

Bringing urban space back in: A multi-level analysis of environmental inequality in Germany

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Authors' preprint version. Please cite the final article:

Rüttenauer, T. (2018). Bringing urban space back in: A multi-level analysis of environmental inequality in Germany. *Urban Studies*, Forthcoming. DOI: 10.1177/0042098018795786

LAST EDITED

November 13, 2018

ABSTRACT

Various studies have shown that minorities bear a disproportionate exposure to environmental pollution. To understand the causes of this environmental inequality, it is important to analyse which structural conditions foster environmental inequality. This study uses an original dataset by combining the German 2011 census with georeferenced pollution data to analyse the variation of environmental inequality between German cities. While structural characteristics derived from standard theories of environmental inequality do a rather poor job of explaining regional differences, an overlooked indicator correlates strongly with environmental inequality: the geographic centrality of polluting facilities within the urban space. Including this structural measure into the city-fixed effects multilevel analysis accounts for more than 25% of the variation between cities. This highlights the importance of taking geographic conditions into account when analysing environmental inequality.

I would like to thank Henning Best, Julia Schulte-Cloos, the editor, two anonymous reviewers, and participants of the Analytical Sociology Seminar 2017 at the Venice International University for helpful comments on earlier versions of this manuscript.

1. Introduction

A huge body of research in the United States and also a growing body of research in Europe has shown that ethnic minorities are exposed to a disproportionately high amount of environmental pollution (e.g. Ard, 2015; Ash and Fetter, 2004; Diekmann and Meyer, 2010; Downey and Hawkins, 2008; Padilla et al., 2014; Pastor et al., 2001, 2005; Rüttenauer, 2018). However, the level of environmental inequality varies considerably between different cities (Downey, 2007; Downey et al., 2008; Padilla et al., 2014), which offers an opportunity to analyse the structural conditions that foster environmental inequality. As has been argued by Schweitzer and Stephenson (2007), comparative research is needed to investigate the influence of urban conditions on the distribution of environmental hazards across social groups. For instance, previous research has shown that riversides, transportation routes, or agglomeration economies play an important role in determining facility locations (e.g. Baden and Coursey, 2002; Elliott and Frickel, 2015; Wolverson, 2012). Identifying such decisive urban conditions helps to improve our understanding of the underlying causal mechanisms, and, in turn, may help urban planners to avoid the persisting disadvantage of minorities.

So far, systematic analyses of the varying inequality levels have been constrained to the United States. Still, it is unclear to which extent findings from the United States are transferable to Germany. First, environmental inequality in the United States is mostly concerned with ethnic minorities like black Americans, Hispanics, or Asians, while minorities in Germany are mostly immigrant-minorities and stem from relatively recent immigration from other European countries or Turkey. Second, the United States exhibits much higher levels of residential segregation, having dissimilarity indices between 41 and 64 (depending on the ethnic group), compared to indices of 20 in Germany (Musterd, 2005). Third, the urban structures differ between the United States and Europe, with a higher population density and more centrally organized cities in Europe (Huang et al., 2007). Those characteristics might play an important role for facility siting decisions or residential mobility, and therefore could on the one hand affect the extent of environmental inequality, but on the other hand also play an important role regarding the causal forces. Thus, it is important to investigate the structural conditions that foster environmental inequality in a different context.

The current study addresses this aim by analysing a novel dataset, combining pollution data from the European Pollutant Release and Transfer Register with socio-demographic data from 2011 German census on the level of 1 square km grid cells and information on the level of German cities. In a first step, city-fixed random-slope multilevel models show that the level of environmental inequality varies considerably between German cities. In the second step, I investigate whether the effect-heterogeneity between the cities can be explained by structural differences between the cities. The findings show that structural characteristics derived from the standard strand of reasoning in environmental inequality literature – like residential segregation – do a relatively poor job of explaining inter-city differences. This is surprising, but in line with previous research from the United States. Still, further analyses emphasise the importance of taking the urban landscape into account. Including the average centrality of industrial facilities explains more than 25% of the inter-city variation in environmental inequality. This result challenges the importance of the standard theory in environmental inequality research, as residential segregation only plays a minor role in determining environmental inequality. Conversely, the analysis highlights the importance of considering the urban space, where social processes like siting or migration

take place. Doing so can enhance our knowledge about the causes of environmental inequality, but can also offer new insights into the side products of urban structures and urban planning.

2. Theoretical background and literature review

Previous literature on environmental inequality has concentrated on two possible explanations for the disproportionate exposure of minority households to environmental pollution: selective siting and selective migration (for an overview see Mohai and Saha, 2015a).

The argument of selective siting assumes that polluting facilities temporally follow the settlement of minority households. The reason that polluting facilities choose areas predominantly occupied by minorities are threefold: taste-based discrimination, profit maximization, and the avoidance of political protest (Campbell et al., 2015; Hamilton, 1995; Grant et al., 2010). First, decision makers may predominantly belong to the majority group and choose to locate unwanted industrial facilities close to minority households and far away from their own group. Second, housing and land-use prices may be lower around high-minority areas, as minority households exhibit generally lower incomes and consequently live in low-rent areas. If companies were economically rational, they would choose low-cost amenities and – as a side-effect – locate close to the minority population. Third, companies may seek the ‘path of the least resistance’ (Saha and Mohai, 2005) and, thus, choose locations where political protest is assumed to be low. If decision-makers within companies assume that minority groups are less likely to organize collective actions against facility siting (‘not in my backyard’) due to their limited resources and political efficacy, minority areas may provide an attractive siting location.

Several studies have used longitudinal data to test the argument of selective siting. Using spatially aggregated data, Funderburg and Laurian (2015); Mohai and Saha (2015b); Pastor et al. (2001); Saha and Mohai (2005); Shaikh and Loomis (1999) conclude that demographic disparities in facility-hosting areas already existed prior to the siting process, which supports the argument of selective siting. However, other longitudinal studies do not exhibit a consistent association between the demographic composition of an area and the probability of receiving a new industrial facility (Been and Gupta, 1997; Downey, 2005; Oakes et al., 1996), and still others rather emphasise infrastructural and historical patterns of facility siting (Baden and Coursey, 2002; Elliott and Frickel, 2013; Wolverson, 2012). Thus, empirical results remain mixed regarding the role of selective siting.

In contrast to selective siting, the argument of selective migration assumes that the in-flow of minority residents temporally follows the occurrence of polluting facilities. Again, two alternative reasons exist: the ‘racial residential discrimination thesis’ and the ‘racial income-inequality thesis’ (Best and Rüttenauer, 2018; Crowder and Downey, 2010; Pais et al., 2014). The ‘racial residential discrimination thesis’ posits that ethnic minorities are discriminated against in the housing market. Independent of socio-economic characteristics, ethnic minorities are steered into neighbourhoods with a lower environmental quality because housing agents or landlords may fear declining attractiveness due to minority in-migration, or spuriously anticipate lower preferences for environmental quality (e.g. Turner and Ross, 2005). The ‘racial income-inequality thesis’, in contrast, argues that selective migration of minority households results from economic disparities between ethnic groups. Assuming that households prefer a high

environmental quality over a low environmental quality, demand, rents and housing prices are higher in clean neighbourhoods. At the same time, the willingness or ability to pay for environmental quality depends on income. Thus, rich households sort into high-quality neighbourhoods, while poor households end up in less desirable and more polluted neighbourhoods (e.g. Banzhaf and Walsh, 2008; Sieg et al., 2004). As minority households hold lower economic resources than their majority counterparts do, those households sort into low-quality neighbourhoods because they simply cannot afford rents and housing prices in high-quality neighbourhoods.

When analysing the aggregated socio-economic development after hosting a new facility, most existing research does not support selective migration as a cause of environmental inequality (e.g. Downey, 2005; Funderburg and Laurian, 2015; Mohai and Saha, 2015b; Oakes et al., 1996; Pastor et al., 2001, 2005). In contrast, studies using individual data and moving trajectories indeed find evidence in favour of the selective migration argument. Best and Rüttenauer (2018), Crowder and Downey (2010), and Pais et al. (2014) conclude that minority households selectively move into more polluted areas than majority households do. Even when controlling for income, these disparities in moving behaviour persist, which indicates that selective migration is not mainly driven by income. This is further supported by the finding that minorities exhibit a lower willingness to pay for the avoidance of environmental pollution (Depro et al., 2015). However, agent-based models of Campbell et al. (2015) indicate that the finding of minorities selectively moving into low-quality areas may be a result of similarity preferences rather than the tendency of choosing lower quality neighbourhoods. Thus, it is unclear how decisive those selective migration processes are for the observed extent of environmental inequality.

3. Macro-structural predictors

Regarding the extent of environmental inequality, previous studies have shown that some cities exhibit a high level of environmental inequality, while others show none or only low levels (Downey, 2007; Downey et al., 2008; Padilla et al., 2014). To explain these variations, this section first describes hypotheses derived from the standard strand of reasoning (outlined in the previous section) and subsequently develops a novel hypothesis that has not been tested by previous research.

The theory of selective siting highlights two factors explaining the level of environmental inequality on the macro level: political efficacy and ethnic residential segregation. First, assuming that companies choose facility locations based on the level of expected political resistance, higher political efficacy of majority members should increase the ‘externalization’ of pollution onto minority groups. Second, independent from the actual motives of a company’s decision, decision makers should only be able to place facilities disproportionately close to minority residents, if residential segregation exists. In cities where minority residents are evenly distributed in space (absolutely desegregated), companies cannot discriminate against minority households and choose a facility location that is disproportionately close to minorities. Thus, higher residential segregation should increase the possibility of selective siting and consequently increase the level of environmental inequality.

The same argument applies for selective migration. An absolutely desegregated area makes selective migration implausible as an explanation for environmental inequality. In a desegregated city, there is no possibility that minority households would have moved selectively into polluted areas in the past, while majority households would

not. If selective migration were at work, minorities would live segregated in areas closer to industrial facilities as a consequence of selective migration. Thus, selective migration processes should produce higher levels of segregation. Second, according to the ‘racial income-inequality thesis’, economic disparities should be the main reason for selective migration processes. Thus, higher levels of economic inequality within a city should lead to higher levels of environmental inequality.

In sum, the standard strand of reasoning in environmental inequality research leads to the following hypotheses: the level of environmental inequality increases with

- H1) increasing levels of residential segregation (selective siting and migration),
- H2) increasing political efficacy of the majority group (selective siting: avoidance of political protest),
- H3) increasing economic inequality (selective migration: ‘racial income-inequality thesis’).

However, previous research produced rather inconclusive results regarding those hypotheses. For instance, Rüttenauer (2018) finds considerable clustering processes of minorities around hazardous industrial pollution, concluding that residential segregation might be a main driver of environmental inequality, and Ard (2016) shows that – for most segregation measures – increasing segregation leads to increasing health risks especially for minority residents. Nonetheless, comparing the level of environmental inequality in U.S. metropolitan areas, Downey et al. (2008) find mixed results regarding the role of income inequality and residential segregation. Though both have a significant effect in some models, the results vary with respect to the operationalisation of the dependent variable and the ethnic group under consideration. Similarly, Downey (2007) finds a significant association between residential segregation and the ethnic toxic concentration ratio, but the effect is small in magnitude and the explanatory power of the model only marginal, which seems to be odd given the emphasis on selective siting and migration in the field.

One explanation for this finding could be that the spatial proximity of industrial facilities to minority households is mainly driven by labour-market characteristics. For example, Hersh (1995) finds that working class households are located closer to facilities because of attractive job opportunities. Similarly, Been and Gupta (1997), and Wolverton (2012) identify the percentage working in manufacturing as an important driver of facility siting. On the one hand, industrial workers offer an attractive labour force for companies, leading to selective siting; on the other hand, people employed in industry may trade-off environmental quality for attractive jobs, leading to selective migration (Wolverton, 2009). If minorities are overrepresented in the class of manufacturing or industrial workers, minorities experience a disproportionate burden. Thus, the extent of environmental inequality might depend on the share of people working in the industrial sector. Thus, the extent of environmental inequality might also depend on the share of people working in the industrial sector. In line with this hypothesis, Krieg (1995) identifies a higher correlation between minority share and toxic waste sites in older industrialized towns, which leads to the hypothesis that the level of environmental inequality increases with

- H4) an increasing share of people employed in the industrial sector (selective siting and migration: job allocation).

Note that this argument conforms to both theoretical lines (selective siting and migration), but assumes a sub-mechanism based on the allocation of jobs rather the mechanisms commonly outlined in the literature (see previous section).

Another explanation is that studies of environmental inequality ‘fail to take the spatial distribution of environmental hazards within metropolitan areas into account’ (Downey, 2007, p. 970). The results of Downey (2005) in Detroit point out that ethnic minorities were somewhat separated from (new) polluting facilities because they lived – due to high residential segregation – in areas where industrial facilities decreased. While the black population resided segregated in central areas of the city, new facilities emerged in suburban and predominately white areas. This process ‘prevented’ the black population from living in areas of newly emerging facilities and led to the conclusion that facilities were not sited selectively in black neighbourhoods between 1970 and 1990.

Elliott and Frickel (2015) support this implication in a historical analysis of hazardous industrial sites in four U.S. cities, finding a persisting geographical accumulation of industrial sites around the urban core. Moreover, they conclude that the extent of environmental inequality diminished over time due to the increasing churning of white middle-class households into those central areas, where minorities have been overrepresented so far. Also for NO₂ concentration levels (including also mobile sources), Padilla et al. (2014) find a positive correlation between deprivation and pollution only in those cities with high deprivation levels in the inner city.

It is well known from segregation research (e.g. Massey and Denton, 1989) that minorities generally tend to cluster around the central city districts. As stated above, this can also prevent minorities from being exposed to environmental pollution if the pollution occurs in more peripheral areas. Altogether, this suggests that, when taking the spatial distribution of pollution into account, especially the centrality of pollution is a crucial driver of environmental inequality. If facilities are located close to the city centre – where minority groups usually cluster – we expect to observe a high correlation between minority share and environmental pollution. This leads to the last (and so far overlooked) hypothesis that the level of environmental inequality increases with

H5) *increasing centrality of facilities within the urban space.*

Though previous results point towards the importance of the spatial distribution of pollution, this hypothesis has not been explicitly tested in previous research.

4. Analytical strategy

4.1. Data

The European Pollutant Transfer and Release Register (E-PRTR; European Commission, 2006) is a register capturing industrial activities and emission reports on all German facilities that fall under one or more of the 65 E-PRTR activities (European Commission, 2006, pp. 79-82) and exceed a pollutant specific threshold of emissions (European Commission, 2006, pp. 83-86). The regulations of this pollutant register are similar to the U.S. Toxics Release Inventory (TRI). All facilities exceeding a pollutant-specific threshold have to report their emissions and geo-locations.¹ In 2011, the dataset contains a total of 1,479 facilities reporting nearly 1b tonnes of emissions to air and nearly 90m tonnes of processed waste. Of those facilities, 367 (24.81%) are located within a 2 kilometre buffer around the 79 metropolitan areas and report emissions to air. Most of the air-polluting facilities in metropolitan areas operate in the energy and waste management sector (both 28%), metal production, chemical industry (both 10%), or the mineral industry (9%).

The 2011 German census (Statistische Ämter des Bundes und der Länder, 2015) provides information about the German population on the level of 361,478 equally distributed 1 kilometre grid cells. Reducing this dataset to non-missing observations (excluding cases with none or low number of inhabitants) and German metropolitan areas (more than 100,000 inhabitants) results in a *final dataset of 9,061 grid cells clustered within 79 cities*. In total these grid cells capture approx. 24 million inhabitants and contain on average 2,650 (median: 1,717) inhabitants.

In addition, the socio-demographic data of the 2011 German census are further enriched by characteristics of the 79 metropolitan cities provided by the ‘Indikatoren und Karten zur Raum- und Stadtentwicklung’ database (INKAR; BBSR, 2017). This is done by using the level of districts (‘Landkreise’) as 66 of the 79 cities are districts by themselves (‘Kreisfreie Stadt’) and this level provides additional variables not available at the municipality level. Though for 13 of the cities, district-level characteristics also include sub-urban regions, additional analyses excluding these cities yield nearly identical results.

4.2. Variables

The main variable of interest is the amount of air pollution for each census grid cell. Therefore, I created a 2 kilometre buffer around the geo-referenced location of each E-PRTR facility and allocated the reported emissions to air proportionate to the spatial overlap between the buffer and each census grid cell. This method is similar to the method Banzhaf and Walsh (2008) apply to the U.S. TRI data. This leads to a dataset of 9,061 census grid cells containing the proportionate amount of industrial emissions to air (including greenhouse gases, chlorinated substances, heavy metals, and other gases and organic substances), without weighting them by toxicity. The reason for not weighting the pollution by toxicity is that using EPA’s RSEI toxicity weights reduces the effective number of facilities within the cities to 179 with only 49 cities holding at least one facility. However, additional analyses using toxicity weights lead to similar results with the same conclusions, no matter whether in- or excluding cities without any toxic facilities (see Figure B1 of the Appendix). To take the right skewness of the emissions into account, the natural logarithm of the emissions (+1) is calculated.

The main explanatory variable on the census level is the minority share, which is available as the percentage of foreigners (not holding German citizenship) in each census cell. Additional control variables on the grid cell level include population (which equals population density because of same-sized spatial units), the percentage of people aged 65 or older, the percentage of vacant housing, and the living space per inhabitant (in m²). The latter can be seen as a proxy for wealth especially within cities. Furthermore, I control for infrastructural characteristics by including the distance to highway junctions and railway lines (e.g. Wolverton, 2012), obtained from OpenStreetMap.

I use the following city-level indicators: residential segregation, economic inequality, political efficacy, the share of employees in industry, and facility centrality. As measure for segregation, the spatial information theory index (\tilde{H}) as proposed by Reardon and O’Sullivan (2004) is computed for each city. The spatial version \tilde{H} is calculated by taking the average proximity-weighted local neighbourhood of each point into account. In the main analysis, a kernel density bandwidth of 2,000m is used to compute the local environment. Economic inequality is operationalised by the German – foreign unemployment ratio (percentage of unemployed foreigners divided by the percentage of unemployed Germans). Political efficacy is measured as the total voter turnout of

each city in the preceding federal election (2009), and the share of industrial workers as the percentage of employees in the industrial sector. Further controls on the city level are the average gross wages per capita in the industrial sector, the city size (area), and population growth rate per squared kilometre within the last ten years.

To calculate the facility centrality, I geo-coded each city's town hall as the city centre.² Subsequently, I computed the distance of each industrial facility within a 2 kilometre range of the city boundaries to the city centre. Finally, the average of these distances was taken and divided by the maximum possible distance between the city centre and each point of the city boundary, ensuring that the centrality measure does not depend on the city's actual size but becomes a relative measure. For ease of interpretation, I calculated the inverse of this average relative distance to receive the average centrality of industrial facilities. Formally, the facility centrality for each city $j = 1, \dots, N$ can be written as

$$FC_j = \left(\frac{\frac{1}{M} \sum_{i=1}^M d_{ij}}{\max(\tilde{\mathbf{d}}_j)} \right)^{-1},$$

where d_{ij} is the distance between each facility $i = 1, \dots, M$ in the 2km surrounding of city j and the city's centre, and $\tilde{\mathbf{d}}_j$ a vector of the distances between the city centre and all coordinates of the city's boundary. The summary statistics of all variables are presented in Table A1 of the Appendix.

4.3. Method

The analyses rely on multilevel models, nesting the 9,061 census grid cells within the 79 cities (e.g. Hox and Wijngaards-de Meij, 2015). The main research question is the comparison of within-city environmental inequality between the cities. As in previous literature (e.g. Ash and Fetter, 2004; Diekmann and Meyer, 2010; Downey and Hawkins, 2008; Rüttenauer, 2018), the air pollution is regressed on the percentage of foreigners, and this regression coefficient is interpreted as the level of environmental inequality. To obtain a within-city effect, the first level (census grid cell) variables are group mean centered (for a discussion on centring see Enders and Tofghi, 2007). This is similar to city-fixed effects estimators (including a dummy for each single city), meanings that all city-wide characteristics are controlled for in the first-level estimates (e.g. generally higher pollution in larger cities). The model can be written as

$$pollution_{ij} = \beta_{0j} + \beta_1 forgn_{ij} + \beta_2 forgn_{ij} segr_j + \dots + u_{1j} forgn_{ij} + \varepsilon_{ij},$$

for all $i = 1, \dots, N$ observations and $j = 1, \dots, J$ cities, where β_{0j} is a city-specific intercept, u_{1j} the random-slope parameter, and ε_{ij} the idiosyncratic disturbance.

The cross-level interactions (β_2) provide an estimate of how city-level characteristics (e.g. segregation) influence the within-city correlation between the percentage of foreigners and industrial air pollution (β_1), i.e. the level of environmental inequality. The main effects of the city-level variables are subsumed by the individual intercepts. Furthermore, the random slope parameter can be used to evaluate the impact of the cross-level interactions on the between-city variation. All second level predictors (city level) were standardized around the grand mean and scaled by their standard deviation. Note that this approach does not claim to identify causal effects, as the cross-sectional design does not allow testing selective siting against selective migra-

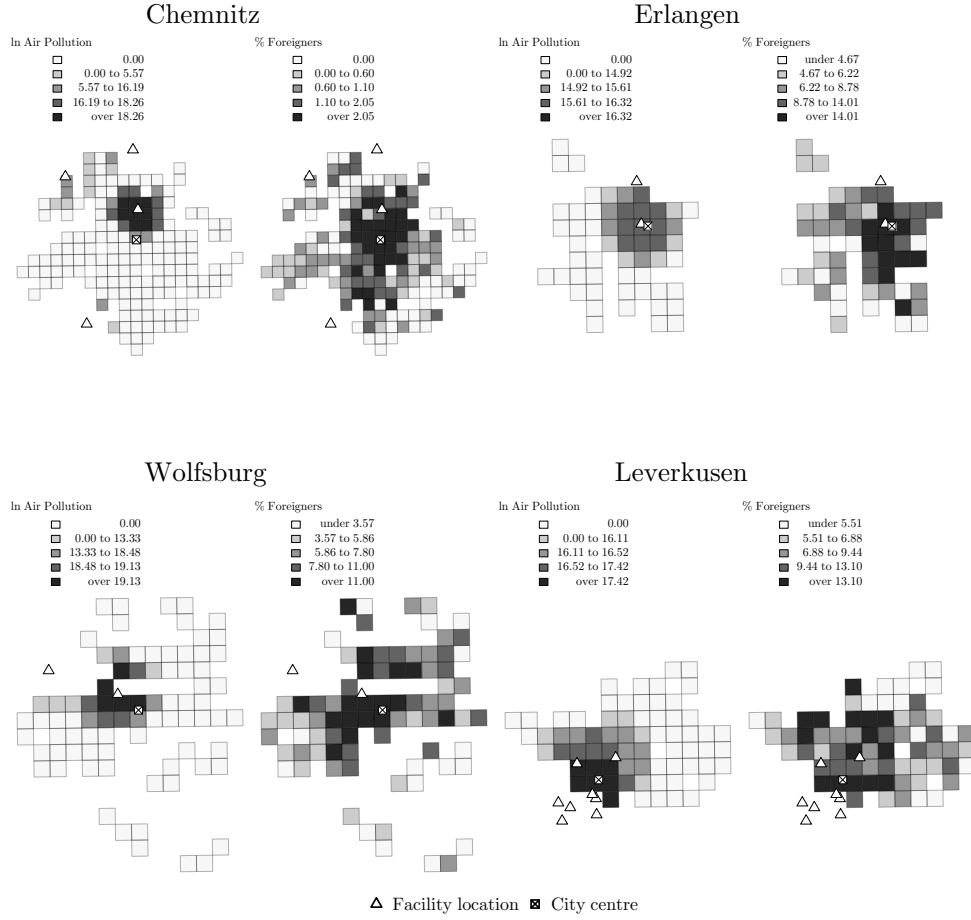


Figure 1. Distribution of pollution and minorities for cities with *high* level of environmental inequality

tion processes (e.g. Baden and Coursey, 2002; Pastor et al., 2001). The aim is to analyse whether city-level characteristics are connected to the extent of environmental inequality. However, similar results are obtained when conditioning on the predicted facility location based on the distances to highway junctions, railways, and rivers, and the presence of agglomeration economies. Though this slightly lowers the coefficient of the minority share, it yields very similar results regarding the cross-level interactions. Moreover, merging 2012 pollution reports with the 2011 census further supports the presented results (see Appendix ??)

5. Results

Model M1 in Table 1 presents the baseline model, only including the minority share as a predictor. The model confirms that, within German cities, there is a significant and strong correlation between minority share and environmental pollution. Furthermore, this effect varies considerably and significantly between the cities (compared to a model without random slope: $\chi^2(1) = 184.01$, $p < 0.001$): the coefficients for the minority share ranges from -0.1557 (Gelsenkirchen) to 0.8567 (Leverkusen).

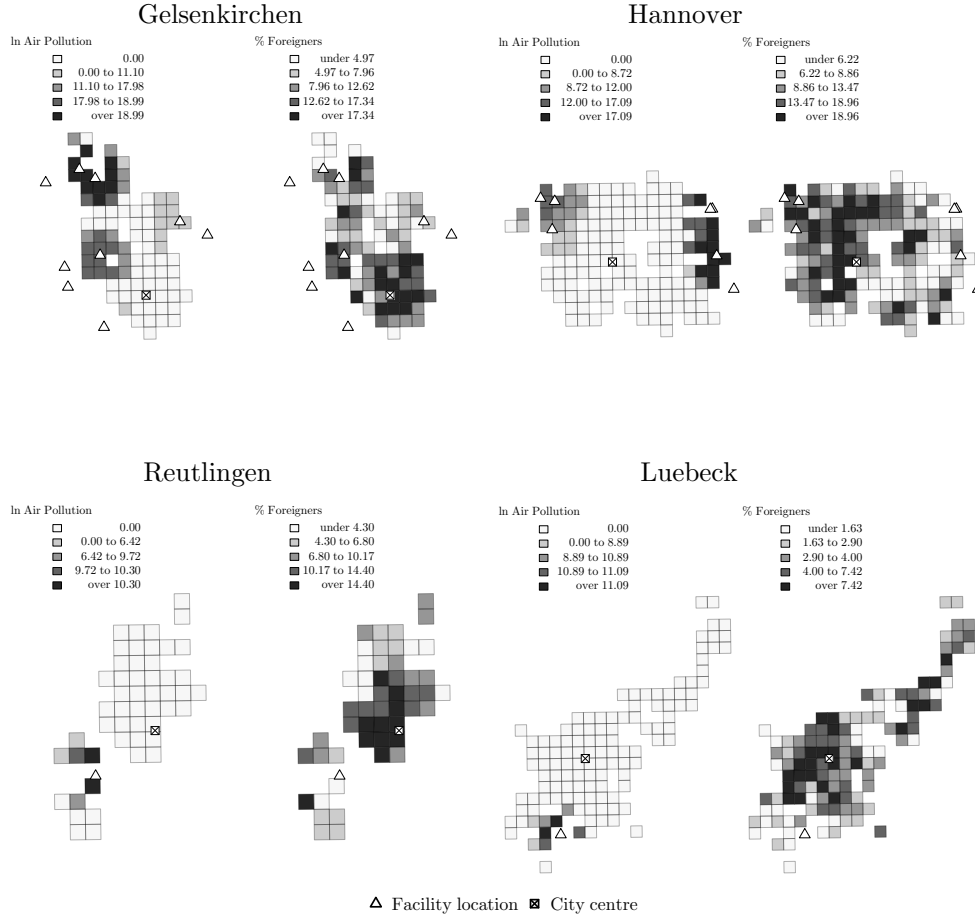


Figure 2. Distribution of pollution and minorities for cities with *low* level of environmental inequality

While some cities have a negative coefficient, i.e. the majority is actually disproportionately more affected by environmental pollution, others have a very strong positive coefficient pointing towards a strong disadvantage of minority groups. For a descriptive inspection, Figures 1 and 2 show the spatial distributions of air pollution and minorities in cities with the highest levels of environmental inequality (Figure 1) and cities with the lowest levels of environmental inequality (Figure 2)

Regarding the distribution of the minority population (right panel for each city), minority households seem to experience relatively identical levels of residential segregation but tend to live closer to industrial facilities in the four cities of Figure 1 than in the cities of Figure 2. Again in both figures, the minority share is higher around the city centre, meaning that minorities in all eight cases cluster around the city centre – a pattern similar to cities in the U.S. (Massey and Denton, 1989). However, the figures exhibit an interesting difference: pollution and facilities appear closer to the city centre in cities with high levels of environmental inequality (Figure 1). Facilities in cities with low levels of environmental inequality (Figure 2), in contrast, are located more distant from the city’s centre. *In those cities, where pollution happens to be strong in the peripheral areas, majority groups seem to be equally or even more affected by pollution than their minority counterparts.*

To investigate the influence of the city-level characteristics statistically, models M2-M5 of Table 1 present the results of the multilevel models including census-level controls and cross-level interactions. Model M2 adds the census-level control variables. The living space per inhabitant – which can be seen as a proxy for wealth in urban areas – is negatively associated with the level of environmental pollution. In line with Wolverson (2012), a higher distance to highway junctions and railway lines is associated with lower levels of environmental pollution. Moreover, including the control variables reduces the minority effect, which is mainly driven by the living space and the distance to railway lines. This indicates that part of the minority disadvantage can be attributed to the higher minority share in less wealthy regions with a higher proximity to transportation routes. Yet, a high level of environmental inequality net of the census-level controls remains.

To analyse the influence of city-specific differences on the level of environmental inequality, models M3 – M5 add the cross-level interactions between structural indicators and the minority share. Model M3, which includes the structural characteristics derived from the standard literature of environmental inequality, presents challenging findings. Neither economic inequality nor political efficacy has a significant influence on the level of environmental inequality. The coefficient regarding economic inequality does not show the assumed direction: higher economic inequality is associated with lower levels of environmental inequality – though far from significant. Residential segregation, in contrast, shows the expected sign: higher residential segregation is associated with higher levels of environmental inequality. However, the effect is only significant at the 10% level and relatively weak in magnitude. Alternative segregation indices like the spatial dissimilarity index (\tilde{D}) or different radii for the local environment yield very similar results (not shown). Only the share of industrial workers yields a significant influence on the level of environmental inequality: the more people employed in industry, the higher the level of environmental inequality. This conforms to the hypothesis that minorities are more affected by pollution, because industrial facilities provide attractive employment opportunities for the working class. Still, adding those cross-level interactions reduces only a small proportion of the slope variance (around 12%). Note that segregation, unemployment ratio, and voter turnout alone would actually increase the variance. Thus, the structural characteristics derived from the standard strand of theoretical reasoning do not explain the varying levels of environmental inequality at all. Though theoretically surprising, those findings reflect the results obtained by Downey (2007) in the U.S.: economic inequality has an insignificant and in some models negative effect on environmental inequality, and residential segregation does an unexpectedly poor job of explaining environmental inequality.

Model M4 adds the facility centrality as a cross-level interaction to test the influence of the geographic distribution of polluters. In line with the impressions from Figures 1 and 2, the centrality of facilities within a city shows a highly significant and positive association with environmental inequality. The higher the average centrality of facilities, the stronger the correlation between minority share and pollution. While a one standard deviation increase in minority share corresponds to a 0.187 standard deviation increase in pollution at the average value of facility centrality, this effect increases by 60% to 0.3 ($0.187 + 0.113$) when the facility centrality lies one standard deviation above the mean. Minorities are disproportionately affected by industrial pollution especially in cities with centrally located facilities. Interestingly, once facility centrality is controlled for, the coefficient for residential segregation is significant at the 5% level. In addition, including the facility centrality explains a large proportion of the random slope variance. When comparing models M4 and M3, more than *one*

Table 1. City-fixed effects multilevel models. Dep Var: ln Air Pollution

	M1	M2	M3	M4	M5
Census cell level					
% Foreigners	0.297*** (0.033)	0.187*** (0.033)	0.187*** (0.034)	0.187*** (0.030)	0.177*** (0.034)
Population		-0.006 (0.011)	-0.006 (0.011)	-0.005 (0.011)	-0.005 (0.011)
% 65 and older		-0.003 (0.010)	-0.004 (0.010)	-0.003 (0.010)	-0.003 (0.010)
% Vacant housing		0.019 [†] (0.011)	0.020 [†] (0.011)	0.021* (0.011)	0.022* (0.011)
Living space		-0.052*** (0.013)	-0.052*** (0.013)	-0.052*** (0.013)	-0.052*** (0.013)
Distance to highway		-0.043*** (0.011)	-0.042*** (0.011)	-0.042*** (0.011)	-0.042*** (0.011)
Distance to rail		-0.159*** (0.011)	-0.158*** (0.011)	-0.157*** (0.011)	-0.157*** (0.011)
City level					
% Foreigners $\times \tilde{H}_{2000}$			0.078 [†] (0.043)	0.085* (0.037)	0.111* (0.048)
% Foreigners \times Unemployment ratio			-0.003 (0.029)	-0.034 (0.027)	-0.034 (0.029)
% Foreigners \times Voter turnout			0.047 (0.034)	0.030 (0.031)	0.028 (0.034)
% Foreigners \times % Employed in industry			0.086** (0.027)	0.066** (0.024)	0.050 (0.031)
% Foreigners \times Facility centrality				0.113*** (0.025)	0.111*** (0.025)
% Foreigners \times Wages in production					0.020 (0.036)
% Foreigners \times Size					-0.051 (0.059)
% Foreigners \times Growth rate					0.023 (0.032)
Fixed effects	yes	yes	yes	yes	yes
Random slope	yes	yes	yes	yes	yes
AIC	23656	23399	23452	23450	23496
N	9061	9061	9061	9061	9061
N cluster	79	79	79	79	79
σ^2 % Foreigners	0.065	0.059	0.052	0.038	0.039
σ^2 Residual	0.784	0.759	0.759	0.759	0.759

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, [†] $p < 0.1$. Multilevel models with group centered first level variables. All variables are scaled by their standard deviation. Standard errors in parentheses.

quarter of the slope variance $((0.052 - 0.038)/0.052 = 0.27)$ can be explained due to the centrality of industrial facilities; more than due to all other variables combined. This highlights the importance of the facilities' centrality within the urban space for the extent of environmental inequality.

Model M5 adds further cross-level controls. Though none of those exhibit a significant effect, they have some influence on other effects of interest. First, the segregation effect increases in its magnitude and now equals the facility centrality effect. This is mainly due to controlling for the city size. Second, the effect of the share employed in the industrial sector is lower in its magnitude and does not reach significance in model M5. This is mainly due to the collinearity between the share of industrial workers and wages in the industrial sector. Still even when adding further controls, the centrality of

industrial facilities exhibits a highly significant effect on the extent of environmental inequality.

The findings are robust against a variety of model specifications.³ When applying RSEI inhalation toxicity weights and thereby excluding greenhouse gases, similar results are obtained regarding the centrality of facilities. Residential segregation and the share of industrial workers, in contrast, exhibits no significant effect on the level of environmental inequality when using toxicity-weighted pollution (see Figure B1 of the Appendix). In sum, the results clearly contradict the hypotheses that the level of environmental inequality increases with increasing political efficacy (H2) or increasing economic inequality (H3). Though we observe some evidence that environmental inequality increases with the level of residential segregation (H1) and the share of people employed in the industrial sector (H4), both effects are sensitive to model specification. The centrality of facilities within the urban space, in contrast, exhibits a strong and significant effect on the level of environmental and a large explanatory power throughout all model specifications (H5).

6. Discussion

Does this mean that environmental inequality is not mainly driven by selective siting or selective migration processes, but rather a result of the urban structure? It is important to keep in mind that this is a cross-sectional finding, making it hard to interpret why the centrality of facilities is so important. In my opinion, there are two possible interpretations: the centrality of facilities is either a confounding or a mediating mechanism.

First, the impact of facility centrality may be the result of two independent processes. Minorities cluster around the city centre because of reasons other than environmental quality (e.g. infrastructure, social networks, or similarity preferences). At the same time, industrial air pollution occurs around the urban core because of infrastructural or historical reasons. Elliott and Frickel (2013), for instance, find a persisting clustering of industrial facilities close to waterways, independent of socio-demographic characteristics. In combination, those two independent processes lead to the fact that minorities bear a disproportionately high level of environmental pollution, questioning the causal link between pollution and minority share.

Second, centrality of industrial facilities may be driven by some kind of selective siting, independent of the applied measures for political efficacy and economic inequality; or the clustering of minorities may be driven by high pollution within the urban core. In contrast to the first interpretation, this would suggest a causal link between pollution and minority share, mediated by the centrality of industrial facilities.

Yet, additional models (Table 2) do not provide an easy conclusion regarding the predictors of facility centrality. The location of the facilities is indeed independent of the centrality of the minority population within the city. Model M1 of Table 2 regresses the facility centrality on the relative minority centralization index (Massey and Denton, 1988), but does not exhibit a significant correlation, meaning that facilities are not located more centrally if minorities live centrally. Similar conclusion apply to the level of segregation (M2). Interestingly, models M3 and M4 indicate that facilities are located more centrally in cities with higher economic inequality and higher political efficacy. While the first model rather supports the interpretation of the facility centrality as confounding mechanisms, models M3 and M4 rather point to its role as a mediator. Additionally, models M6 and M7 show that neither the centrality of rivers

Table 2. Linear OLS models (city level). Dep Var: Facility Centrality

	M1	M2	M3	M4	M5	M6	M7	M8
Centralization index ^a	0.020 (0.114)							0.186 (0.171)
\tilde{H}_{2000}		-0.105 (0.113)						-0.198 (0.155)
Unemployment ratio			0.295** (0.109)					0.255 [†] (0.130)
Voter turnout				0.244* (0.111)				0.160 (0.138)
% Employed in industry					0.118 (0.113)			0.147 (0.122)
Cenrality of rivers						-0.071 (0.114)		-0.142 (0.114)
Public transport							-0.084 (0.114)	0.021 (0.118)
R ²	0.000	0.011	0.087	0.059	0.014	0.005	0.007	0.164
Adj. R ²	-0.013	-0.002	0.075	0.047	0.001	-0.008	-0.006	0.082
N	79	79	79	79	79	79	79	79

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, [†] $p < 0.1$. All variables are centered around their mean and scaled by their standard deviation. Standard errors in parentheses.

^a Relative Centralization Index as described by Massey and Denton (1988): proximity of the foreign population to the city centre relative to the proximity of the German population to the city centre.

(measured as the minimal distance to the city centre), nor the extent of public transport opportunities (measured as the public transport stops per square kilometre) yield a significant effect on the centrality of industrial facilities. Though central facilities are often located next to rivers, many cities exhibit central rivers but no centrally located facilities. Thus, it remains inconclusive why some cities exhibit centrally located facilities, while others do not. Further research using longitudinal data is needed to draw appropriate conclusions about the occurrence of centrally located facilities.

7. Conclusion

Though many studies investigate environmental inequality, there is surprisingly little consensus about the causal forces. While some empirical studies confirm that selective siting plays an important role, others rather emphasise the role of selective migration. The present analyses under which circumstances we observe high levels of environmental inequality by investigating varying levels of environmental inequality between German cities and testing whether different structural characteristics explain those variations.

The results of the city-fixed multilevel models reveal that residential segregation, economic inequality and political efficacy of the majority population do a rather poor job of explaining the level of environmental inequality. Though segregation has the expected positive effect, its significance depends on model specifications and its explanatory power is rather low. This is also what Downey (2007) concludes for the U.S. but nonetheless is a surprising result, given the importance of residential segregation for the most common explanations of environmental inequality. Without a substantial level of spatial segregation, neither selective siting nor selective migration seem to be plausible explanations. Though the share of employees in the industrial sector is significantly correlated with higher levels of environmental inequality, pointing towards the importance of employment opportunities, this effect is sensitive to different

specifications and disappears when using toxicity-weights. In contrast, the spatial distribution of pollution within the urban space exhibits a strong and quite robust effect on the level of environmental pollution. Including the spatial centrality of industrial facilities as a cross-level interaction explains more than 25% of the random slope variance. Though the measure of centrality applied in this study is rather simple (not considering the spatial distribution or density of facilities), it does a very good job of explaining the varying levels of environmental inequality. Minorities are disproportionately affected if pollution occurs around the city centre – where minorities tend to cluster. These results point to the importance of incorporating the spatial structure of polluters within the urban space into the analysis of environmental inequality.

The results pose some questions for further research. First, the analysis is based on Germany which has low levels of spatial segregation and rather dense metropolitan areas. Further research has to test whether the presented findings apply to other countries with other structural conditions. Second, the analysis relies only on industrial air pollution, while ignoring pollution coming from mobile sources like traffic. Results for mobile sources are likely to differ, as pollution is generally more concentrated around the urban core. Third, this study is cross-sectional in nature. Hence, it is not possible to investigate the temporal order of facility siting and residential moving behaviour. Finally, further research should also aim to enrich the analyses by additional data of the urban form. Other factors than the centrality of rivers or public transport could play an important role in determining the centrality of industrial facilities. For instance, distinct transitions from manufacturing to service economies or historical patterns of infrastructure may have fostered the presence of centrally located facilities.

Nonetheless, the findings of this study challenge the standard reasoning of environmental inequality research. While most environmental inequality research focuses on individual decisions, only few studies have analysed the spatial context in which those individual processes occur. However, structural constraints seem to play an important role in determining the level of environmental inequality observed at the macro level. This is not to say that selective migration or siting does not occur, but only that the importance of these causal mechanisms may be overstated. Though companies may consider the minority share next to potential sites, other factors may be more important (e.g. Elliott and Frickel, 2015; Wolverson, 2012). Similarly, environmental quality certainly plays a role for moving decisions, but other factors may be more important. For instance, Alba et al. (1999) show that speaking the language of the host country facilitated the access to other networks and infrastructures, increasing the probability of immigrant households to move from the central city to suburban districts. Still, structural conditions may contribute to the (possibly unintended) consequence that minorities end up in more polluted neighbourhoods. This interpretation of the findings is also supported by the fact that agent-based models do not reach realistic levels of environmental inequality until including similarity preferences as part of the migration decision (Campbell et al., 2015).

In sum, the results encourage further research not only to ‘bring the polluters back in’ (Grant et al., 2010), but also to bring the urban space back in, thereby considering the geographic location of polluters within urban areas. This might also help urban planners to develop strategies for avoiding or reducing the disproportionate exposure of minority households to environmental pollution.

Notes

¹Note that information in the E-PRTR is self-reported. To control for reporting biases, a model using 3-years average emissions was estimated, producing similar results.

²Manual inspection of the 79 cities confirms this strategy to be adequate.

³Like excluding cities with extreme values, restricting the data to observations with at least 200 inhabitants, using an absolute instead of a relative centrality index, estimating separate models for each hypothesis, using the proximity to air polluting facilities within the city as dependent variable, or including spatial spillover effects.

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Appendix A. Descriptives

Table A1. Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
ln Air pollution	9,061	4.04	6.65	0.00	20.93
% Foreigners	9,061	9.00	8.43	0.00	87.10
Population	9,061	2,649.91	2,887.97	3.00	23,379.00
% 65 and older	9,061	20.57	7.44	0.00	99.60
% Vacant housing	9,061	3.50	3.54	0.00	60.00
Living space	9,061	41.74	5.95	11.00	95.90
Distance to highway	9,061	2,683.66	2,094.72	23.29	17,239.26
Distance to rail	9,061	1,236.04	1,240.91	0.02	10,170.87
\hat{H}_{2000}	79	0.03	0.01	0.01	0.08
\hat{D}_{2000}	79	0.17	0.05	0.08	0.30
Unemployment ratio	79	2.34	0.37	1.28	3.43
Voter turnout	79	69.18	3.75	60.10	77.10
% Employed in industry	79	16.72	10.41	5.10	76.60
Facility centrality	79	2.78	2.17	0.00	17.78
Wages in production	79	3,498.37	625.28	2,422.90	5,076.50
Size	79	17,211.42	12,977.61	4,489.00	89,170.00
Growth rate	79	0.80	4.20	-8.31	10.46

Appendix B. Toxicity-weighted pollution

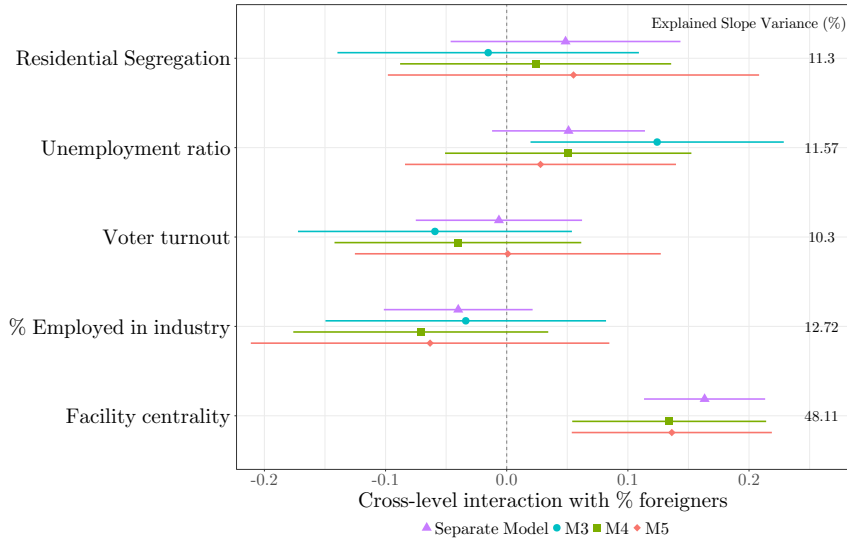


Figure B1. Coefficients of cross-level interactions with 95% CI using toxicity-weighted air pollution, including explained slope variance for separate models.

Appendix C. Additional models

Table C1. City-fixed effects multilevel models conditioning on facility location. Dep Var: ln Air Pollution

	M1	M2	M3	M4	M5
Census cell level					
% Foreigners	0.297*** (0.033)	0.150*** (0.033)	0.148*** (0.034)	0.147*** (0.029)	0.142*** (0.032)
Population		0.007 (0.011)	0.008 (0.011)	0.008 (0.011)	0.008 (0.011)
% 65 and older		0.001 (0.010)	0.000 (0.010)	0.000 (0.010)	0.000 (0.010)
% Vacant housing		0.012 (0.011)	0.013 (0.011)	0.014 (0.011)	0.015 (0.011)
Living space		−0.048*** (0.012)	−0.047*** (0.012)	−0.047*** (0.012)	−0.047*** (0.012)
Predicted probability ^a		0.232*** (0.011)	0.232*** (0.011)	0.232*** (0.011)	0.232*** (0.011)
City level					
% Foreigners $\times \tilde{H}_{2000}$			0.076 [†] (0.042)	0.083* (0.035)	0.103* (0.045)
% Foreigners \times Unemployment ratio			−0.002 (0.029)	−0.036 (0.026)	−0.033 (0.028)
% Foreigners \times Voter turnout			0.054 (0.034)	0.036 (0.029)	0.032 (0.033)
% Foreigners \times % Employed in industry			0.091*** (0.026)	0.069** (0.023)	0.059* (0.030)
% Foreigners \times Facility centrality				0.123*** (0.024)	0.121*** (0.024)
% Foreigners \times Wages in production					0.011 (0.034)
% Foreigners \times Size					−0.036 (0.056)
% Foreigners \times Growth rate					0.029 (0.030)
AIC	23656	23179	23230	23224	23270
N	9061	9061	9061	9061	9061
N cluster	79	79	79	79	79
σ^2 % Foreigners	0.065	0.058	0.051	0.033	0.035
σ^2 Residual	0.784	0.741	0.741	0.741	0.741

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, [†] $p < 0.1$. Multilevel models with group centered first level variables. All variables are scaled by their standard deviation. Standard errors in parentheses.

^a Predicted probability of probit model (see Table ?? for first stage). Dep. var: Hosting a facility (yes/no). Indep. vars: Distance to next highway junction, distance to next railway, distance to next river, av. number of facilities in neighbouring units.

Table C2. First stage probit model. Dep Var: Hosting a facility (yes/no)

	M1
(Intercept)	−1.697*** (0.030)
Distance to next highway junction	−0.113*** (0.025)
Distance to next railway	−0.595*** (0.043)
Distance to next river	−0.101*** (0.025)
Av. number of facilities in neighbouring units	0.057** (0.019)
AIC	4186
N	9061

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$. All variables are scaled by their standard deviation. Standard errors in parentheses.

Table C3. City-fixed effects multilevel models. Dep Var: In Air Pollution in 2012

	M1	M2	M3	M4	M5
Census cell level					
% Foreigners	0.314*** (0.029)	0.203*** (0.029)	0.196*** (0.031)	0.196*** (0.029)	0.188*** (0.032)
Population		−0.001 (0.011)	−0.001 (0.011)	−0.000 (0.011)	−0.000 (0.011)
% 65 and older		−0.005 (0.010)	−0.006 (0.010)	−0.006 (0.010)	−0.006 (0.010)
% Vacant housing		0.026* (0.011)	0.027* (0.011)	0.028* (0.011)	0.028** (0.011)
Living space		−0.047*** (0.013)	−0.047*** (0.013)	−0.047*** (0.013)	−0.047*** (0.013)
Distance to highway		−0.048*** (0.011)	−0.047*** (0.011)	−0.047*** (0.011)	−0.047*** (0.011)
Distance to rail		−0.155*** (0.011)	−0.154*** (0.011)	−0.153*** (0.011)	−0.153*** (0.011)
City level					
% Foreigners $\times \tilde{H}_{2000}$			0.048 (0.038)	0.054 (0.035)	0.078 [†] (0.045)
% Foreigners \times Unemployment ratio			0.021 (0.027)	−0.000 (0.026)	−0.001 (0.028)
% Foreigners \times Voter turnout			0.031 (0.031)	0.020 (0.029)	0.020 (0.033)
% Foreigners \times % Employed in industry			0.075** (0.024)	0.061** (0.023)	0.050 [†] (0.030)
% Foreigners \times Facility centrality				0.082*** (0.024)	0.080*** (0.024)
% Foreigners \times Wages in production					0.013 (0.034)
% Foreigners \times Size					−0.047 (0.055)
% Foreigners \times Growth rate					0.020 (0.030)
AIC	23644	23390	23445	23451	23497
N	9061	9061	9061	9061	9061
N cluster	79	79	79	79	79
σ^2 % Foreigners	0.049	0.042	0.039	0.033	0.034
σ^2 Residual	0.785	0.759	0.759	0.759	0.760

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, [†] $p < 0.1$. Multilevel models with group centered first level variables. All variables are scaled by their standard deviation. Standard errors in parentheses.

Table C4. Linear OLS models. Dep Var: Coefficient first stage^a

	M1	M2	M3	M4	M5
\tilde{H}_{2000}	0.181 (0.112)		0.241* (0.113)	0.271** (0.100)	0.349** (0.122)
Facility centrality		0.474*** (0.100)		0.463*** (0.099)	0.456*** (0.100)
Unemployment ratio			0.010 (0.116)	-0.112 (0.106)	-0.111 (0.110)
Voter turnout			0.222 [†] (0.123)	0.162 (0.110)	0.137 (0.121)
% Employed in industry			0.353** (0.106)	0.276** (0.095)	0.205 [†] (0.122)
Wages in production					0.070 (0.123)
Size					-0.132 (0.118)
Growth rate					0.122 (0.105)
R ²	0.033	0.224	0.191	0.376	0.397
Adj. R ²	0.020	0.214	0.147	0.333	0.328
N	79	79	79	79	79

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, [†] $p < 0.1$. All variables are scaled by their standard deviation. Standard errors in parentheses.

^a Interaction coefficient between % foreigners and city dummy, dep. var.: ln air pollution, same control variables as first level controls in Table 1.