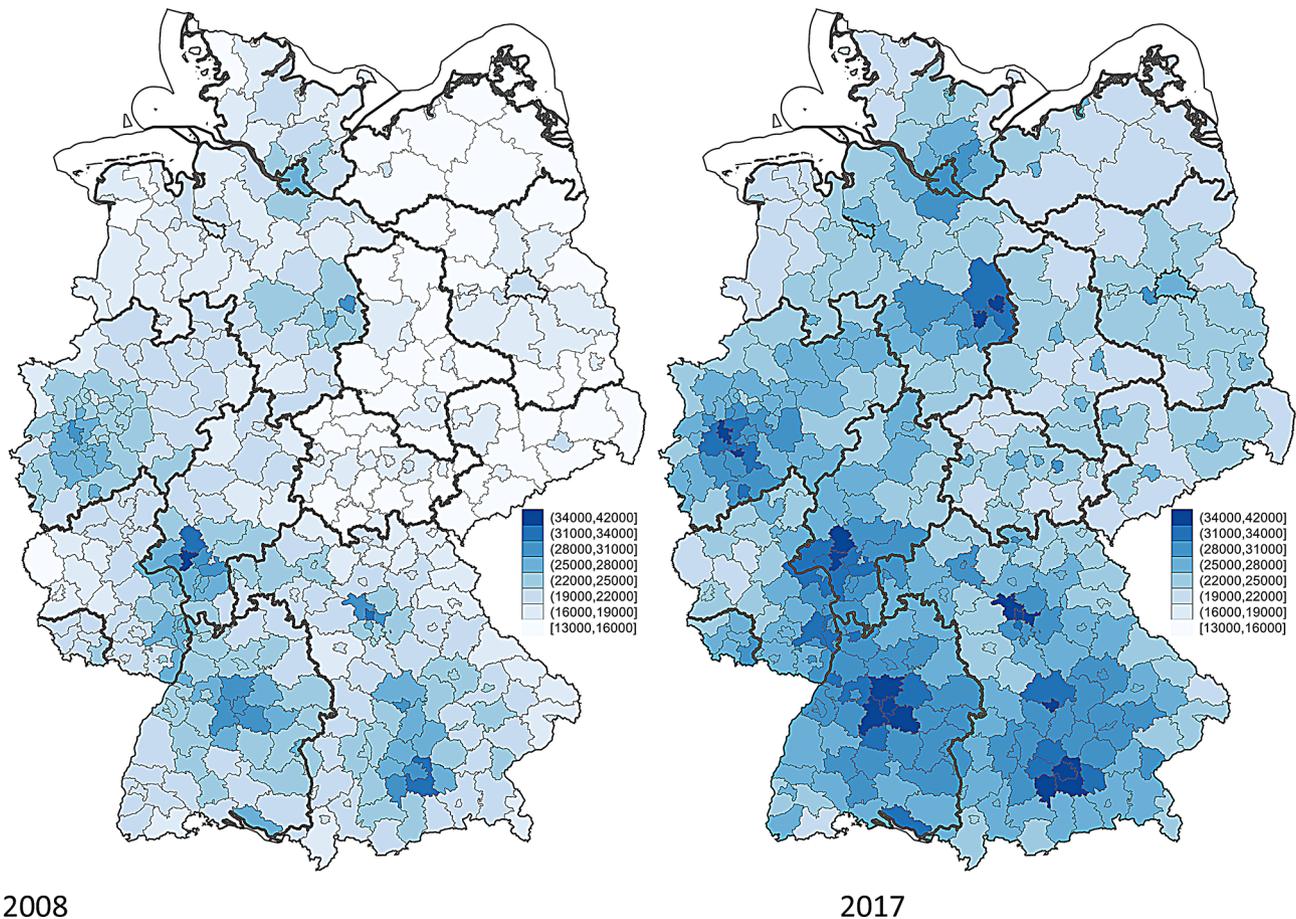
Our findings leads us to draw at least two conclusions. First, at the broad level of Germany as a whole, neighborhood income inequality is decreasing while rent price inequality is increasing. Both of these are good signs for relatively poor neighborhoods suffering from lower earnings. In comparison to the mean earnings across Germany and within each region, the observed earnings are relatively high, while the observed increase in housing costs is below the mean increase. Second, disentangling results and focusing on large cities, we find a divergent picture. Here, the poorer neighborhoods have under-average earnings developments. Although their housing costs are increasing below average the differences to less poor neighborhoods are less pronounced than in more rural areas. Urban households in poorer neighborhoods thus did not benefit from such positive developments in the earnings-costs-ratio. Further, the analyses underscore the importance of highly disaggregated data in the analysis of regional inequality.

The paper is structured as follows: Sect. 2 describes the two data sets we apply in our analysis. The third section presents the inequality measures. Section 4 shows the results and finally, Sect. 5 concludes.

## 2 Data

The **GridAB** data was generated as a regionally aggregated data set from the administrative data *Integrated Employment Biographies (IEB)* by the German Federal Employment Agency. It is a comprehensive dataset of labor market variables for Germany accumulated on  $1 \text{ km}^2$  grid level to describe neighborhoods effect. Besides other variables the data set covers the mean daily wage of all workers living in the respective grid. Further, each grid is assigned to a county (NUTS3). The GridAB data gives wage information for all grids with 10 or more employees; in 2017, that are 181 855 grids. We restrict the data set to workers in regular employment due to social security contributions and marginal employed workers. A data description of the GridAB data set can be found in Ostermann et al. (2022).

Figure 1 displays the county specific mean of yearly earnings for the years 2008 and 2017. It becomes obvious that there are substantial differences between the counties. The 90th percentile has two thirds higher earnings than the 10th percentile. However, the differences somewhat decrease in 2017 which also becomes obvious in Fig. 2. The highest increase in earnings is in East Germany which has had lower earnings than the West. Since we only capture earnings (instead of wages), it remains unclear if the increase is induced by higher wages or by more stable jobs and therefore less periods without earnings.



**Fig. 1** Earnings distribution on county level GridAB. Source: Own calculation based on GridAB. Mean yearly earnings aggregated on county level

As housing cost make up the largest share of the income basket, we issue this regionally varying consumption item. We restrict our analysis, though, to the rental costs since over 50% of Germans are renters (Destatis 2019). The dataset, which is used for modeling regional rent costs, is the **RWI-GEO-RED** dataset (version 7.1, RWI; ImmobilienScout24 (2022)). It is based on offers published by owners or agents on the German listing website *immobilienscout24.de*. For a detailed data description see Schaffner and Thiel (2022). The underlying dataset covers the years 2007 until June 2022. We only use geocoded rent offers for apartments. Additional to the rent prices, the data provide information on facilities and features of the dwellings. This comprises e.g. apartment size in m<sup>2</sup>, the number of rooms or the availability of a balcony or garden but also quality assessments like the renovation status of the apartment. With this, an estimation of a hedonic price regression is possible and regional rent costs can be modeled.

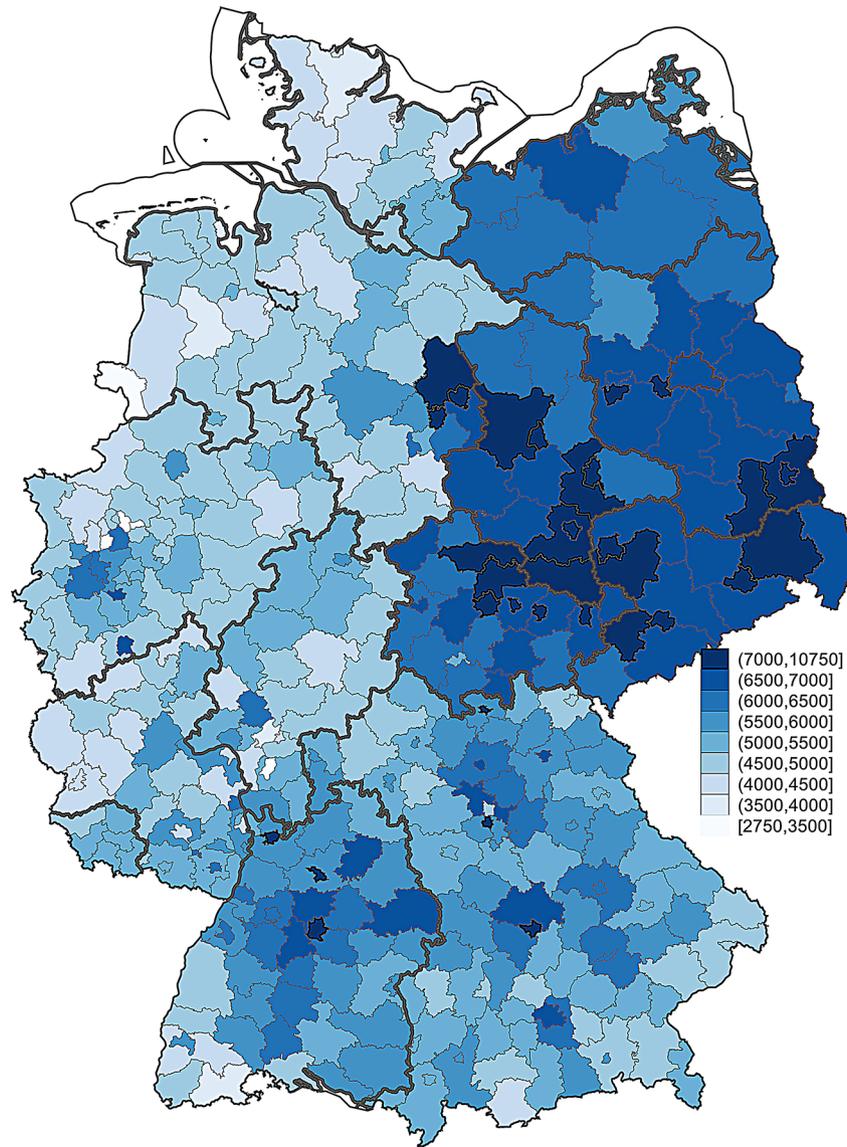
The methodology of the rent price indices proceeds from the RWI-GEO-REDX data, described in Klick and Schaffner (2021), the index is based on RWI-GEO-RED data, too. While the RWI-GEO-REDX data set focuses

on the estimation of indices on labor market area, county and municipality level, the upcoming rent price index is estimated on zip-code level with the same methodology, respectively as a zip code fixed effect:

$$\ln(p_{izt}) = \hat{\beta} x_{izt} + \hat{\delta}_{zt} + \hat{\epsilon}_{izt} \quad (1)$$

with  $p_{izt}$  being the advertised rent without utilities (*Kaltmiete*) per square meter and  $x_{izt}$  the equipment and features of the apartment used as exogenous variables in the hedonic price regression of the offered apartment  $i$  in year  $t$  and zip code  $z$ . The exogeneous variables are construction year, first occupancy, balcony, garden, kitchenette, additional bathroom, quality number of rooms. The mean rent cost per square meter in a specific zip code  $z$  at time  $t$  are than predicted at the median of all Germany of equipment. We restrict the analysis to zip codes with at least 5 advertisements in the respective year.

Figure 3 presents the regional distribution on county level. It becomes obvious that regional differences between rental prices have increased. Further, rental



**Fig. 2** Change in county earnings 2008 to 2017. Source: Own calculation based on GridAB

prices are the highest in the big cities and in South Germany.

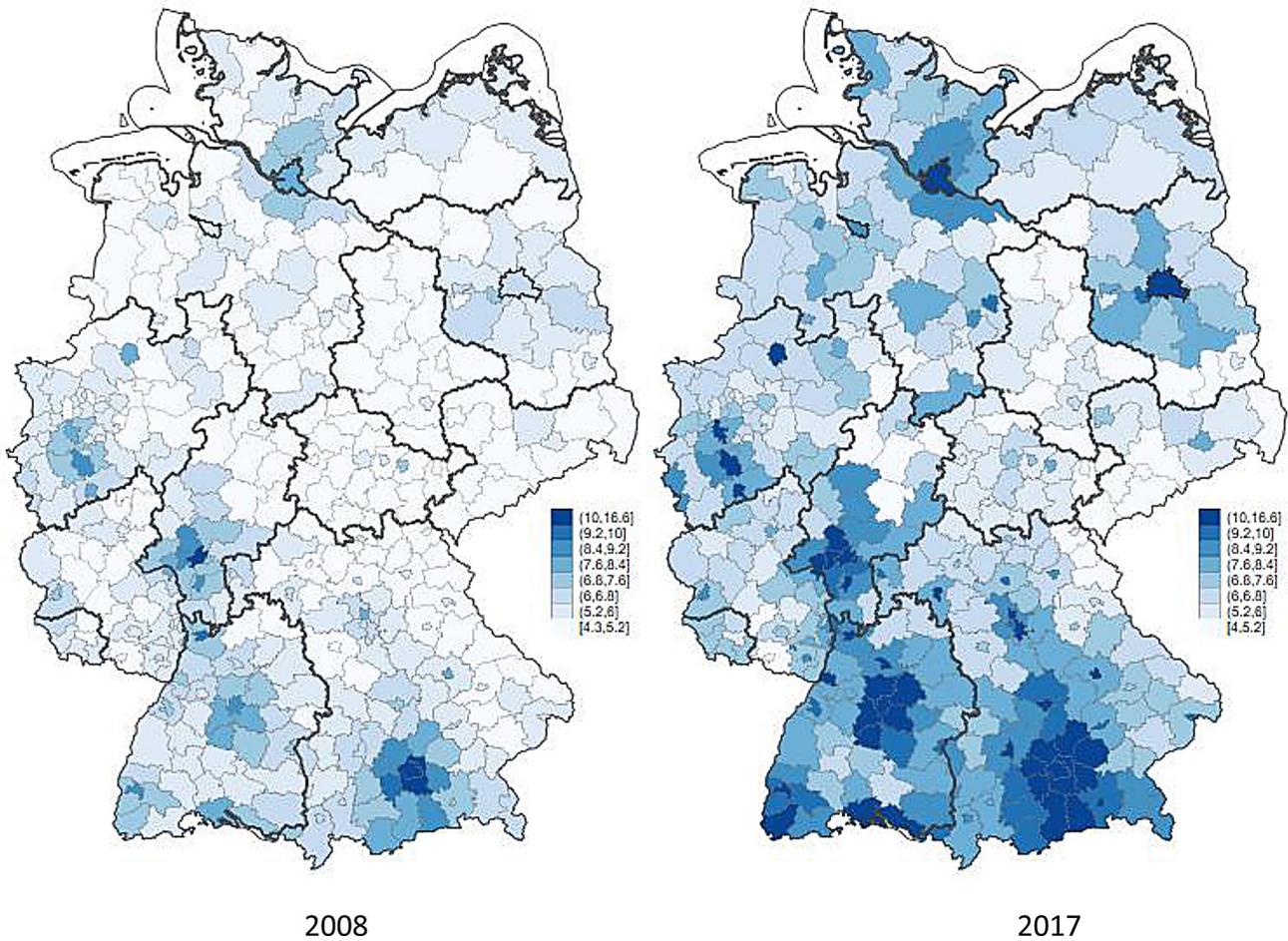
### 3 Measures of income inequality

Our goal is to analyze the development of inequality. A wide variety of inequality measures exist. We apply the Theil 1-Index in our analysis. However, we compare the general measures with those derived by different methods. The overall picture and trends are not sensitive to the choice of other inequality measures like percentile ratios or the Gini index instead.

There are several inequality measures from the Generalized Entropy (GE) index family. We can set the analytical focus with a sensitivity parameter to different parts of the income distribution without the need for welfare assumptions or inequality preferences. While the mean

log deviation  $GE(\alpha = 0)$  focuses on the lower end of the income distribution, the Theil 1 (or Theil T)-Index  $GE(\alpha = 1)$  is more sensitive to income changes in the upper tail. The main advantage, and the crucial point for focusing on an index from the generalized entropy family, is its decomposability into subgroups, each with a within-region and between-region inequality component. To be more rigorous in our analysis, we focus on the Theil 1-Index. It is represented as

$$GE(\alpha = 1)_t = I_{Theil1}(y_j) = \frac{1}{N} \sum_{i=1}^N \frac{y_{jt}}{\bar{y}_t} \log \left( \frac{y_{jt}}{\bar{y}_t} \right) \quad (2)$$



**Fig. 3** Mean county rents per square meter. Source: RWI-GEO-RED, own calculations

with  $y_i$  as mean income in 1 km<sup>2</sup> cell  $j$  in year  $t$ ,  $\bar{y}$  as the overall mean and  $N := N_t$  total number of all populated 1 km<sup>2</sup> cell. Its decomposition in a within and between subgroup component stems from

$$I_{theil}(y_t) = GE_{within}(1)_t + GE_{between}(1)_t \quad (3)$$

given by

$$\begin{aligned} GE_{within}(1) &= \sum_{k=1}^K w_{kt} I^{kt} \text{ and } GE_{between}(1) \\ &= \sum_{k=1}^K w_{kt} \log\left(\frac{\bar{y}_{kt}}{\bar{y}_t}\right) \quad (4) \\ \text{with } w_{kt} &= \frac{n_{kt}}{N} \cdot \frac{\bar{y}_{kt}}{\bar{y}_t} \end{aligned}$$

as the weight for subgroup  $k$  in year  $t$ ,  $I^{kt}$  as the Theil-Index of disposable income p.c. in 1 km<sup>2</sup> cells for a given subgroup  $k$  and year,  $\bar{y}_{kt}$  as mean income and  $n_{kt}$  no. of cells in subgroup  $k$ . Since the subgroups are German

counties, the within component describes the size-weighted inequality within each county or the weighted sum of the income inequality indices between the grids in each county. The between component defines the inequality of the county's mean income and thus how much of the regional inequality lies between the different German counties.

With respect to the question of whether rent deductibility reduces income inequality in Germany, the within-component describes the small-scale income convergence of neighborhoods within administrative county boundaries. A decrease in the within component of disposable income over time describes a convergence of income disparities within counties. When netting out disposable income with grid-level rental prices, a decline in the within component implies that housing costs are increasing most where incomes are high. The convergence of average income inequality between regions can be observed by a decreasing inequality between regions.

Nevertheless, Theil's index is sensitive not only to the differences between the values studied, but also to the level of the values themselves. A direct comparison of

inequality measures such as the Theil 1 (GE1) -Index of net income and net income minus regional housing costs is not helpful in determining the level of inequality. This is due to the homogeneity assumption and the higher sensitivity of inequality measures to smaller income values. We therefore reduce all earnings and income values by the German national average housing costs (by year) to avoid changes in the indices caused by the additive sensitivity of the Theil index.

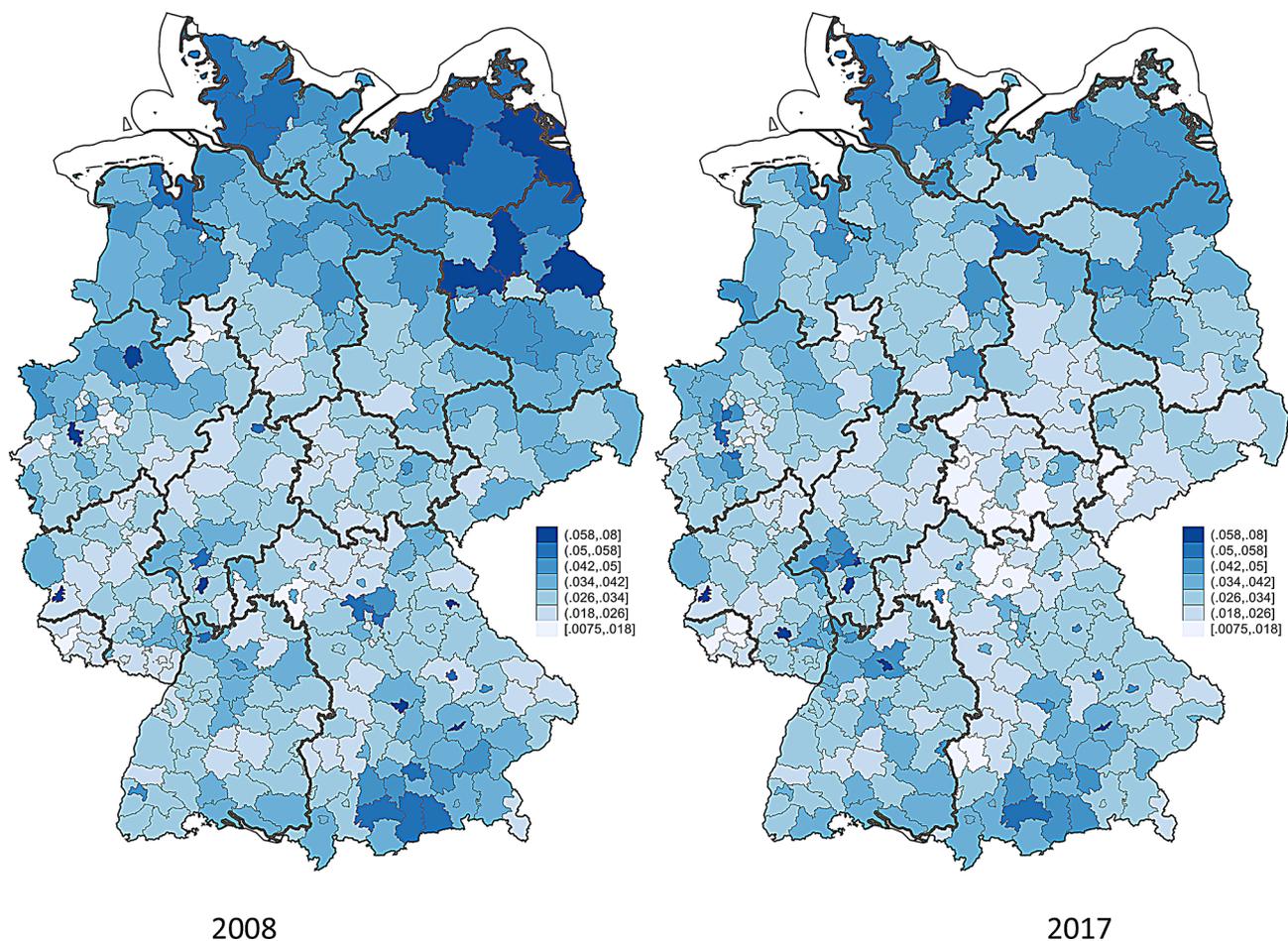
Figure 4 shows the inequality of earnings within counties for the years 2008 and 2017. The inequality measure (Theil 1-Index) shows the inequality between neighborhoods (1 km<sup>2</sup> grid cells) within the county. Inequality is higher in the north, while there is no other clear pattern. Differences in the absolute value of inequality may also be due to differences in the size of counties. It becomes obvious that inequality decreases between 2008 and 2017. There are more counties in the highest group in 2008 and more counties in the lowest group in 2017. While income inequality decreases in eastern Germany between 2008 and 2017 (Fig. 5), it increases in several parts of western Germany.

We also calculate the inequality of house prices within counties (Fig. 6). Here we see that inequality is higher in cities than in rural areas. In 2017, inequality is very high in East Germany and some other, mainly rural parts. Furthermore, inequality is increasing in most parts of Germany (Fig. 7). Almost all counties in East Germany have experienced large inequality increases.

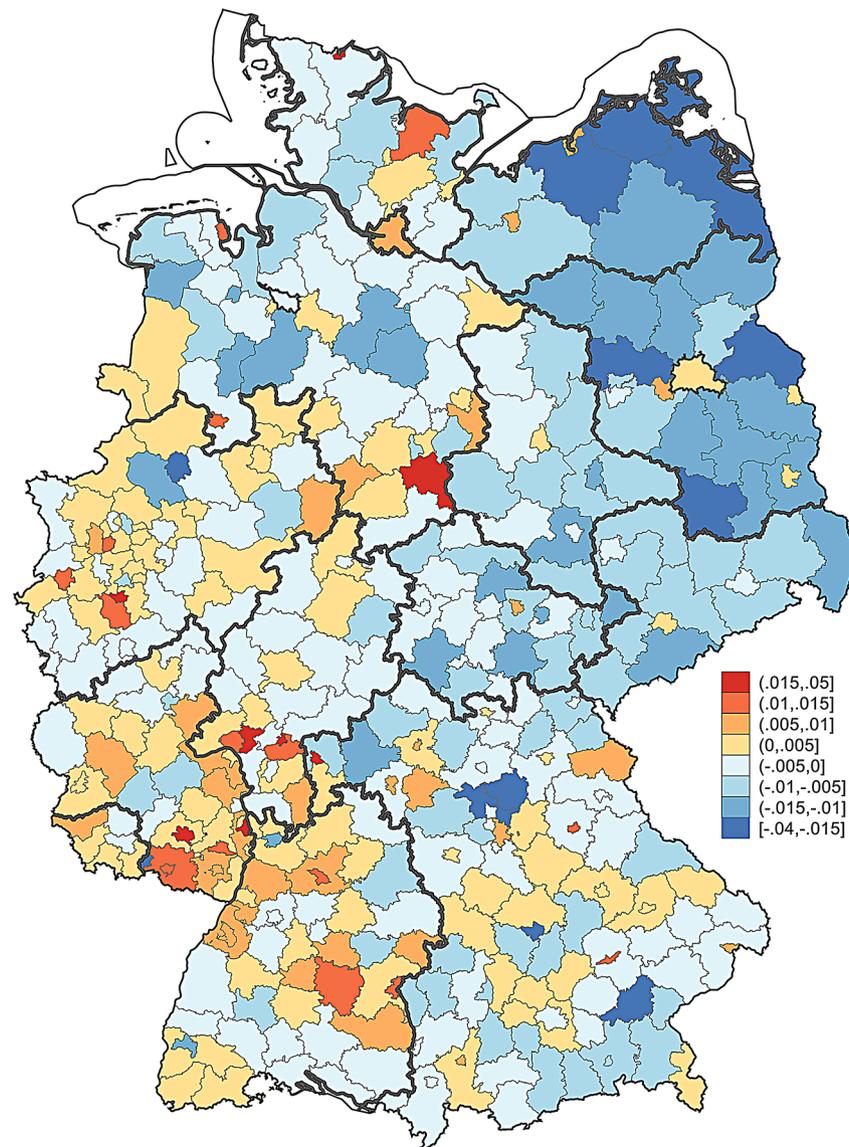
#### 4 Results

The analyses start with a closer look at developments in earnings over time. First, we show developments within and between counties for Germany as a whole. Second, we go beyond the analysis of the entire country and focus on the developments within the subgroup of Germany's largest cities. Similarly, we analyze housing cost developments.

Figure 8 shows the development of earnings inequality based on the GridAB data. Looking at all counties and county-free cities in Germany, the overall Theil index decreases by about 13% in the ten years from 2008 to 2017. The decreasing Theil index reflects a decrease in overall wage inequality across German neighborhoods



**Fig. 4** Earnings inequality (Theil 1) within counties – GridAB. Source: Own calculation based on GridAB



**Fig. 5** Change in earnings inequality (Theil 1) within counties – GridAB 2008 to 2017. Source: Own calculation based on GridAB

(1 km<sup>2</sup> grid cells), since the observation unit is the neighborhood.

As noted above, the Theil index allows for a decomposition into two regional components. The first component is the inequality within counties (between neighborhoods). The second remaining inequality is the inequality between counties.

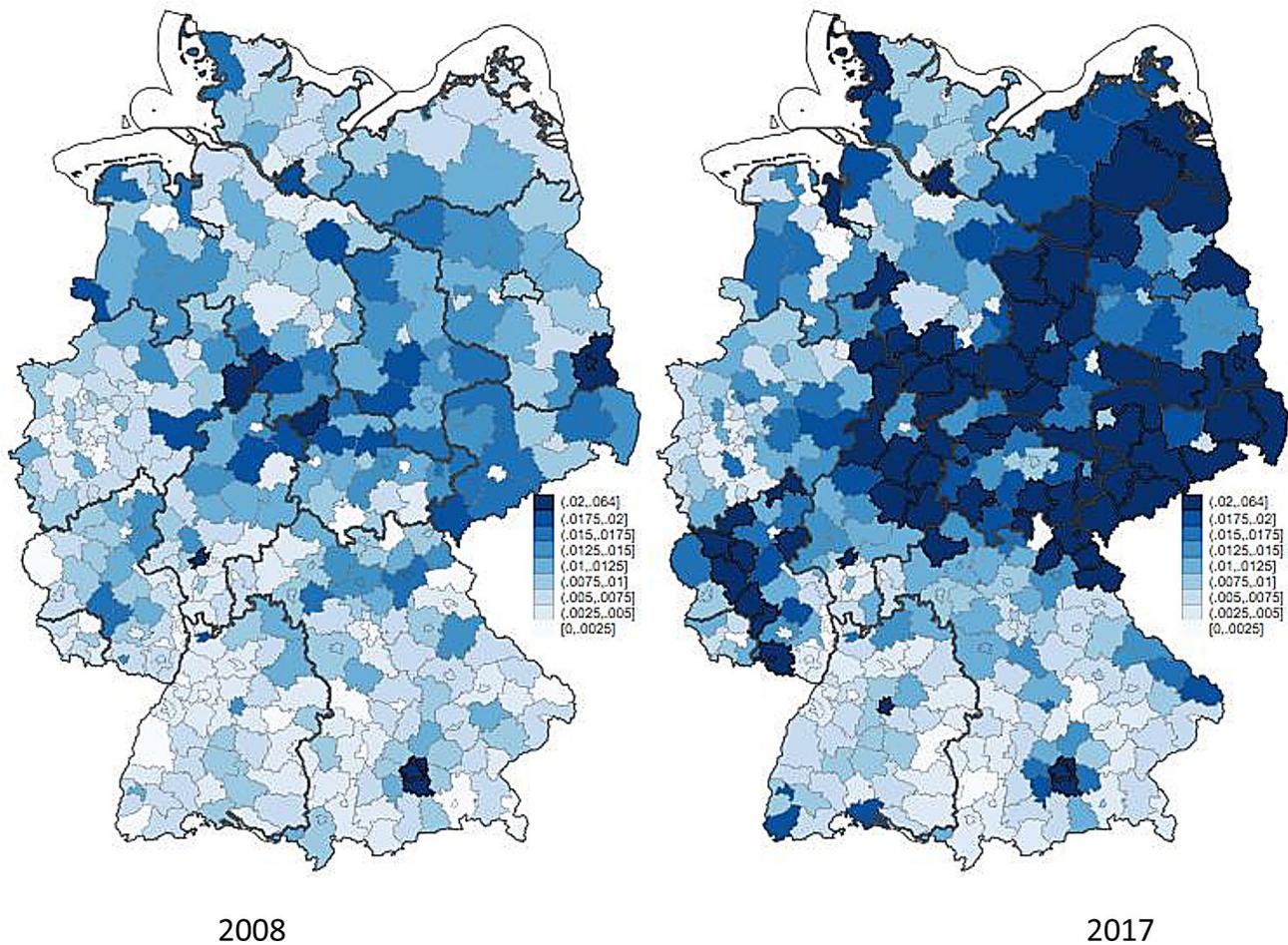
The overall change in the Theil index is mainly driven by a decline in inequality between counties, which fell by about a third (31%) during the observation period from 2008 to 2017. In contrast, inequality within regions hardly decreased at all. Intra-county inequality decreased by only 5% over time.

Up to this point, the analyses refer to Germany as a whole. In the next step, we want to focus on the development of inequality in Germany's largest cities. We start

with the 15 most populous cities, all of which have more than 500,000 inhabitants. The cities included in this category are Berlin, Hamburg, Munich, Cologne, Frankfurt, Stuttgart, Düsseldorf, Leipzig, Dortmund, Essen, Bremen, Dresden, Hannover, Nuremberg and Duisburg<sup>1</sup>. These cities are mainly in West Germany with the exception of Dresden, Leipzig and the special case Berlin. In particular, most of the largest cities have experienced population and economic growth.

Focusing on these Top15 cities (Fig. 9), we see greater differences between the evolution of inequality within and between counties. The overall Theil index increases

<sup>1</sup> The city of Duisburg has a population of approximately 500,000 during the observation period. At times, the population is just below this figure, but it has since rebounded to exceed it once more.



**Fig. 6** Rent price inequality (Theil 1) within counties -RWI-GEO-RED. Source: Own calculation based on RWI-GEO-RED

slightly. The 2017 value is about 6% higher than the inequality in 2008. This overall development is split into two divergent processes between the counties and within the counties. Inequality between the 15 largest cities is decreasing significantly. With a decrease of about 28%, the decline is much stronger than at the overall German level. Within the Top15 cities, the trend is reversed. Within those cities the inequality has increased by about 13%. It is possible that some of the differences depend on the minimum wage introduction since its bite was higher in rural and especially East German regions.

This picture is even more pronounced in the four largest cities (Fig. 10). These are the German cities with more than one million inhabitants, namely Berlin, Munich, Hamburg and Cologne. The increase in inequality within these cities is even more pronounced. Intra-city inequality is about 19% higher in 2017 than in 2008. Similar to the previously observed Top15 cities, the inequality between these four cities also decreases by about 14%.

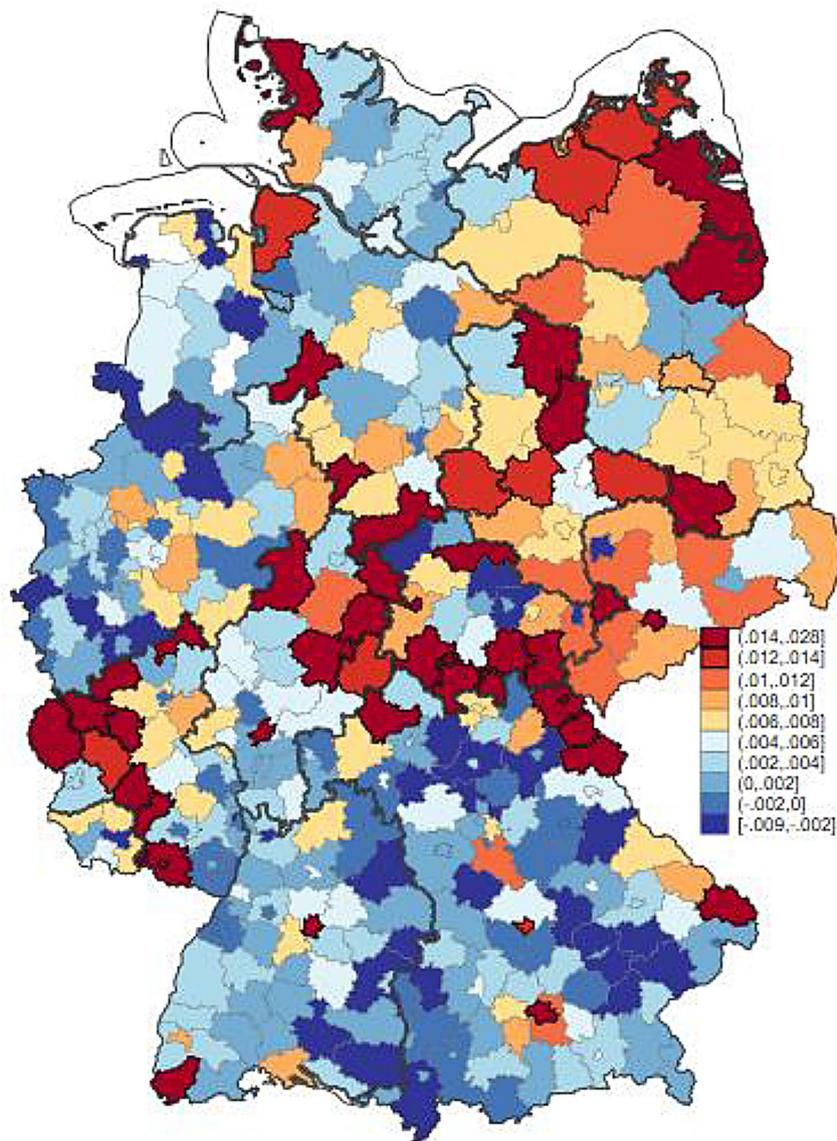
Focusing on the overall development of earnings, a contrasting picture emerges. While there is a trend of declining inequality within counties for the entire

country, the trends are reversed in the biggest cities of Germany. Within these cities, overall inequality is growing significantly. Around 10% of all Germans live in these four cities.

We also look at different tails of the wage distribution to distinguish whether the changes in inequality are associated with the upper or lower tail of the distribution. For this purpose, we use the percentile distances between the 90th percentile and the 10th percentile and between the median and the 10th percentile. The evolution of these two variables can give an idea of whether the changes in inequality tend to come from the top or the bottom of the distribution. As far as earnings are concerned, we do not see any different patterns. The percentile distances develop in the same way in all subgroups (Germany, Top15 cities and Top4 cities).

#### 4.1 Inequality of the housing market

So far, our analyses have focused entirely on the distribution and inequality of nominal earnings within and between counties. As prices (especially housing costs) vary substantially between (and even within) counties,



**Fig. 7** Change in rent price inequality (Theil 1) within counties between 2008 and 2017. Source: Own calculation based on RWI-GEO-RED

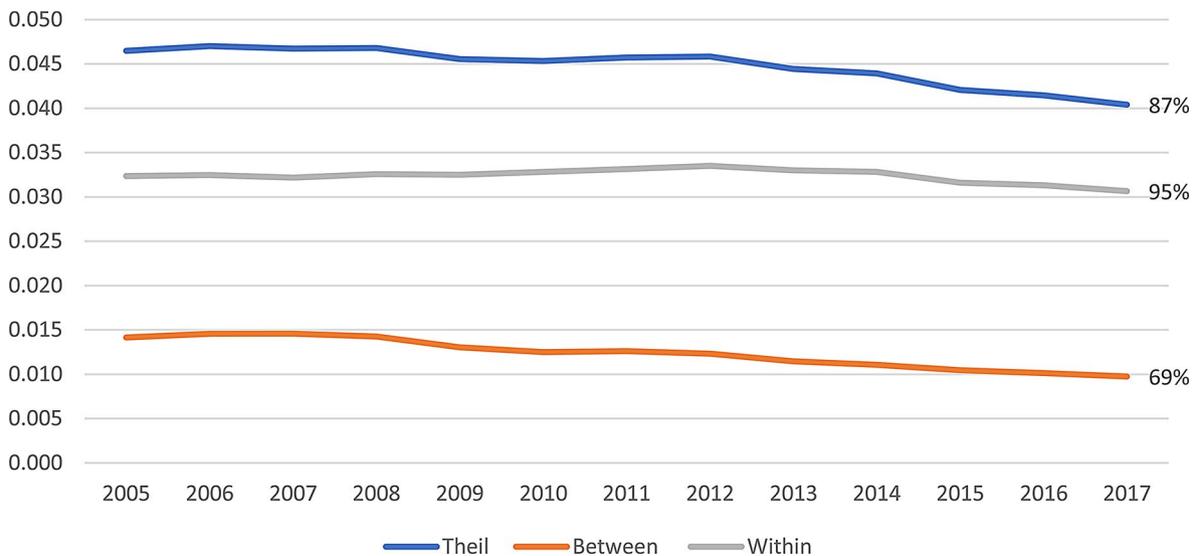
those nominal values can only give limited information on the development of inequality. Housing costs (shown here in terms of asking rents) obtain high importance for disposable income for two reasons. First, housing costs are usually the largest expenditure item for households. Second, housing costs strongly vary locally (especially at the small-area level), so they can have a significant impact on disposable income alongside wages on the income side.

In particular, poorer households tend to live in less expensive housing locations within cities. Thus, an increase of housing costs inequality means that expensive residential locations experience stronger price trends than the mean and/or that the less expensive residential locations experience weaker trends. Thus, in contrast to the trends in wages considered earlier, when considering

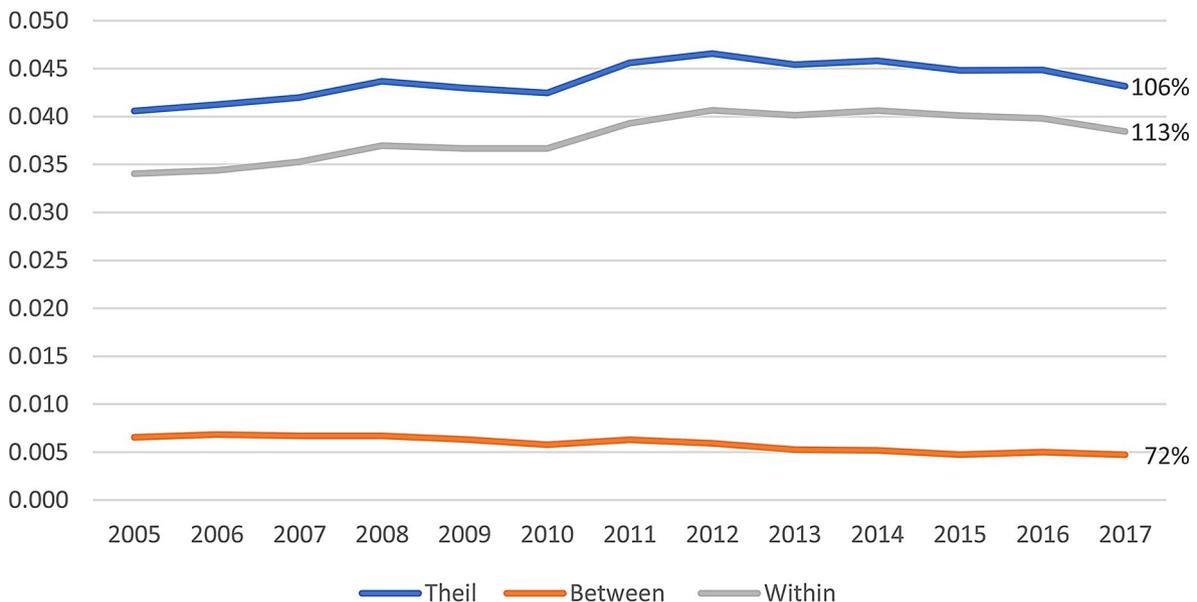
housing costs, a decline in inequality indicates a growing burden on poorer households (growing inequalities in disposable income).

Consistent with the wage data the supply data for rental housing are also aggregated on a small-area neighborhood basis. Since there is no full survey of all existing rents in Germany, we rely on the subset of asking rents. These cannot be mapped at such a granular grid level. Especially in rural areas, there are too few observations. Therefore, rent prices are aggregated at the zip code level. These areas are comparatively large-sliced in rural areas, but within large cities they are also able to map differences between neighborhoods sufficiently well.

Regarding the inequality of housing cost development across Germany as a whole (Fig. 11), there is an increase in inequality between zip code areas to 166% of the 2008



**Fig. 8** Development of earnings inequality. Source: Own calculation based on GridAB



**Fig. 9** Development of earnings inequality in Top15 cities. Source: Own calculation based on GridAB

value. Again, focusing on the split between evolution within and between counties, the costs between counties become more unequal. Here, inequality has risen by about 69%. This growing inequality can also be associated with the growing price differences between urban and rural areas.

Inequality has also risen within counties and district-free cities. With an increase of about 54%, this rise is slightly lower than the increase of between-inequality, but still substantial. These findings indicate that the differences between low-income and high-income neighborhoods increased regarding housing costs. This accounts for the differences between neighborhoods within counties as well as for the differences between counties.

Up to this point, low-income neighborhoods across Germany have experienced positive developments over the period. While income inequality has decreased—with low-income neighborhoods showing stronger gains compared to high-income areas—housing costs in these neighborhoods have increased at a slower rate, contributing to rising inequality in housing affordability. As a result, real incomes have generally improved more significantly in economically weaker neighborhoods.

The results are much less pronounced when looking at the 15 largest cities (Fig. 12). Here, we observe a lower increase in inequality to 110% of the 2008 value. Inequality was even much lower in the years preceding 2017 which was mainly driven by decreased between

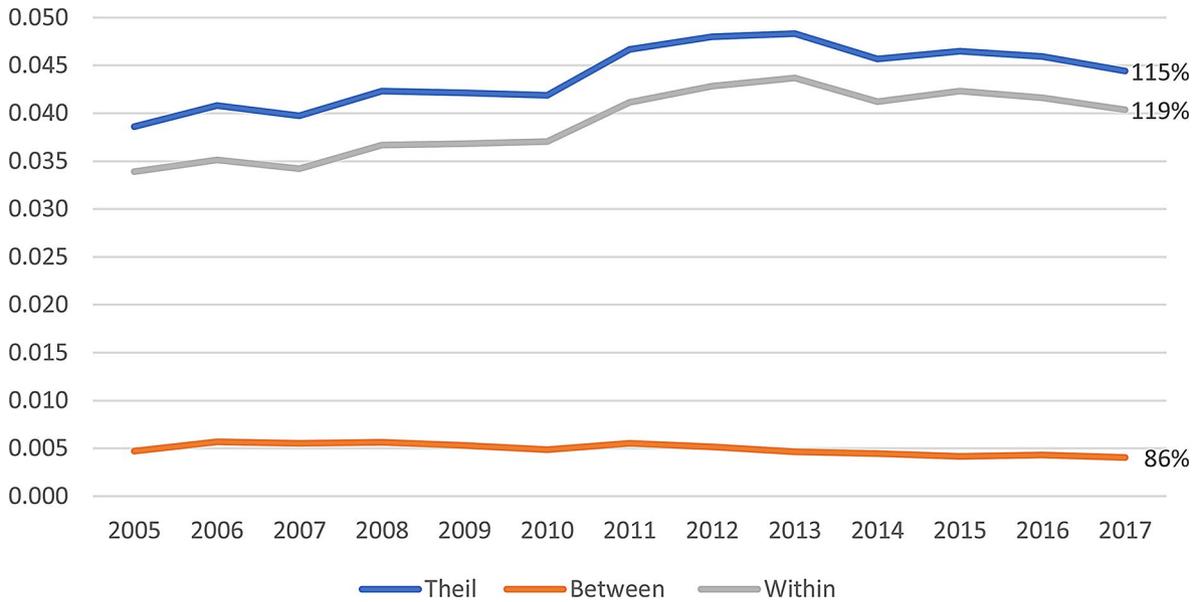


Fig. 10 Development of earnings inequality in the four largest cities. Source: Own calculation based on GridAB

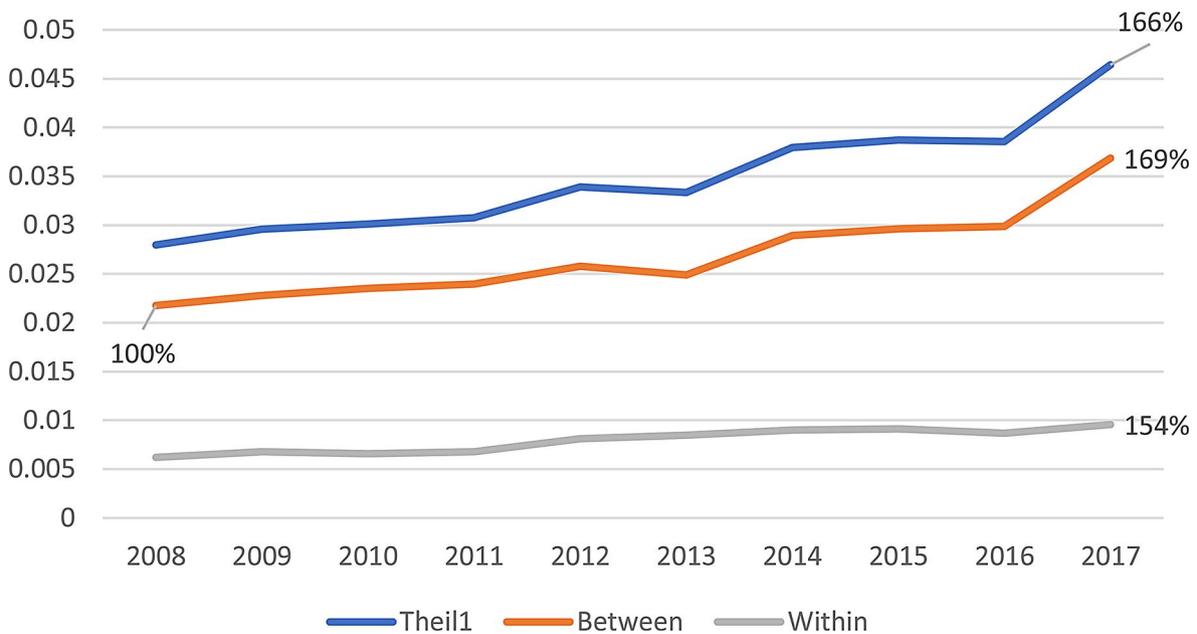


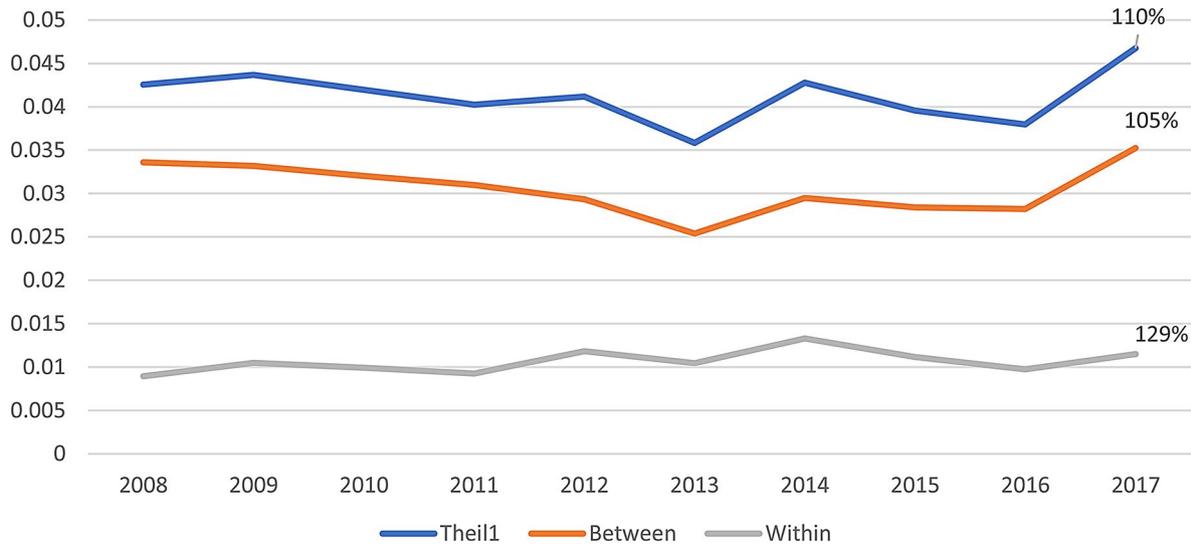
Fig. 11 Development of housing prices inequality. Source: Own calculation based on RWI-GEO-RED

inequality that is only 5% higher than in 2008. The within inequality in prices increased by 29% over the observed period (See Fig. 12).

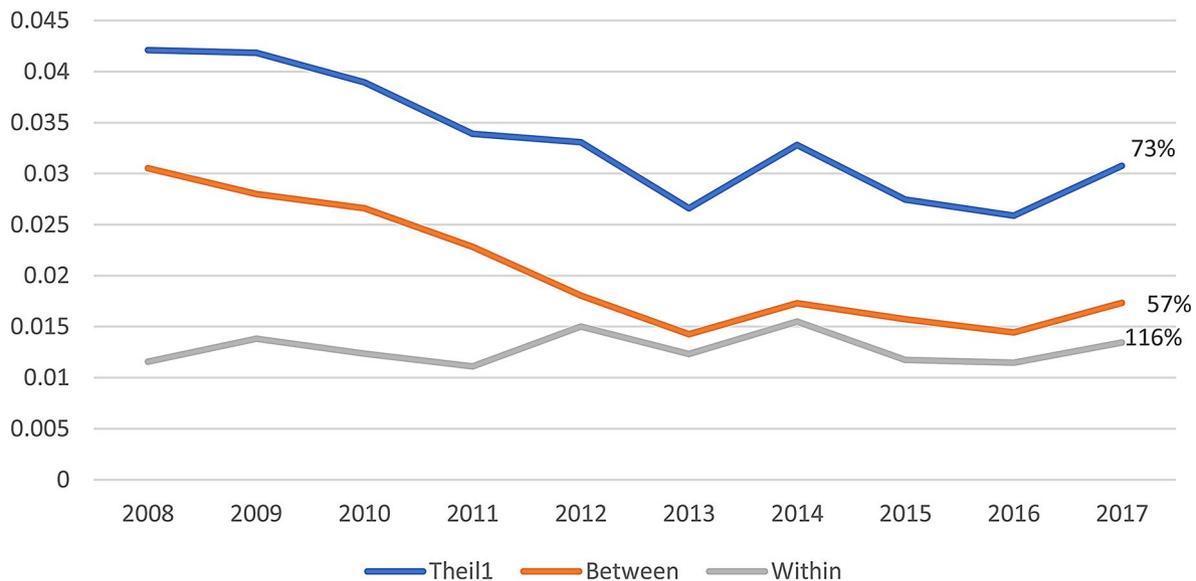
When looking at the four biggest cities (Berlin, Hamburg, Munich and Cologne), we are observing the opposite trend. There is a sharp decline in overall inequality to only 73% of the 2008 value. This is mainly driven by the inequality between the different cities. As Berlin has caught up considerably, the inequality between the cities has decreased. In the four largest cities, within inequality

between neighborhoods has increased less outside these cities (See Fig. 13).

This finding of declining inequality within regions initially leaves open the question of whether the effect is driven more by originally expensive or inexpensive residential locations. This distinction is significant insofar as a decline in inequality due to more favorable housing locations suggests that poorer households in particular are confronted with disproportionately rising housing costs.



**Fig. 12** Development of rental prices inequality in Top15 cities. Source: Own calculation based on RWI-GEO-RED



**Fig. 13** Development of rental prices inequality in biggest four cities. Source: Own calculation based on RWI-GEO-RED

For better illustration, we consider percentile gaps (See Table 1). Here, the focus is on the price ratios between the 90% percentile and the median - the trend in expensive residential locations - and the price ratios between the median and the 10% percentile - the trend in less expensive residential locations.

In the Top4 cities, the percentile gap decreases in the upper and the lower part of the distribution, meaning that cheap and medium-priced accommodations catch up. In these cities, with strongly increasing price trends over the observed period cheaper houses were faced even stronger increases. In all other counties inequality rises in the upper and in the lower part of the housing price distribution. The results do not show substantial differences between inequality increases in the upper and lower tail.

### 5 Conclusion

Earnings and income inequality have been the subject of much debate in Germany and around the world. While earlier research documented rising inequality in Germany at the beginning of the century, more recent studies suggest a reversal of this trend. In this paper, we use innovative small-scale regional data to examine earnings and housing cost inequality across neighborhoods. Our results show a clear decline in earnings inequality between 2008 and 2017, with a reduction of about 7%. This decline has particularly benefited worse-off neighborhoods, as lower-income segments have made gains relative to higher-income areas. The reduction is even more pronounced at the regional level, where inequality between counties fell by 31%. In contrast, income

**Table 1** Percentile ratios of neighborhood housing prices

	All counties		TOP 15		TOP 4	
	p90p10	p50p10	p90p10	p50p10	p90p10	p50p10
2008	1.736	1.240	2.150	1.351	2.170	1.418
2009	1.748	1.230	2.163	1.380	2.149	1.411
2010	1.745	1.223	2.167	1.397	2.100	1.392
2011	1.772	1.236	2.174	1.428	2.002	1.347
2012	1.819	1.253	2.203	1.492	1.962	1.364
2013	1.850	1.268	2.124	1.486	1.845	1.313
2014	1.898	1.275	2.271	1.507	1.938	1.345
2015	1.929	1.293	2.254	1.518	1.825	1.290
2016	1.958	1.329	2.133	1.495	1.834	1.309
2017	2.079	1.374	2.350	1.546	1.923	1.308

Source: Own calculation based on RWI-GEO-RED

inequality between neighborhoods (measured in 1 km<sup>2</sup> grid cells) decreased only slightly.

Despite the overall trend of decreasing inequality, we observe an increase in inequality within neighborhoods in Germany's largest cities (with more than 500,000 inhabitants, or 18% of the German population). This is most pronounced in the four largest cities, where neighborhood inequality increased by 19%. These cities account for about 10% of the total population.

In terms of housing prices, there was a strong increase in price levels over the period. In terms of inequality, rental price inequality increased by 66%. In particular, within-county inequality increased by 69%, outpacing the 54% increase in between-county inequality. Interestingly, worse-off neighborhoods with lower initial price levels appear to be benefiting from the growing gap as the gap between the lower and upper price segments widens.

Within the four largest cities, inequality between neighborhoods (measured by zip codes) increased less, by 16%. Because of the large price increases in these cities, this result suggests that the increase in housing price inequality does not account for the increase in income inequality. These results suggest that those living in the poorer neighborhoods of the large and expensive cities saw their position worsen.

Overall, this paper finds that regional income inequality has declined significantly while housing price inequality has risen sharply. This suggests that poorer neighborhoods and regions are benefiting from the earnings trend, although the picture is less clear in Germany's largest cities, where poorer neighborhoods have underperformed relative to their less disadvantaged counterparts. Moreover, the disparity in rental price performance is less pronounced in these urban areas. However, we cannot analyze both data sets at the same time, which is why we cannot check which changes occur in which neighborhoods.

These findings underscore the importance of highly disaggregated data in the analysis of regional inequality.

Standard administrative data, typically aggregated at the city or county level, would not reveal the intra-regional inequality captured in this analysis, particularly the variation within cities.

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#### Authors' contributions

All authors contributed equally to all sections and steps of the study.

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#### Data availability

The GridAB is not publicly available as the authors use administrative data of the Institute for Employment Research. The data are social data with administrative origin which are processed and kept by Institute for Employment Research (IAB) according to Social Code III. There are certain legal restrictions due to the protection of data privacy. The data contain sensitive information and therefore are subject to the confidentiality regulations of the German Social Code (Book I, Sect. 35, Paragraph 1). The data are held by the IAB (email: iab@iab.de, phone: +49 911 1790) and are on-site available on reasonable request.

The RWI-GEO-RED data is available as scientific use file for researchers. Data application through <https://www.rwi-essen.de/en/research-advice/further/research-data-center-ruhr-fdz/data-access>. For use of replication please contact [fdz@rwi-essen.de](mailto:fdz@rwi-essen.de).

The code is available and archived at FDZ Ruhr at RWI and can be accessed upon request ([breidenbach@rwi-essen.de](mailto:breidenbach@rwi-essen.de)).

#### Declarations

##### Competing interests

None of the authors have any competing interests.

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