Valuing and localizing externalities: Evidence from the housing market in Hamburg

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I Introduction [*]

1 Summary report

In the tradition of von Thünen (1826), Alonso (1964), Muth (1969), and Mills (1972) have improved upon the land rent theory by including the aspect of the relationship between property prices and access to jobs, which are to be found in a central location according to the model assumptions. With increasing computer performance, the development of geographical information systems (GIS) and the improved quality and availability of real estate data and other geo-coded data, the influence of numerous other location and site characteristics have been studied on the basis of hedonic models in the past decades. When hedonic pricing models are employed to examine the amenities or disamenities of an urban or a suburban location analyses are typically based on the price structures of adjacent residential properties.

This research project supplements the existing hedonic literature on the effects of externalities in various ways. Analyzing the impact of road noise and access to public transit the articles "Road noise exposure and residential property prices: Evidence from Hamburg" and "The impact of rail access on condominium prices in Hamburg", respectively, focus on two determinants of urban house prices, that already have been investigated multiple times. This research project, however, adds new aspects to the existing literature. Brandt and Maennig (2011a), thus, examine the influence of road noise in relation to the emission levels of other

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sources of noise, and have observed increasing price discounts for each additional dB(A) of road noise. The study results are based on a dataset on road noise pollution with around 6.9 million receptor points. As far as housing studies are concerned, this may well be unique when it comes to small scale and scope. Brandt and Maennig (2011b) analyze the sensitivity of the coefficients calculated for access to rail stations. It is shown that the results of hedonic analyses can be biased if determinants are neglected that are correlated with access to rail stations. The empirical findings of the first two articles of this research give evidence that public expenditure on public transit and/or noise abatement measures – at least partially – can be offset by increased property tax gains due to higher real estate prices.

In the two articles "Perceived externalities of cell phone base stations – The case of property prices in Hamburg, Germany" and "Do places of worship affect housing prices? Evidence from Germany" the external effects of cell phone towers and houses of worship, respectively, are examined. So far, however, both aspects have been largely ignored in hedonic housing studies.

Since research has thus far failed to provide unambiguous results on the health risks posed by the electromagnetic fields from cell phone base stations, possible health implications of mobile phone radiation continues to be a controversial topic among citizens, politicians, researchers, and cell phone service providers. Brandt and Maennig (2011c), to the authors` knowledge, are the first to examine the external effects of cell phone base stations for an entire metropolis. It is shown that in Hamburg only proximity to certain base stations is priced by the housing market. From this, conclusions can be drawn about the spatial arrangement of future cell phone base stations.

The fourth article of this research project is the first to examine the effects that houses of worship of all five world religions have on surrounding property prices. On the one hand, the findings provide new input on the public debate on the construction of minarets and/or the public muezzin's call. On the other hand, the results may supply input on the debate on the future use of former places of worship.

All four articles of this research have in common that they contribute to expanding the limited empirical evidence on the influence of externalities for German sites.[1] One reason for the scant empirical literature in Germany may be the difficult access to disaggregated property transaction data. In the past few years a growing number of service providers have set up new businesses that readout real estate supply data from Internet platforms to process and geo-code them. Brandt and Maennig (2011b, 2011c) have addressed potential methodological concerns in connection with the use of supply data in hedonic studies. The authors conclude that systematic biases of coefficients are not to be expected. Accordingly, supply data are used as an empirical basis in all articles of this research project. That the use of supply data in scientific studies has been accepted by international peer-reviewed journals should encourage other researchers to rely on such data as well if transaction data are not available or only accessible at disproportionately high costs.

The following subsections of the introduction discuss at first the development of the research question. Subsection 3 describes the underlying data and Subsection 4 specifies the models. In addition, for each of the four papers, a section with supplementary information on data description, model specification and results has been created. This way, observations made by the reviewers of this dissertation thesis are to be taken into account as well as additional information provided to which the papers could not refer due to lack of space and/or that are not usual in connection with the publication in journals, but that are necessary for a complete representation of the research and its findings. The models presented in the supplementary sections have been revised so as to standardize the control variables used and to take into

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[1] The studies, for example, by Ahlfeldt and Maennig (2009, 2010a, 2010b) and Ahlfeldt (2011), which have examined the external effects of built environment on real estate markets in Berlin, are an exception.

account the results of the other three articles. The results presented in the supplementary sections, thus, represent the most recent research status of the study. A robustness test and subsequent recognition of the results are included in Section X.

2 Development of the Research Question

The different questions related to this research project are all based on a personal interest. Inspired by the studies of Bateman et al. (2001), Theebe (2004) and Wilhelmsson (2000), I initially wanted to examine whether the findings on the effects of road noise could be transferred also to a German location. Then – upon drafting the first paper – I realized that apart from the effects of road noise, access to local transit had been largely ignored by German researchers as well. This piqued my research interest in this externality, which I then studied in the second article. My literature search yielded a variety of new inspirations. When I found that the public debate on the effects of cell phone base stations and houses of worship of recent years was based on very little empirical evidence even by global standards, I turned my attention to these areas. But addressing these research questions required at first extensive data collection (see Section I.3.1), which is why the topics were examined separately in subsequent studies. The consecutive processing of the individual questions has the advantage that it allows for a detailed and differentiated analysis of the different factors. This was done by expanding the basic models by means of interactives and/or other model modifications to include additional aspects. The sequence in which the individual articles were completed[2] is analogous to the structure of this dissertation.

The research method selected is hedonic pricing. This method is seen as the most reliable for evaluating the influence of spatial externalities, because utility and/or disutility is measured on the basis of actual pricing behavior (Des Rosiers 2002; Sims and Dent 2005). Opinion-based surveys and hypothetical valuations, however, are criticized for their frequent de-

[2] Time of the initial submission to a journal

viations between the opinion expressed and actual behavior (Sims and Dent 2005). Sims and Reed (2005) have shown that such deviations can occur, in particular, in evaluating environmental externalities. In their survey of 850 households (161 responses) in four British towns, residents were asked whether they had considered buying or renting a property near a phone mast in the last five years. Among the households that answered "yes", only 16% said that proximity to a phone mast had had a moderate to very strong influence on their decision to buy/rent. All households were also asked the hypothetical question whether their decision concerning their current residence would have been different if a phone mast had been located within a radius of 100m. Here, 86% responded that this would have affected their decision to buy/rent. Forty-five percent of the households surveyed would not have considered such a location at all.

As mentioned above this dissertation relies on hedonic pricing and uses extensive geocoded datasets, such as on property attributes and prices, traffic noise, cell phone base stations, churches, rail stations, parks, forests, and nature protection areas as well as bodies of water. The data is to a large extend self-provided and has been extensively edited (see Section I.3.1). The externalities are measured on the basis of continuous (linear and non-linear) variables, dummy variables and potentiality variables, and are used together with control variables in cross-sectional approaches. Gibbons and Machin (2005) criticize the use of cross-sectional models in that the results of the regression analyses may be biased if variables that are correlated with the variables to be examined are not included in the regression equation. However, the findings from longitudinal analyses favored by Gibbons and Machin (2005) may also be biased, as it seems unclear how fast property markets adjust to a change in the quality and/or quantity of an external effect (Henneberry 1998). McMillen and McDonald (2004), for example, have observed that house prices react to new transport infrastructure as early as six years before and as many as six years after the opening of a new railway line. If one chooses a period of investigation that is too short, the effect of the externality may be underestimated. The criticism of Gibbons and Machin (2005) is taken into account by controlling for a large number of factors potentially correlated to residential property prices or to the variables to be examined.

3 Data collection and descriptive statistics of data

3.1 Data collection

Following the vast majority of empirical housing studies, the collection and preparation of the data base were not dealt with as separate and main topics in the journal papers. This is to be done instead in the following subsections. Unless expressly stated otherwise, all the data were collected and/or computed by the author himself. The data base regarding the factors studied in the individual articles is described in the respective supplementary notes.

3.1.1 Housing data

A record of data concerning the supply of condominiums in Hamburg was provided by the company F+B Forschung und Beratung für Wohnen, Immobilien und Umwelt GmbH. Data records that lacked one of the following aspects were not considered in further studies:

1) Complete address
2) Year built
3) Surface area, or
4) Specific features.

The specific features were subsequently encoded to dummy variables using SPSS. Then, all 3,131 addresses of the real-estate portfolio reviewed were allocated manually to the 938 statistical districts of Hamburg.

For the addresses, longitudes and latitudes were then calculated using MS MapPoint. One difficulty was that many street names had been stored in MS MapPoint with the wrong spelling; thus, for a large number of datasets, it was impossible to calculate longitudes and latitudes automatically. They had to be allocated manually instead.

3.1.2 Socio-demographic data

There were two data sources available for socio-demographic indicators. The Statistical Office in Hamburg publishes annual city district profiles, which contain many indicators at the district level, such as population, social structure, housing and crime. In addition, there was a dataset with indicators at the level of the 938 statistical districts of Hamburg. Previous tests have shown that the smaller number of indicators at the level of the smaller statistical districts capture the structure of condominium prices better – measured by the adjusted R^2. This may be due to the higher level of heterogeneity of the population and development structure at the city district level, which is why the city district data have not been considered for further evaluations. At the level of the statistical districts, the following data were available:

1) Population
2) Proportion of population below the age of 18
3) Proportion of population that is 65 years and older
4) Mean income of population p.a.
5) Proportion of the employed subject to social insurance contributions in terms of total population, ages 15 to under 65
6) Proportion of foreign population
7) Surface area in sq. km and
8) Number of social housing units.

The data from the Statistical Office in Hamburg for 2002-2008 were processed in MS Excel for further use.

3.1.3 Distance data

First, the following areas were geo-coded manually for the entire city of Hamburg in MS MapPoint using physical and digital maps:

1) Water surfaces
2) Parks
3) Nature protection areas
4) Forests and

5) Industrial and commercial areas.

Subsequently, the distances between residential properties and the respective nearest area were calculated using MS MapPoint and the software MileCharter.

In addition, a gravity variable was calculated (cf. Section II.3.1) to capture access to employment. Data on the number of jobs in the 103 city districts were derived from Schmidt and Gutsche (2003). The employment data for the 307 suburban communities in the metropolitan region of Hamburg were taken from "Statistik lokal", an annual publication of the Federal Statistical Office. The centroids of the city district and community areas were calculated using ArcView. The distances between all n centroids were calculated using MS MapPoint and MileCharter. The result was an n x n matrix of all distances between city district and community centroids.

To calculate the spatial lag terms, first the distances between all n=3,131 property coordinates were computed using MS MapPoint and MileCharter. The result was an n x n matrix of all distances between n residential properties. Using a self-authored Visual Basic program, spatial lag terms with different critical values for distances and time periods were calculated (cf., e.g., Section II.3.2).

3.1.4 Noise data

The Hamburg Office for Urban Development and the Environment (BSU) provided a dataset on air-traffic noise pollution. In order to allocate to each condominium of the portfolio studied a value for the degree of air-traffic noise pollution, the following working steps were necessary:

1) The raw data supplied by BSU contained Gauss-Krüger coordinates. Since MS MapPoint can process only longitudinal and latitudinal data, the coordinates were first converted to longitudinal and latitudinal data using the software TRANSDAT Coordinate Transformations.

2) The geo-coded air-traffic noise data were then imported into MS MapPoint.
3) Subsequently, using MileCharter, each property coordinate was allocated the nearest receptor point with information on air-traffic noise pollution.
4) Then, using MS Access, the property coordinates and addresses, the nearest receptor points and the corresponding air noise levels were consolidated.

BSU also provided a dataset on rail noise pollution in the vicinity of the above-ground subway rails as well as around the facilities of the harbor railway. For this data, the above described working steps, 1) through 4), were carried out in identical fashion. Data on rail noise in the vicinity of other tracks in the city of Hamburg were gleaned from maps of Deutsche Bahn (DB, German Rail) and captured manually for all 3,131 addresses. The aggregation of the noise data into a railroad noise index (*RAILNOISE*) was done according to the formula (Lang 1994, p. 16):

$$RAILNOISE = 10\log_{10}(10^{0.1NoiseBSU} + 10^{0.1NoiseDB}), \quad (I.1)$$

with *NoiseBSU* and/or *NoiseDB* representing the noise data supplied by BSU and/or DB. If *NoiseBSU* and *NoiseDB* differ by more than 10 dB, the higher value will dominate.

3.2 Descriptive statistics of data

Table I.1 shows descriptive statistics of the offer data used for the period 2002 to 2008. The sales data published by the Committee of Valuation Experts in Hamburg (2003–2009) for the same period are shown in Table I.2. Compared to the sales data, the offer data are characterized by more variance in the average values over the period under review, which may be explained primarily by the smaller number of cases. But the comparison of total values yields a clear picture: While the mean property size is identical for properties sold and/or put up for sale, the properties offered tend to be, on average, six years younger than the properties sold. This may also be the primary reason for the offer prices that are, on average, 3.9% higher.[3]

Table I.1 Descriptive statistics of condominium offers for 2002-2008

Year	Number	Mean property price in €	Mean property price in €/m²	Mean year of construction	Mean size
2002	110	219,714	2,118	1966	98
2003	141	169,537	2,043	1968	78
2004	667	214,899	2,308	1970	87
2005	1,063	205,663	2,208	1968	86
2006	1,171	180,971	2,168	1965	77
2007	1,023	179,162	2,134	1967	78
2008	657	200,426	2,218	1969	82
Total	4,832	193,897	2,191	1967	82

Source: IDN ImmoDaten, author's own calculations

Table I.2 Descriptive statistics of condominium sales for 2002-2008

Year	Number	Mean property price in €	Mean property price in €/m²	Mean year of construction	Mean size
2002	5,506	172,000	2,029	1961	80
2003	5,089	177,000	2,024	1958	82
2004	5,129	182,000	2,054	1961	83
2005	6,373	180,000	2,029	1963	82
2006	5,772	213,000	2,233	1964	85
2007	5,953	189,000	2,158	1959	81
2008	6,300	195,000	2,212	1962	81
Total	40,122	187,215	2,109	1961	82

Source: Committee of Valuation Experts in Hamburg (2003–2009)

Table I.3 compares the distribution of supply and sales data across the 103 city districts of Hamburg that existed during the period under review. The column "Proportion sales" and/or "Proportion offers" represents the share of properties located in a city district in terms of the total number of condominiums sold and/or offered during the study period.[4] The rows are

[3] A significant transaction discount – as reported by F+B (2002) (see Section IV.3) – does not seem to exist.

[4] For the years 2005 and 2006, the Committee of Valuation Experts did not publish any district-specific sales figures, which is why those years had to be excluded from the evaluation.

sorted in an ascending order, from the column "Prop. offers - prop. sales". Due to limited space, only the five rows with the greatest deviations (negative as well as positive) are shown. The relatively minor deviations in the distribution of properties across the city districts indicate a good representativity of the offer data.

Table I.3 Spatial distribution of condominium sales and offers across city districts

No.	City district	Committee of Val. Experts		IDN ImmoDaten		Prop. offers - prop. sales
		Number sales	Proportion sales	Number offers	Proportion offers	
1	Winterhude	1,835	6.63%	230	4.76%	-1.87%
2	Ottensen	1,119	4.04%	113	2.34%	-1.70%
3	Harvestehude	600	2.17%	44	0.91%	-1.26%
4	Eppendorf	1,206	4.36%	164	3.39%	-0.96%
5	Uhlenhorst	817	2.95%	100	2.07%	-0.88%
…	…	…	…	…	…	…
99	Niendorf	771	2.79%	168	3.48%	0.69%
100	Farmsen-Berne	266	0.96%	91	1.88%	0.92%
101	Barmbek	1,242	4.49%	267	5.53%	1.04%
102	Rahlstedt	1,118	4.04%	253	5.24%	1.20%
103	Alsterdorf	269	0.97%	116	2.40%	1.43%

Source: Committee of Valuation Experts in Hamburg (2003, 2004, 2005, 2008, 2009), IDN ImmoDaten, author's own calculations

In summary, it can be said that the properties offered are representative in terms of their essence of the condominiums actually sold. A bias in estimations is not to be expected in this respect. Other possible limitations in connection with the use of the offer data are discussed in Section IV.3.

A-weighted L_{DEN} indices

All traffic noise measures are A-weighted[5] L_{DEN} index values, which are measured on a logarithmic scale that takes into account the higher sensitivity of the human ear to medium and high-range frequencies by attaching greater weight to these frequency ranges. For the pur-

[5] In order to make statements about the perception of a noise event, the spectrum of the noise will have to be dissected and weighted (evaluated) according to frequency-dependent human perception. The way in which the frequency range is dissected and evaluated is determined by standardized frequency filters, with the A filter having become the dominant one.

poses of this research L_{DEN} indices are employed that take into account the distribution of traffic noise throughout the day. The indices take into account the additional nuisance created by noise pollution during evening and night hours by weighting it higher.

4 Empirical methodology

In order to assess the influence of individual factors on condominium prices, it is necessary first to render the heterogeneous properties comparable. The hedonic approach, developed, for example, by Rosen (1974)[6], is based on the assumption that real estate properties consist of a bundle of heterogeneous goods, such as property, neighborhood and location characteristics. The individual goods cannot be traded separately on markets, but it is possible to estimate marginal implicit prices for the individual goods using the hedonic approach (Chesire and Sheppard, 1998). The hedonic price function can thus be written as:

$$P = f(O, N, L), \tag{I.2}$$

where P is the listing price of the condominium. O is a vector of the property's physical characteristics. The neighborhood and/or location characteristics are represented by vector N and/or L.

Vector O (property's physical characteristics)

For the identification of the property-specific control variables, the findings of Sirmans, Macpherson, and Zietz (2005), as well as Wilhelmsson (2000) have been taken into account, who have evaluated the control variables most commonly used in hedonic studies and who have provided an overview on the current state of research.

Vector N (neighborhood characteristics)

The socio-demographic data provided by the Statistical Office in Hamburg were used to map the neighborhood vector. Following previous tests, the four indicators below, for which the

[6] An overview of other authors who made substantial contributions to the development of the approach can be found in Freeman (1979) and Sheppard (1999).

tests have shown significant effects and whose influence has already been confirmed by previous studies (see Section IV.4.2), have been taken into account.

1) Proportion of population that is 65 years and older
2) Mean income of population p.a.
3) Proportion of foreign population and
4) Number of social housing units per 1,000 inhabitants.

The indicators

- Proportion of population below the age of 18
- Inhabitants/sq. km and
- Proportion of the employed subject to social insurance contributions in terms of total population, ages 15 to under 65

were excluded, because they had been found to be not significant in preliminary tests.

Vector L (location characteristics)

The location vector can be divided into the subvectors *ACCESS, NOISE,* and *VIEW.* The selection of control variables was based again on the study by Sirmans, Macpherson, and Zietz (2005). Aside from the *ACCESS* variables used in the models, further factors were tested too. These are:

- Distance from the nearest kindergarten
- Distance from the nearest playground
- Distance from the nearest hospital
- Distance from the nearest sports ground, and
- Distance from the nearest highway on-ramp (in street kilometers).

However, no significant effects were observed for any of the tested specifications – neither for continuous (linear, log, square) nor non-continuous (dummy variables capturing various distance rings). This is plausible insofar as kindergartens, hospitals, as well as playgrounds and sports grounds, are distributed densely across the study area and/or as good accessibility is relevant only for a relatively small group of households. Access to the highway system in Hamburg, too, seems crucial only for a small group, which is why this factor, too, is not significant (cf. also Section IV.4.2). Another reason for the insignificant results could lie in the fact that there was no quality information available for the access variables (e.g., quality of the nearest kindergartens).

Using the indices for road, air-traffic and railroad noise, it was possible to take into account almost every significant source of urban noise pollution. What is missing is an index for industrial noise and an index for noise caused by neighbors (Borgstedt, Christ, and Reusswig 2010). As for industrial noise, the distance from the nearest industrial area, included in the models, should serve as a sufficiently precise approximated value. Noise created by neighbors cannot be measured objectively, but can be seen largely as subject to unsystematic variance. There could be a correlation between the noise immission and the year in which the property was built, because new buildings are generally better insulated than older ones. This influence, if it exists, however, is captured by the variables *AGE* and *AGESQ.*

In recent years, the influence of a good or bad view on residential property prices has been confirmed, e.g., for views of bodies of water (Bourassa, Hoesli, and Peng 2003), mountains (Song and Knapp 2003), trees (Cavailhès et al. 2009), industrial view (Bateman et al. 2001) or a wide street (Wilhelmsson 2000). The data material underlying this study, however, only contains information on whether a property is located on a wide street (cf. Section III.1). Additional *VIEW* variables could not be obtained from third parties, nor was the expenditure of collecting such data reasonable in view of the benefit. The distance variables *DISTWATER, DISTPARK* and *DISTIND*, however, should be reasonable approximations for the *VIEW* indicators.

The control variables used are not identical for all four articles, or results from previous articles have not been considered at all times in the following papers, because the respective focus of the study would have been lost, because the number of variables could have resulted in overfitting problems, and – also for these reasons – such "all in one" estimations are usually rejected by high-level journals. The differences between the papers are described below. To test whether the deviating control variables produce biased results, the models are recalculated for all four papers (see "Supplementary Notes" on each paper), but this time with identical control variables.

TOM

The third article, in its final version, also controls for time-on-market. Since the corresponding coefficient is significant for all models, the variable has been included also in all models of the other papers as part of the revision.

DISTSCH and DISTSCHSQ

In preliminary tests for the first article of this dissertation, various control variables had been tested (see above). In the process, the influence of schools was found to be not significant. This seemed plausible insofar as schools are distributed densely across the territory of the City of Hamburg, which allows for good access to educational facilities for almost all neighborhoods. As well, no data on the quality of schools have been published (Clark and Herrin 2000), which is why access to schools was excluded from articles one to three. The influence of schools was retested only during the model specifications for the fourth article, because of suspected correlations with the distance from houses of worship. The now-significant influence of proximity to schools was attributed to existing correlations with houses of worship. It was therefore considered irrelevant for the previous articles.

As part of the model adjustments, the models were recalculated using the variables *DISTSCH* and *DISTSCHSQ*, and all *ACCESS* variables were retested that had been excluded previously (see above). In summary, the exclusion of the *DISTSCH* variables did not produce biased coefficients, which is explained in detail in the supplementary notes. The new tests also confirmed that none of the excluded *ACCESS* variables have any significant influence.

DISTSTAT and DISTSTATSQ

The relation between residential property prices and access to train stations was captured in the first paper by means of the continuous variables *DISTSTAT* and *DISTSTATSQ*. In the second paper, it was established that access to train stations could be mapped better by means of a set of dummy variables than via continuous variables (see Section IV.4.2). Following the findings of the second article, proximity to train stations was then also mapped in the third paper using dummy variables. In the meantime, however, an anonymous referee had commented that the use of continuous variables was more intuitive. Consequently, access to train stations was captured in the fourth paper again on the basis of the continuous variables *DISTSTAT* and *DISTSTATSQ*. Against the background that proximity to train stations for Hamburg is best captured via dummy variables (see above), as well as to test for any possible biases in the estimates, the models of the first and fourth papers were reestimated, this time using the dummy variables *DISTSTAT_250, DISTSTAT_250_750, DISTSTAT_750_1250* and *DISTSTAT_1250_1750*. The results are outlined in the supplementary notes on the individual papers.

DISTCENT x CBD, DISTCENT x B_CENT, and DISTCENT x C_CENT

In contrast to the other papers, the distance from the nearest central place according to the zoning plan is interacted in the second paper with the type of central place (see Section IV.4.2). The results for the interactives are partially significant, and are therefore considered also in the models of the other papers following the revision.

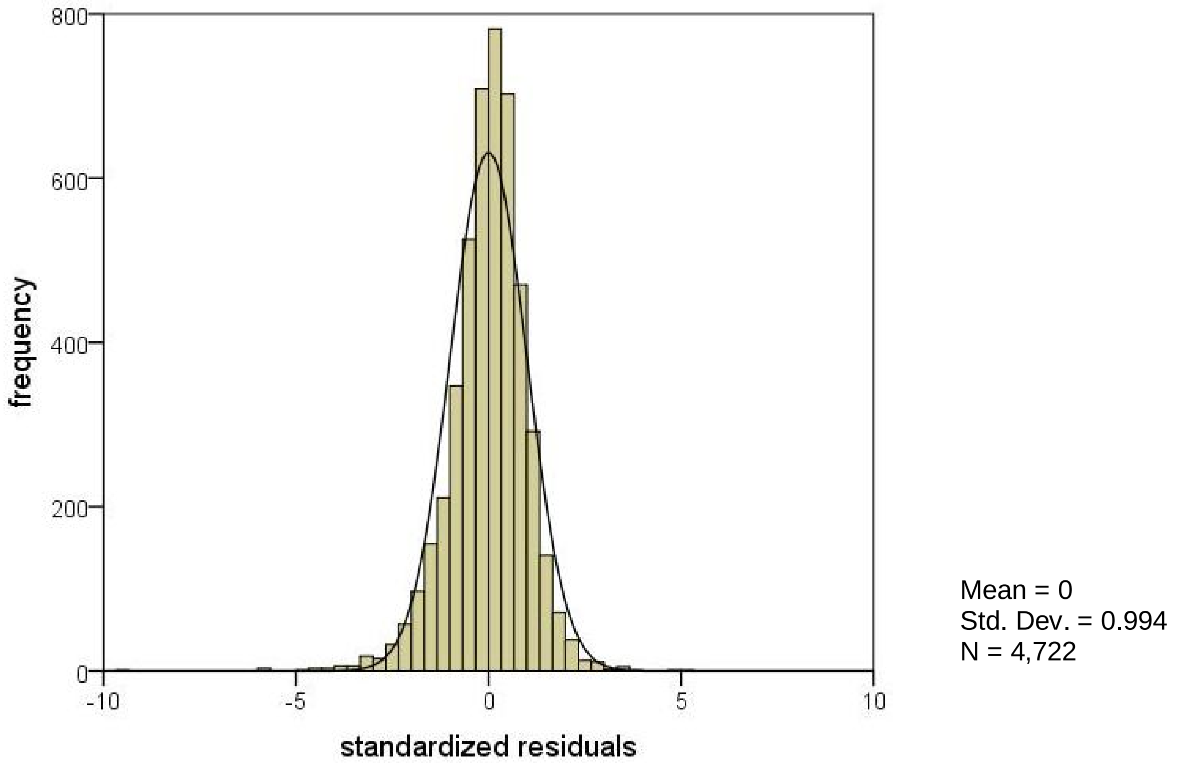
Seasonal dummy variables

The first two papers captured the time-based trend using annual dummy variables. The third and fourth papers then added seasonal dummy variables, since subsequent tests confirmed a significant influence. As for the revised estimation of the models, the seasonal dummies were also taken into account in the models of the first and second articles.

Normal distribution of the residuals

Statistical test methods require the normal distribution of residuals. If this assumption is fulfilled, the estimated coefficients will be normally distributed as well. In the case of the extensive dataset on Hamburg condominium prices, a sufficiently large sample size for achieving asymptotically unbiased estimates can be assumed (Cannon, Miller, and Pandher 2006). That the residuals and thus also the estimators are approximately normally distributed is shown by the histogram of the residuals for Model 1.1 in Fig. I.1 (Lin and Hwang 2004; Sims and Dent 2005).[7]

Fig. I.1 Distribution of frequency and standardized residuals



Multicollinearity

The variance inflation factor (VIF) is used to control for multicollinearity:

$$VIF = 1/(1 - R^2_{k_j}) , \quad (I.3)$$

with $R^2_{k_j}$ being the R^2 of a linear model where the explanatory variable k_j is regressed on the other independent variables (Greene 2003, p. 57). For VIF > 10, it is generally assumed that k_j has a significant collinearity with other variables (Lin and Hwang 2004). Table I.4

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[7] Since the histograms of the residuals are almost identical for all other models of the four papers, they are not presented due to the lack of space.

Table I.4 Descriptive statistics of variance inflation factors

Variable	Min.	Max.	No.	Variable	Min.	Max.	No.
AUTOREG	1.99	2.08	12	DISTSTAT_250_750	6.51	7.74	12
YEAR_2002	1.35	1.36	9	DISTSTAT_750_1250	5.49	6.79	12
YEAR_2003	1.43	1.43	9	DISTSTAT_1250_1750	2.98	4.93	12
YEAR_2004	2.36	2.39	9	DISTSTAT_250 x UNDERGR	1.79	1.79	1
YEAR_2005	2.98	3.02	12	DISTSTAT_250_750 x UNDERGR	1.47	1.47	1
YEAR_2006	3.06	3.16	12	DISTSTAT_750_1250 x UNDERGR	1.18	1.18	1
YEAR_2007	2.42	2.52	12	DISTSTAT_1250_1750 x UNDERGR	1.11	1.11	1
QUARTER_1	2.21	2.38	12	DISTSTAT_250 x HIGHINC	2.04	2.04	1
QUARTER_2	1.50	1.60	12	DISTSTAT_250_750 x HIGHINC	2.16	2.16	1
QUARTER_3	1.53	1.62	12	DISTSTAT_750_1250 x HIGHINC	2.47	2.47	1
TOM	1.05	1.07	12	DISTSTAT_1250_1750 x HIGHINC	3.24	3.24	1
SIZE	4.70	4.88	12	DISTCPBS_100	1.16	1.20	10
SIZESQ	2.80	3.00	12	DISTCPBS_100_200	1.28	1.31	10
AGE	6.74	7.07	12	DISTCPBS_100 x SMALL_CPBS	1.10	1.18	2
AGESQ	5.99	6.41	12	DISTCPBS_100_200 x SMALL_CPBS	1.13	1.19	2
ROOMS	2.39	2.52	12	DISTCPBS_100 x BIG_CPBS	1.10	1.25	2
GARAGE	1.55	1.60	12	DISTCPBS_100_200 x BIG_CPBS	1.20	1.45	2
BALCONY	1.70	1.89	12	DISTCPBS_100 x GROUP_CPBS	1.13	2.15	2
TERRACE	1.86	2.05	12	DISTCPBS_100_200 x GROUP_CPBS	1.23	2.07	2
KITCHEN	1.14	1.18	12	DISTCPBS_100 x MULTISTOREY	1.65	1.65	1
POOL	1.04	1.05	12	DISTCPBS_100_200 x MULTISTOREY	2.05	2.05	1
FIREPLACE	1.10	1.11	12	DISTCPBS_100 x MAST	1.13	1.13	1
GOOD COND	1.22	1.25	12	DISTCPBS_100_200 x MAST	1.10	1.10	1
BAD COND	1.07	1.08	12	DISTCPBS_100 x BADVIEW	2.39	2.39	1
ELDERLYPOP	1.85	1.91	12	DISTCPBS_100_200 x BADVIEW	2.29	2.29	1
INCOME	1.64	2.01	12	DISTCPBS_100 x NOISYNEIGH	2.35	2.35	1
FOREIGNPOP	1.83	1.98	12	DISTCPBS_100_200 x NOISYNEIGH	2.46	2.46	1
SOCHOUSE	1.42	1.47	12	POW_POTENTIALITY	1.80	1.80	1
DISTCENT x CBD	1.19	1.38	12	DISTPOW_100	2.53	2.80	11
DISTCENT x B_CENT	2.19	2.31	12	DISTPOW_100_200	5.17	5.28	11
DISTCENT x C_CENT	1.96	2.04	12	DISTPOW_200_400	7.55	8.58	11
EMPGRAV	3.77	4.06	12	DISTPOW_400_600	6.82	7.58	11
DISTWATER	3.14	3.27	12	DISTPOW_600_1000	5.44	5.67	11
DISTPARK	1.22	1.35	12	DISTPOW_100 x MOSQUE	1.13	1.13	2
DISTSCH	4.97	7.08	12	DISTPOW_100_200 x MOSQUE	1.14	1.14	2
DISTSCHSQ	4.88	7.16	12	DISTPOW_200_400 x MOSQUE	1.10	1.10	2
WIDEROAD	1.24	1.33	12	DISTPOW_400_600 x MOSQUE	1.08	1.08	2
AIRNOISE	1.07	1.98	12	DISTPOW_600_1000 x MOSQUE	1.04	1.04	2
RAILNOISE	1.18	4.99	12	DISTPOW_100 x DECON	1.07	1.07	2
DISTIND	1.60	1.63	12	DISTPOW_100_200 x DECON	1.06	1.06	2
ROADNOISE	1.32	1.35	2	DISTPOW_200_400 x DECON	1.08	1.08	2
ROADNOISE x AIRNOISEZONE	2.06	2.06	1	DISTPOW_400_600 x DECON	1.15	1.15	2
ROADNOISE x RAILNOISEZONE	4.74	4.74	1	DISTPOW_600_1000 x DECON	1.02	1.02	2
ROADNOISESQ	1.34	1.45	10	CHIME_DAY_POTENTIALITY	3.15	3.15	1
BUS_NUMBER	1.42	1.46	2	CHIME_NIGHT_POTENTIALITY	2.97	2.97	1
DISTSTAT_250	3.28	5.32	12				

summarizes the minimum and maximum VIFs per coefficient for all the models used in this dissertation. The variance of inflation tests reject the hypothesis of multicollinearity, because none of the variables examined has a VIF greater than 10 in any of the models.

Heteroskedasticity

White tests have shown that the null hypothesis of no heteroskedasticity is rejected on the 1% level for all models employed. Therefore, the significance levels of the coefficients were calculated on the basis of heteroskedasticity-robust standard errors according to White (1980).

Spatial lag versus spatial error model

Spatial dependence and/or spatial autocorrelation can be modeled appropriately by way of spatial lag or spatial error models (Anselin 1999). For a linear hedonic model, spatial lag and spatial error models can be written as follows (Kim, Phipps, and Anselin 2003):

$$P = \rho WP + A\beta + \varepsilon \,, \tag{I.4}$$

$$P = A\beta + \varepsilon \tag{I.5}$$

where $\varepsilon = \lambda W\varepsilon + u$ and *W* being a spatial weight matrix that describes the dependencies between the observations. The spatial error model in Eq. I.5 assumes that spatial autocorrelation emerges from omitted variables that follow a spatial pattern (Kim, Phipps, and Anselin 2003). Thus, the spatial error model is best suited for properties that share characteristics, that follow a spatial pattern, and when it is impossible to control for these characteristics (Andersson, Jonsson, and Ögren 2010). The spatial lag model in Eq. I.4 implies that the price of a property does not only depend on its property characteristics, but also on the prices of adjacent properties. Accordingly, a change in the characteristics of a certain property does not only change its own value (direct effect), but also impacts the values of adjacent properties, while changes in their values in turn affect the price of the property with modified characteristics (indirect effect) (Andersson, Jonsson, Ögren 2010).

To determine whether the underlying data are best described by a spatial lag or an error model, global tests for spatial dependence have been run. The findings for Model 1.1 are exemplary illustrated in Table I.5. Based on the results of Moran's I test, the possibility that there is no spatial dependence must be rejected. The results of the Lagrange multiplier tests strongly suggest the use of a spatial lag model. This is also true of all the other models used in this dissertation.

Table I.5 Results of global tests for spatial dependence

	Statistic	MI/DF	*p*-value
Spatial error			
Moran's I	34.2	0.183	0.000
Lagrange multiplier	1,075.4	1	0.000
Robust Lagrange multiplier	162.2	1	0.000
Spatial lag			
Lagrange multiplier	1,188.4	1	0.000
Robust Lagrange multiplier	275.1	1	0.000

Notes: MI, Moran's I test-value; DF, degrees of freedom in the Lagrange multiplier test. Results are based on a row-standardized inverse distance weight matrix; the critical distance is 2km.

Now, this raises the question whether the indirect effect should be taken into account for the spatial lag model when estimating the marginal implicit prices. According to Small and Steimetz (2007), this depends on whether an externality is technological or pecuniary. Accordingly, a technological externality increases the utility of residents, such as those living close to a high-priced property, because such a property is, for example, nice to look at or creates a status effect. If an indirect effect is linked with a change in utility, it is relevant for estimating marginal implicit prices (Andersson, Jonsson, and Ögren 2010). With pecuniary externalities an increase in value of a neighboring property does not affect the utility of living close to that property. Pecuniary externalities may occur, for example, when the value determination of a property is geared to the prices of adjacent properties. Such effects are welfare-neutral and, therefore, should not be used in the estimation of marginal implicit prices (Small and Steimetz 2007).

For the setting of offer prices, the (offer) prices of nearby properties are likely to play an important role (cf. Section II.3.2), which indicates that the indirect effect is a pecuniary externality. However, if we assume that it is a technological externality, the marginal implicit prices would have to be adjusted for the indirect effect.[8] But since the use of offer data suggests a pecuniary externality, it is assumed that the indirect effect is pecuniary, which is why the estimated marginal implicit prices are not adjusted (Andersson, Jonsson, and Ögren 2010).

Software

The software programs SPSS (releases 17-19) and R (releases 2.7.2 and 2.12.2) were used for statistical evaluations. The data were prepared and processed using the programs mentioned in Section I.3.1.

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[8] For a row-standardized weight matrix the indirect effect is $(1-\rho)^{-1}$ where ρ is the coefficient of *AUTOREG* (Kim, Phipps, and Anselin 2003).

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Sebastian Brandt & Wolfgang Maennig

II Road noise exposure and residential property prices: Evidence from Hamburg

Abstract: This study examines the influence of road noise on the prices of condominiums in Hamburg, Germany. On the basis of micro-level datasets capturing traffic-noise exposure, price discounts in the amount of 0.23% following a 1 dB(A) increase in road noise have been observed. The discounts calculated are, thus, significantly lower than average price discounts reported in previous studies, which were almost exclusively based on single-family homes. Using a nonlinear approach, we show that the discounts are not constant, but actually increase disproportionately. Even though it has been shown that noise coefficients can be biased if we do not control for other sources of noise, the effect of road noise on condominium prices in Hamburg is independent of whether or not a residential area is affected by other types of noise besides road noise.

Keywords: *Hedonic method, environmental disamenity, traffic-noise exposure, real estate economics, Hamburg*

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1 Introduction

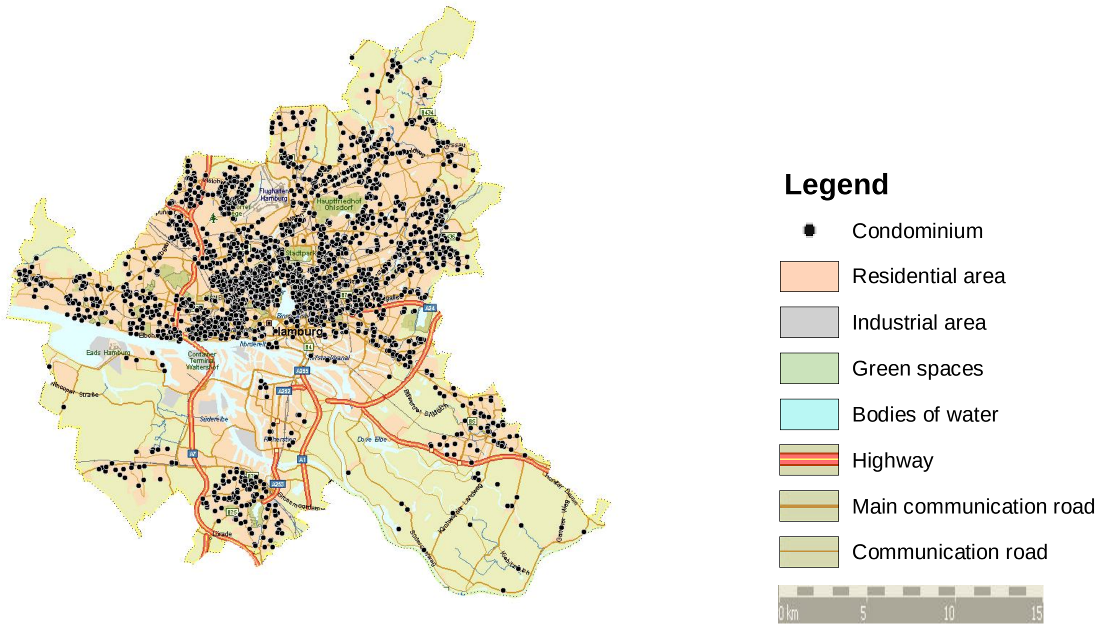
In Germany, road noise is the dominant source of nuisance in residential areas (Kuckartz and Grunenberg 2002). One should, therefore, be able to assume that a quiet residential area is an attractive place to live in. The fact that housing markets value road noise has been shown on the basis of hedonic regression models by, for example, Andersson, Jonsson, and Ögren (2010), Day, Bateman, and Lake (2007) and Kim, Park, and Kweon (2007).[1] Employing hedonic regression models this study examines the effects of road noise on condominium

[1] Studies on the impact of traffic noise by means of hedonic models have mostly been carried out with respect to air-traffic (cf., e.g., Lijesen et al. 2010; McMillen 2004; Morrell and Lu 2000; Pope 2008). For meta-analysis of the effects of air noise, see Johnson and Button (1997), Nelson (2004) and Schipper, Nijkamp, and Rietveld (1998). Concerning railroad noise, cf. Andersson, Jonsson, and Ögren (2010) and Day, Bateman, and Lake (2007).

prices in the city of Hamburg being innovative in at least three ways. On the one hand, the findings of our study are based on datasets regarding noise from road, air and rail traffic, which capture noise levels on a micro-level grid with receptor points, with each one 10m apart from the next, for the entire city area. As far as housing studies are concerned, this may well be unique when it comes to small scale and scope. On the other hand, to our knowledge this is the first study to examine the influence that mixed traffic noise pollution has on housing prices. A reduction in road noise in residential areas, that are not affected by any further noise-related nuisances, gives rise to the expectation of higher premiums for residential properties than in areas additionally exposed to other traffic noise. As well, we employ a constant nonlinear approach considering road noise as a quadratic term assuming increasing price discounts per dB(A) as noise pollution increases.

Section 2 introduces the data underlying this study. Section 3 presents the empirical model used to examine the effect of road noise on property prices. Section 4 presents the results of the study. Conclusions are drawn and presented in Section 5.

Fig. II.1 Spatial distribution of condominiums



2 Data

The study area comprises the entire city of Hamburg, which has an area of 755.2km² and a population of 1.772 million (December 31, 2008). The primary source of data for this study is a dataset supplied by F + B GmbH that contains 4,832 listing prices for condominiums in Hamburg that were put up for sale on about 100 different Internet portals between April 1, 2002, and March 31, 2008. All datasets contain information on the year of construction, size of the condominium, listing price and date, time on market as well as the complete address of the property. In addition, information on the characteristics of the condominiums was extracted from the portals. We further considered the location of the properties by calculating a variety of variables related to neighborhood and accessibility.[2] Using a directory supplied by the Hamburg Office for Urban Development and the Environment (BSU), each address was allocated to one of the 938 statistical districts of Hamburg. A statistical district is the smallest statistical unit for which the Statistics Office of Hamburg collects demographic and socioeconomic population data.[3] In addition, we used GIS to calculate the distance between properties and public infrastructure (such as schools, kindergartens, shopping and train stops), water and greenfield areas, jobs as well as sources of noise like industrial areas.

The BSU also supplied a dataset that depicts road-noise levels for the entire city area according to the calculation method VBUS, which is mandatory for German municipalities.[4] We also received from the BSU information on air-traffic noise around the airport of Hamburg ac-

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[2] The distribution of the condominiums examined across the area of Hamburg can be seen in Fig. II.1.

[3] All population data refer to the year in which the property was offered for sale most recently. The information regarding average income, however, was available only for 1995.

[4] Noise levels were calculated on the basis of the regulation titled ''Temporary calculation method regarding ambient noise along roadways and streets (VBUS), dated May 10, 2006". The calculation method takes into account intensity and composition of traffic, distance between the source and the receiver of noise, speed limits, upward and downward gradients, road surface as well as shielding provided by topography, anti-noise barriers and the area's development.

cording to the calculation method VBUF[5] and on railroad noise levels around rail tracks calculated according to the VBUSch method.[6] All noise measures are A-weighted L_{DEN} index values, which capture noise pollution in a grid with receptor points spaced 10m from each other as of 2007 (road and railroad noise) and 2005 (airport noise).

3 Empirical methodology

3.1 Variables

Many hedonic studies have found that a high percentage of price variation can be explained by property's size and age – variables that we have considered in both linear and quadratic form. Annual dummy variables account for general price trends in the condominium market of Hamburg. Furthermore, we control for the property's physical characteristics and condition by introducing dummy variables. In selecting the variables, we have relied in Sirmans, Macpherson, and Zietz (2005) and Wilhelmsson (2000), who evaluated the control variables most commonly used in hedonic studies.[7]

By including the proportion of those aged 65 and older (*ELDERLYPOP*), we take into account the age structure of a neighborhood, while the social structure of the population is measured by the average income (*INCOME*) and the proportion of foreign population (*FOREIGNPOP*). The number of social housing units per 1,000 inhabitants (*SOCHOUSE*)

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5 Temporary calculation method for ambient noise at airports (VBUF), dated May 10, 2006.

6 Temporary calculation method for ambient noise around railroad tracks (VBUSch), dated May 10, 2006.

7 Since Sirmans, Macpherson, and Zietz (2005) and Wilhelmsson (2000) primarily used studies on US housing markets in their analyses, it seemed meaningful to us, in our analysis of a German market, to consider some other characteristics. Given that Hamburg in Northern Germany has a moderate climate even in the summer, which essentially negates the use of air-conditioning for residential property, we have decided to drop this control variable. In contrast to the North-American housing markets, which are dominated mostly by single-family homes, the characteristics *BALCONY* and *KITCHEN* can have a considerable impact on the value of German condominiums.

allows for conclusions to be drawn about the social population structure as well as the quality of the local housing stock. All variables refer to the statistical districts previously described.

Access to jobs is measured by a gravity variable (Bowes and Ihlanfeldt 2001), which captures the distance between the city district where the condominium is located and the jobs located in the metropolitan area of Hamburg. This applies to all 103 districts of Hamburg as well as the 307 surrounding communities in the metropolitan region of Hamburg:

$$EMPGRAV_i = \sum_j \frac{Emp_j}{d_{ij}} \qquad , d_{ii} = \frac{1}{3}\sqrt{\frac{area_i}{\Pi}} \, , \tag{II.1}$$

where *Emp* represents all jobs subject to social insurance in a city district or in one of the surrounding communities. j stands for all city districts and communities other than i, and d_{ij} is the distance between the centroids of i and j. Since some of the city districts cover relatively large areas, we also take into account a district-internal distance measure d_{ii} (cf., e.g., Crafts 2005).[8] Proximity to shopping and recreation has been captured by the distance to central locations (*DISTCENT*) according to the zoning plan of Hamburg (BSU 2003). These 35 locations are characterized by a differentiated supply of everyday goods as well as bars, restaurants, movie theaters, etc., despite a scarcity of space. Other accessibility measures are the distance from the closest green space (*DISTPARK*), the nearest bodies of water (Inner and Outer Alster Lake and Elbe River: *DISTWATER*) and the distance to the nearest train station (*DISTSTAT*) as well as a quadratic term of the distance to the closest station (*DISTSTATSQ*). All distance variables were calculated as straight-line distances.

To estimate the influence of road traffic, its various negative external effects have to be taken into account. Disruptions and nuisances for residents are not only caused by noise, but also by vibration as well as pollution of the air, land and buildings, visual intrusions created by the

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8 In order to avoid overestimation of Emp_j and/or Emp_i, we did not allow d_{ij} and/or d_{ii} to take values smaller than 1. The regression coefficient of the gravity variable calculated from the graded weights shows a higher *t*-value than the coefficient of the variable calculated from nongraded weights.

road itself and artificial lighting. Even though noise is only one of several externalities of road traffic, most studies examining the effects of road traffic on residential property prices have focused on this external effect, because noise, particularly when compared to other factors, is perceived as the most annoying (Bateman et al. 2001). Our study relies on the aforementioned dataset from BSU, which measures the noise pollution created by streets with heavy and medium volumes by means of a micro-level L_{DEN} index which is represented by the variable *ROADNOISE*. Mean noise exposure for the sample is 57 dB(A), ranging from 15 to 79 dB(A) (descriptive statistics of the variables included in the final model specifications are listed in Table II.1). For testing whether the effect of road traffic on residential property prices is affected not only by traffic noise but also visual intrusions, we introduce a dummy variable (*WIDEROAD*) that takes the value of 1 and/or 0 if a property is located on a street with at least two lanes and/or on a street with one lane for each driving direction (Wilhelmsson 2000).

As well, we control for air-traffic noise pollution affecting condominiums in the flight paths of the Hamburg Airport (*AIRNOISE*) and rail noise exposure in the vicinity of railroad tracks (*RAILNOISE*) as well as the distance from industrial areas (*DISTIND*).

3.2 Empirical model

In our basic model we use a standard hedonic approach that takes into account property and neighborhood characteristics as well as accessibility and noise indicators. For the semi-logarithmic form, the basic model (1.1) can be written as:

$$\begin{aligned} ln(P) = \alpha + \beta\ OBJECT + \gamma\ NEIGH + \delta\ ACCESS + \eta\ WIDEROAD + \theta\ NOISECONTR \\ + \lambda\ ROADNOISE + \mu\ AUTOREG + \omega\ YEAR + \varepsilon\ , \end{aligned} \tag{II.2}$$

where α, β, γ, δ, η, θ, λ, μ and ω are representing the set of coefficients to be estimated and ε is an error term. *OBJECT* is a vector capturing the property characteristics, including infor-

Table II.1 Variable names, definitions and summary statistics

Variable	Definition	Mean	Std. dev.
Dependent variable			
PRICE	Last listing price of property	193,897	77,747
Property			
SIZE	Living area in square meters	81.78	47.10
AGE	Age of property in years	39.41	35.25
ROOMS	Number of rooms	2.79	1.71
GARAGE	1 if property has a garage, 0 otherwise	0.52	0.50
BALCONY	1 if property has a balcony, 0 otherwise	0.82	0.38
TERRACE	1 if property has a terrace, 0 otherwise	0.77	0.42
KITCHEN	1 if property has a built-in kitchen, 0 otherwise	0.65	0.48
POOL	1 if property has a pool, 0 otherwise	0.03	0.16
FIREPLACE	1 if property has a fireplace, 0 otherwise	0.04	0.20
GOOD COND	1 if property is in good condition, 0 otherwise	0.13	0.34
BAD COND	1 if property is in bad condition, 0 otherwise	0.06	0.24
Neighborhood			
ELDERLYPOP	Proportion of population in stat. district that is 65 years and older	18.93	6.73
INCOME	Mean income of population in stat. district (in 1,000€)	34.80	15.18
FOREIGNPOP	Proportion of foreign population in stat. district	13.06	6.64
SOCHOUSE	Number of social housing units per 1,000 inhabitants in stat. district	40.65	62.27
Accessibility			
DISTCENT	Distance to next central place according to zoning plan (in kilometers)	1.16	0.82
EMPGRAV	District proximity to employment (measured by a gravity variable)	146,016	44,153
DISTSTAT	Distance to next metro station (in kilometers)	0.78	0.54
DISTWATER	Distance to closest of the bodies of water Elbe and Binnen-/Aussenalster (in kilometers)	4.68	3.67
DISTPARK	Distance to next park, forest or nature protection area (in kilometers)	0.69	0.51
Noise exposure / visual intrusions			
DISTIND	Distance to next industrial area (in kilometers)	0.55	0.46
AIRNOISE	Air noise in dB(A) as measured by a L_{DEN} index if property is located within noise protection zone two (>67 dB(A)) or three (>62 dB(A)) around Hamburg Airport, 0 otherwise	2.19	10.95
AIRNOISEZONE	1 if property is located within noise protection zone two (>67 dB(A)) or three (>62 dB(A)) around Hamburg Airport, 0 otherwise	0.04	0.19
RAILNOISE	Rail noise in dB (A) as measured by a L_{DEN} index if the property is located in the vicinity of rail tracks, 0 otherwise	9.36	20.93
RAILNOISEZONE	1 if the property is exposed to rail noise ≥55 dB (A), 0 otherwise	0.12	0.33
WIDEROAD	1 if property is located on a wide road (with at least two lanes per driving direction), 0 otherwise	0.08	0.27
ROADNOISE	Road noise in dB(A) as measured by a L_{DEN} index	56.67	11.69

mation regarding age and size as well as dummy variables for the property's physical attributes. *NEIGH* is a vector representing neighborhood characteristics described earlier. Apart from negative externalities such as noise, visual intrusions, vibrations, etc., traffic infrastructure also produces positive effects in the form of improved accessibility. If a model only captures the negative effects of road traffic, it will only exhibit the net effect of traffic (that is, positive minus negative effects), which would underestimate negative external effects (Wilhelmsson 2000). Therefore, we introduced *ACCESS* as a vector with the aforementioned accessibility variables. Following the majority of studies, road noise is initially captured in linear form by *ROADNOISE*. In recent studies examining the effects of traffic noise on housing prices, observations for noise levels below a certain cutoff were excluded from the analysis. This cutoff ranges from 50 to 55 dB(A) (e.g., Andersson, Jonsson, and Ögren 2010). Miedema and Vos (1998), according to Navrud (2002), showed that the traffic noise cutoff for nuisance and disturbance might be lower and could be 37-40 dB(A). Thus, we used 40 dB(A) as the cutoff and excluded datasets for road noise levels < 40 dB(A) from the analysis.

Omitting other sources of noise could result in a biased regression coefficient for road noise which would also stand for all other forms of traffic and industrial noise (Wilhelmsson 2000). The vector *NOISECONTR* captures air-traffic and railroad noise, as well as the distance from the nearest industrial area. By introducing a spatial lag term (*AUTOREG*), we assume that listing prices, in addition to their attributes, depend on the prices of the properties previously put up for sale in the neighborhood (Ahlfeldt and Maennig 2009, 2010). Owing to the nature of listing prices, which are generally guided by neighboring property prices, we favor the spatial lag model over the spatial error model, which assumes that spatial autocorrelation emerges from omitted variables that follow a spatial pattern (Kim, Phipps, and Anselin 2003). For condominium *i* the value of the term is equivalent to the prices weighted by

$w_{ij} = (1/d_{ij})/\Sigma_j 1/d_{ij}$ of the surrounding *j* summed-up apartments, when $1/d_{ij}$ is the reciprocal distance between the condominiums *i* and *j* (Can and Megbolugbe 1997)[9]:

$$AUTOREG_i = \sum_j \frac{(1/d_{ij})}{\sum_j 1/d_{ij}} P_{j,t-m}\,,\;\; m = 1,...,12;\, j = 1,...,N;\, d_{ij} \leq 2\ km\,. \tag{II.3}$$

The dummy variables representing the most recent year in which a property was offered for sale are captured by the vector *YEAR*.

In the model with interactives (1.2), we explore the question of whether there are divergent price discounts for road noise in areas affected not only by road noise but also other types of traffic noise. In such neighborhoods, we expect that any reduction in road noise will result in smaller premiums for properties than in residential areas without additional noise problems. On the one hand, it can be assumed that residents that are less noise-sensitive are more likely to locate in areas with several sources of noise. On the other hand, any reduction in road noise in such areas would probably result in another source of noise becoming dominant. Our expanded semi-logarithmic model is as follows:

$$\begin{aligned} ln(P) = \alpha + \beta\ OBJECT + \gamma\ NEIGH + \delta\ ACCESS + \eta\ WIDEROAD\ + \theta\ NOISECONTR \\ + \lambda\ ROADNOISE\ + \sigma\ NOISEINTACT + \mu\ AUTOREG + \omega\ YEAR + \varepsilon\,, \end{aligned} \tag{II.4}$$

where *NOISEINTACT* is an additional vector that represents the combination of noise from different sources. *ROADNOISE* is multiplied by two dummy variables that each take the value of 1 when a property is located within the noise-protection zone 2 or 3 (>62 dB(A)) around the airport of Hamburg and/or if a property is exposed to railroad noise of at least 55 dB(A). Otherwise the dummies take a value of 0. The coefficients σ capture the difference in price

9 We computed *AUTOREG* using various critical distances (0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 7.5 and 10.0km) and found the best model fit when we considered properties within a radius of 2km. In contrast to Can and Megbolugbe (1997), who take into account surrounding properties if they were sold in the previous 6 months, we believe, given the relatively low volatility of the condominium market in Hamburg, that it is reasonable to include properties in the neighborhood that were offered for sale within the previous 12 months.

discounts for road noise between neighborhoods with one source of noise and residential areas with multiple noise sources.

Finally, using the nonlinear model (1.3), we test for increasing discounts on condominium prices as road noise increases. Owing to the logarithmic dB(A) scale, doubling of noise exposure increases the dB(A) scale by 10. It should be reasonable to find different discounts for a doubling of road noise exposure at different initial levels. For example, an increase from 40 to 50 dB(A) results in a noise level that is still tolerable, whereas an increase from 60 to 70 dB(A) corresponds to a change from moderate noise emission to a level that causes interference with speech (Bateman et al. 2001). As a result, it seems worthwhile to allow for increasing price discounts as noise levels rise:

$$\begin{aligned} ln(P) = \alpha + \beta\ OBJECT + \gamma\ NEIGH + \delta\ ACCESS + \eta\ WIDEROAD + \theta\ NOISECONTR \\ + \varphi\ ROADNOISESQ + \mu\ AUTOREG + \omega\ YEAR + \varepsilon\ , \end{aligned} \tag{II.5}$$

where *ROADNOISESQ* is capturing road noise in quadratic form and φ being the coefficient to be estimated. The other variables have the meanings previously defined.

4 Results and discussion

Since White's test rejects homoscedasticity for all three models, the standard errors were corrected using White's Correction. Approximately 87.2% of the variance of listing prices can be explained by the hedonic pricing models used (Table II.2).[10] This is an average value when compared to other hedonic housing price studies that control for spatial dependence. It should also be noted that all regressors have the expected signs and that almost all coefficients are highly significant, yielding values that are plausible also in terms of their amounts.

[10] If the models are specified without the spatial lag term (OLS model), the adjusted R^2 value is reduced by approximately 1.0%.

Table II.2 Results

	Basic model	Model with interactives	Nonlinear model
CONSTANT	8.3382***	8.3298***	8.2682***
Property			
SIZE	0.0132***	0.0132***	0.0132***
SIZESQ	–0.000009***	–0.000009***	–0.000009***
AGE	–0.0127***	–0.0127***	–0.0127***
AGESQ	0.000096***	0.000096***	0.000096***
ROOMS	0.0276**	0.0275**	0.0275**
GARAGE	0.0307***	0.0306***	0.0308***
BALCONY	0.0540***	0.0541***	0.0538***
TERRACE	0.0446***	0.0448***	0.0447***
KITCHEN	0.0450***	0.0453***	0.0451***
POOL	0.0434*	0.0428*	0.0433*
FIREPLACE	0.0170	0.0172	0.0168
GOOD COND	0.0459***	0.0455***	0.0460***
BAD COND	–0.1071***	–0.1068***	–0.1070***
Neighborhood			
ELDERLYPOP	–0.0033***	–0.0032***	–0.0033***
INCOME	0.0030***	0.0030***	0.0030***
FOREIGNPOP	–0.0055***	–0.0055***	–0.0055***
SOCHOUSE	–0.0001**	–0.0001**	–0.0001**
Accessibility			
DISTCENT	–0.0259***	–0.0248***	–0.0260***
EMPGRAV	0.000002***	0.000002***	0.000002***
DISTSTAT	0.0247	0.0243	0.0249
DISTSTATSQ	–0.0160	–0.0161	–0.0160
DISTWATER	–0.0067***	–0.0068***	–0.0067***
DISTPARK	–0.0405***	–0.0395***	–0.0405***
Noise exposure / visual intrusions			
DISTIND	0.0173*	0.0175*	0.0176*
AIRNOISE	–0.0013***	–0.0010***	–0.0013***
RAILNOISE	–0.0011***	–0.0008**	–0.0011***
WIDEROAD	–0.0499***	–0.0505***	–0.0478***
ROADNOISE	–0.0023***	–0.0022***	
ROADNOISE x AIRNOISEZONE		–0.0002	
ROADNOISE x RAILNOISEZONE		–0.0003	
ROADNOISESQ			–0.0000200***
Spatial lag term	YES	YES	YES
Number of observations	4,722	4,722	4,722
White's correction	YES	YES	YES
Adjusted R^2	0.87212	0.87210	0.87213

Notes: The endogenous variable is the natural log of the last listing price of property. All models include yearly dummy variables.

* Significance at the 10% level

** Significance at the 5% level

*** Significance at the 1% level.

4.1 Control variables

The coefficients estimated for *SIZE* and *SIZESQ* show an intuitively expected positive effect of property size on condominium prices that decreases as size increases. On the basis of the regressors *AGE* and *AGESQ*, we find a quadratic influence for the property's age, with the lowest prices for condominiums that are 66 years old. Regarding the other condominium's physical characteristics, only a generally bad condition of the property (*BAD COND*), has a negative effect on condominium prices.[11]

The effect of the proportion of foreigners on property prices is significantly negative, exceeding the negative effect of the proportion of those aged 65 and older. The relationship between medium income in the statistical district (*INCOME*) and condominium prices is positive and statistically highly significant. If, for example, the average income in the neighborhood is not at the level of the median income in Hamburg (€30,502), but instead at the level of the 0.75 quantile (€37,737), the condominium prices in the neighborhood with higher income will be about 2.2% above the level of the residential area with an income level corresponding to the median. Almost all accessibility indicators have statistically highly significant effects on property prices. While proximity to jobs, represented by a gravity variable, is seen as positive, all variables that measure distance from local amenities have the expected negative signs. The exceptions are *DISTSTAT* and *DISTSTATSQ*, which show a quadratic impact of property distance to the next train station on housing prices, although this effect is not statistically significant.

As distance to industrial areas (*DISTIND*) increases, property prices increase, as expected. A condominium that is exposed to air-traffic noise of 70 dB(A) – as is the case in noise-protection zone 2 around the airport of Hamburg – exhibits a price discount of approximately

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11 Following Halvorsen and Palmquist (1980), the coefficients of dummy variables used in the semi-log form were transformed by (e^a – 1), where *a* is the OLS coefficient.

9.1% compared to a property not exposed to air-traffic noise. The price discounts for properties affected by rail noise are, however, marginally lower. A condominium located on a wide street tends to be offered for sale with an average discount of approximately 5.0%.

4.2 Impact of road noise

As the coefficient estimates for the road noise terms are our main interest, we report our findings for both controlling for spatial dependence (spatial lag model) and the ordinary OLS model.

4.2.1 Basic model results (Model 1.1)

Regardless of whether the spatial lag term is considered or not, the coefficient of *ROADNOISE* is statistically significant at the 1% confidence level and takes a value of approximately –0.0023, which is equivalent to a price discount of 0.23% following a 1 dB(A) increase in noise pollution (Table II.3). Taking into account the logarithmic dB(A) scale, a doubling of road noise would, thus, result in a reduction of condominium prices in the amount of 2.3%. To facilitate comparison of findings from numerous studies on the impact of traffic noise on housing prices, it is standard to report results in terms of the noise sensitivity depreciation index (NSDI). This index measures the percentage change in housing values for a change in noise exposure of 1 dB(A),

Table II.3 NSDI for road noise estimates

	OLS	Spatial lag
ROADNOISE (Model 1.1)	0.233	0.230
ROADNOISESQ (Model 1.3)		
40 dB(A)	0.163	0.160
50 dB(A)	0.204	0.200
60 dB(A)	0.245	0.240
70 dB(A)	0.286	0.280
79 dB(A)	0.322	0.316

$$NSDI = \frac{\dfrac{change\ in\ noise\ discount}{change\ in\ noise\ exposure}}{housing\ value} = \frac{\dfrac{\partial P}{\partial N}}{P} \cdot 100 = \frac{change\ in\ housing\ value}{change\ in\ noise\ exposure} = \frac{\partial P}{\partial N}\frac{100}{P}\,. \qquad \text{(II.6)}$$

For the semi-logarithmic form, the estimated regression coefficient can be taken as an approximation of the NSDI (Andersson, Jonsson, and Ögren 2010).[12] Our findings are at the lower end of the range of results previously reported by other studies, which range from 0.08% to 2.22% per dB(A) noise pollution with an average discount of 0.55% per dB(A) (Bateman et al. 2001). However, our results are similar to those of Bateman et al. (2001), who studied the impact of road noise on the prices of residential properties in the city of Glasgow, Scotland, and who also controlled for a variety of accessibility indicators as well as other sources of noise.

The importance of controlling for the aforementioned variables with respect to a reliable estimate of the impact of road noise is shown by the following for the spatial lag model. Controlling for property and neighborhood characteristics only, would result in a coefficient estimate for road noise of merely –0.0020. This corresponds to the net effect of road traffic, which is also connected to positive effects, such as improved accessibility, besides being a source of disruptions and nuisance. If accessibility variables (*ACCESS*) are also taken into account, the coefficient for road noise drops to –0.0030. Other sources of noise should be included as control variables, because, otherwise, the regressor for road noise would represent all sources of noise to which a property is exposed. If we also control for other sources of noise (*NOISECONTR*) in our model, the coefficient rises to –0.0028. If we then add *WIDEROAD* to the model, the coefficient estimate increases to –0.0023, our final estimated value for the impact of road traffic noise on listing prices of condominiums in the city of Hamburg.

[12] Since the results are similar for the OLS and spatial lag models for all our models (Table II.3), we do not adjust our estimates for spatial correlation (Andersson, Jonsson, and Ögren 2010).

4.2.2 Results for model with interactives (Model 1.2)

While, in comparison to the basic model, all control variables have about the same values and significance levels, the coefficients of the two interactive terms are insignificant at conventional levels for the spatial lag model, as well as the OLS model. Thus, our findings show that a reduction in road noise in residential areas that are also affected by other traffic noise is not valued differently than it would be in neighborhoods affected only by road noise. This contradicts our expectations insofar as – as previously mentioned – any reduction in the emissions from a source of noise in areas with several noise emitters may result in another source becoming dominant. Consequently, in these areas residents' willingness to pay for a reduction of road noise should be less.

4.2.3 Nonlinear model results (Model 1.3)

As for *ROADNOISESQ*, we obtain a statistically significant coefficient of –0.0000200 controlling for spatial dependence and –0.0000204 for the OLS model. Using the semi-logarithmic functional form, for the squared road noise term the NSDI can be calculated as

$$NSDI\ (ROADNOISESQ) = e^{(2\,\varphi\ ROADNOISE)} - 1\,. \qquad \text{(II.7)}$$

At a noise exposure of 40 dB(A), the noise cutoff chosen for our portfolio, we have observed price discounts of only 0.16% per dB(A) for the spatial lag and OLS model, respectively. Meanwhile, the discounts for properties contained in the underlying portfolio that suffered the highest level of road noise at 79 dB(A) have been quantified at 0.32% per dB(A) for both the spatial lag and the OLS model. The coefficient of *ROADNOISESQ* φ with a *t*-value of –6.681 is lower than the coefficient λ estimated for *ROADNOISE* in Model 1.1, which takes a *t*-value of –6.655. As a result, the squared specification of road noise should be given preference over the linear term with respect to the portfolio examined. In the case of high noise levels a linear trend underestimates the influence of road noise on surrounding residential properties.

In neighborhoods exposed to low road-noise levels, a linear term overestimates the impact of road noise.

5 Conclusions

Using a hedonic regression technique and controlling for spatial dependence, we have estimated the effect of road noise on the listing prices of condominiums in Hamburg, initially at around 0.23% following a 1 dB(A) increase in noise pollution. We have shown that to obtain adequate coefficients for the impact of road noise we need to control for variables that might be correlated to road noise. For a quadratic specification of the influence of road noise on condominium prices, we have demonstrated that price discounts depend on the noise level and that they are significantly lower for low levels of road noise as well as significantly higher for high noise levels than the price discounts estimated on the basis of a linear trend. Whether or not a property is affected by sources of noise other than road noise, however, seems to be irrelevant for the effect of road noise on condominium prices in Hamburg. The costs of reducing noise exposure in residential neighborhoods, such as for new noise barriers, could be at least partially offset by increasing property tax gains for local authorities.

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III Road noise exposure and residential property prices: Evidence from Hamburg – Supplementary notes

1 Data collection and descriptive statistics of data

BSU also provided a dataset on road noise, which captures road noise in a grid pattern with approx. 6.9 million receptor points spaced 10 meters apart for the entire territory of the City of Hamburg. Road noise data was merged with the condominium dataset in a way that was generally analogous to the approach employed in determining air-traffic noise (cf. Section I.3.1.4). In order to allocate to each of the 3,131 property coordinates the nearest of the approx. 6.9 million receptor points, a PC with high computing capacity would take about 3 months. The city territory was divided into 12 areas to shorten the computing time. Then, the coordinates of the receptor points and of the properties for each area were imported into MS MapPoint separately. Subsequently, for each property coordinate of an area, the nearest receptor point with data on road noise was determined.

The variable *WIDEROAD* was determined by the author manually using digital aerial photography. For each of the 3,131 addresses, it was determined whether the respective address was situated on a wide road (with at least two lanes per driving direction).

Table III.1 shows the road noise distribution in the city of Hamburg and compares it to the road noise distribution of the residential portfolio under review. The data reveal that approx. 40% of the area of Hamburg is affected by minor road noise (< 40 dB(A)). This involves primarily rural regions on the city's periphery. In those regions, there are generally fewer condominiums, which is why only 110 properties of the portfolio are situated in locations subject to noise pollution of less than 40 dB(A). Most condominiums studied are affected by moderate to high road noise (≥ 40 and < 80 dB(A)). Very high road noise (≥ 80 dB(A)), as is measured along or near highways or expressways, affects 3.5km² of the city territory, but none of the properties studied. Against the background of the logarithmized dB(A) scale[1], too, a sufficient distribution of the portfolio across the various noise clusters can be assumed.

Table III.1 Description of road noise data

dB(A)	Area of Hamburg		Portfolio	
	Area in km²	Proportion	Number	Proportion
< 30	242.6	32.1%	12	0.2%
≥ 30 and < 40	60.4	8.0%	98	2.0%
≥ 40 and < 50	188.3	24.9%	1,684	34.9%
≥ 50 and < 60	156.1	20.7%	1,014	21.0%
≥ 60 and < 70	78.0	10.3%	1,071	22.2%
≥ 70 and < 80	26.3	3.5%	953	19.7%
≥ 80 and < 90	3.4	0.4%	0	0.0%
≥ 90	0.1	0.0%	0	0.0%
Total	755.2	100.0%	4,832	100.0%

Source: Hamburg Office for Urban Development and the Environment, 2007; author's own calculations

2 Results

Table III.2 presents the results for the influence of road noise on condominium prices in Hamburg derived from the adjusted model specifications (see Section I.4). First, it has to be mentioned that the modified models capture the variance of residential property prices better than the initial models, which is reflected by an increase in the adjusted R^2 by around 0.1 percentage points.

The model adjustments did not cause any significant changes to the results. The coefficient of *ROADNOISE* increased by 0.0001 (see Model 1.1); *ROADNOISE x AIRNOISEZONE* as well as *ROADNOISE x RAILNOISEZONE* continue to be insignificant (see Model 1.2), and the coefficient of *ROADNOISESQ* only changes at the fifth decimal position (see Model 1.3). If the spatial lag term is not included in the models, the coefficients generally continue to be unchanged. For the assumed pecuniary spatial externalities (see Section I.4), this means

1 As a result, the noise level at 80 dB(A) is 16 times higher than that at 40 dB(A).

that the implicit price on the basis of OLS and the direct effect for the spatial lag model are virtually identical (Andersson, Jonsson, and Ögren 2010).

Table III.2 Results

	Basic model *(Model 1.1)*	Model with interactives *(Model 1.2)*	Nonlinear model *(Model 1.3)*
CONSTANT	8.3146***	8.3068***	8.2478***
TOM	–0.0001***	–0.0001***	–0.0001***
AUTOREG			
AUTOREG	0.2209***	0.2210***	0.2215***
YEAR			
YEAR_2002	–0.0544**	–0.0546**	–0.0543**
YEAR_2003	–0.0045	–0.0049	–0.0049
YEAR_2004	–0.0304**	–0.0304**	–0.0305**
YEAR_2005	–0.0643***	–0.0647***	–0.0647***
YEAR_2006	–0.0366**	–0.0368***	–0.0366**
YEAR_2007	–0.0215	–0.0219	–0.0216
QUARTER1	0.0023	0.0018	0.0023
QUARTER2	0.0151	0.0147	0.0150
QUARTER3	0.0080	0.0075	0.0080
OBJECT			
SIZE	0.0133***	0.0133***	0.0133***
SIZESQ	–0.000009***	–0.000009***	–0.000009***
AGE	–0.0126***	–0.0126***	–0.0126***
AGESQ	0.000094***	0.000094***	0.000094***
ROOMS	0.0269**	0.0269**	0.0268**
GARAGE	0.0296***	0.0296***	0.0296***
BALCONY	0.0484***	0.0485***	0.0481***
TERRACE	0.0465***	0.0467***	0.0466***
KITCHEN	0.0431***	0.0433***	0.0431***
POOL	0.0439*	0.0434*	0.0438*
FIREPLACE	0.0196	0.0199	0.0195
GOOD COND	0.0461***	0.0457***	0.0462***
BAD COND	–0.1084***	–0.1082***	–0.1083***
NEIGH			
ELDERLYPOP	–0.0036***	–0.0036***	–0.0037***
INCOME	0.0033***	0.0033***	0.0033***
FOREIGNPOP	–0.0061***	–0.0061***	–0.0061***
SOCHOUSE	0.0000	–0.0001	0.0000
ACCESS			
DISTCENT x CBD	–0.0570*	–0.0567*	–0.0575*
DISTCENT x B_CENT	–0.0124*	–0.0115	–0.0125*
DISTCENT x C_CENT	–0.0322***	–0.0311***	–0.0324***
EMPGRAV	0.000002***	0.000002***	0.000002***

Table III.2 (continued)

	Basic model *(Model 1.1)*	Model with interactives *(Model 1.2)*	Nonlinear model *(Model 1.3)*
DISTSTAT_250	0.0070	0.0078	0.0067
DISTSTAT_250_750	0.0438**	0.0449**	0.0434**
DISTSTAT_750_1250	0.0231	0.0233	0.0229
DISTSTAT_1250_1750	0.0230	0.0234	0.0227
DISTWATER	–0.0086***	–0.0087***	–0.0086***
DISTPARK	–0.0298***	–0.0290***	–0.0298***
DISTSCH	0.1282**	0.1252**	0.1289**
DISTSCHSQ	–0.1085*	–0.1045*	–0.1093*
DISTPOW_100	0.0362	0.0361	0.0352
DISTPOW_100_200	0.0534**	0.0542**	0.0525**
DISTPOW_200_400	0.0265	0.0273	0.0258
DISTPOW_400_600	0.0150	0.0155	0.0143
DISTPOW_600_1000	0.0053	0.0052	0.0051
NOISECONTR			
DISTCPBS_100	–0.0097	–0.0089	–0.0096
DISTCPBS_100_200	0.0134	0.0140	0.0135
AIRNOISE	–0.0012***	–0.0010**	–0.0012***
RAILNOISE	–0.0011***	–0.0007**	–0.0011***
DISTIND	0.0209**	0.0213**	0.0212**
WIDEROAD			
WIDEROAD	–0.0490***	–0.0492***	–0.0471***
ROADNOISE			
ROADNOISE	–0.0022***	–0.0022***	
ROADNOISE x AIRNOISEZONE		–0.0002	
ROADNOISE x RAILNOISEZONE		–0.0004	
ROADNOISESQ			–0.0000190***
Spatial lag term	YES	YES	YES
Number of observations	4,722	4,722	4,722
White's correction	YES	YES	YES
Adjusted R^2	0.87332	0.87331	0.87333

Notes: The endogenous variable is the natural log of the last listing price of property. * indicates significance at the 10% level; ** indicates significance at the 5% level; *** indicates significance at the 1% level.

As explained in Section II.4.2.1, the estimated discounts for road noise are at the lower end of the range that other authors have observed (Bateman et al. 2001; Navrud 2002). This statement remains valid when considering more recent studies (cf., e.g., Andersson, Jonsson, and Ögren 2010; Day, Bateman, and Lake 2007; Kim, Park, and Kwen 2007). When interpreting the results of the study, three aspects should be taken into account:

1) The price discounts for residential locations exposed to road noise should be higher for single- and two-family homes than those observed for condominiums. The amount of time residents spend at their lot but outside the building, where noise exposure would be the most severe, is higher for single- and two-family homes than for condominiums. It is true, though, that most condominiums have a balcony or a terrace, but it can be assumed that house owners spend more time in their backyards due to the multiple uses, which would make them more willing to pay for a quiet residential location.
2) The social costs of road noise tend to be underestimated by the methods applied rather than overestimated. Transaction costs – such as the fees for realtors and notary, the property transfer tax and moving costs – are priced into listing and sales prices. Therefore, high transaction costs can cause noise-related costs to be underestimated (Nelson, 1982).
3) People who are less sensitive to noise tend to move to areas with high noise levels and can, therefore, be expected to be less willing to pay for peace and quiet. This should not be a problem for analyzing existing traffic infrastructure. However, if the study results for existing infrastructure are applied to new traffic projects that affect neighborhoods with residents who are substantially more sensitive to noise, the social costs of traffic noise are likely to be underestimated (Theebe, 2004).

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Sebastian Brandt & Wolfgang Maennig

IV The impact of rail access on condominium prices in Hamburg

Abstract: Using hedonic price functions, we study the influence of access to public railway stations on the prices of surrounding condominiums in Hamburg, Germany. The study examines the influence of rail infrastructure on residential property prices, not only of individual lines, but for the entire rail network of a metropolitan region. We test the stability of the coefficients for different sets of control variables. The study also estimates public-transit-induced increases in tax revenues due to real estate price increases for a study area outside the United States. We control for spatial dependence and numerous variables correlated with the proximity of railway stations and show that access to the public transit system of the city of Hamburg is to be rated with price increases of up to 4.6%. Such premiums for higher-income neighbourhoods and for subterranean stations tend to be higher. The premiums calculated are significantly lower than average price premiums reported in previous studies, which were mostly based on much fewer variables that rail access might be correlated to.

Keywords: Accessibility, real estate economics, public transport, location choice, Hamburg
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1 Introduction

Public transit companies in Germany achieve an average cost recovery ratio of about 70% (BMVBW 1999) and are therefore dependent on the support of the public sector.[1] One of the justifications usually given for such subsidies are the positive externalities of public transit. Accordingly, the CO_2 emissions of rail transport per passenger-km are well below the CO_2 emissions of motor vehicles (IFEU 2008; Kennedy 2002). Also, especially railway transport helps to relieve the road network, thus reducing congestion and increasing accessibility, for example, of workplaces, shopping and leisure destinations (Baum-Snow and Kahn 2000). High quality public transport reduces travel times at constant distances or increases the mo-

[1] The companies in the linked transport system in the city of Hamburg (HVV) investigated in this study have recently generated 71% of their costs (Gassdorf 2007).

bility range at constant travel times (Gibbons and Machin 2005), which could be reflected in higher property prices in the vicinity of railway stations (Bowes and Ihlanfeldt 2001). Put literally, these arguments do not prove positive externalities for public transport. Instead, it could be argued that public transport generates some negative externalities (e.g., noise, pollution) that are, however, much smaller than the negative externalities for road transport in cars and trucks. The failure of governments to charge appropriately for (larger) negative externalities for individual transport modes and distributional principles (the rich might be relatively less inclined to use public transport than the poor) may be relevant arguments for public transport subsidies.[2]

The present study examines the structure of condominium prices in the city of Hamburg using a cross-sectional hedonic approach that controls for spatial dependence and differentiates according to above-ground and underground stations as well as with regard to neighbourhoods with high and low incomes.

The investigation is limited to public transit by rail: With an average cruising speed of 33.1 kph (elevated railway, Hochbahn 2009) or 40.0 kph (city train, S-Bahn Hamburg 2009), both underground rail and the city train are well above the average speed of buses, which on average travel at only 20.0 kph (Hochbahn 2009), as well as above the speed of cars, which travel in the Hamburg metropolitan area at an average speed of 28.3 kph (BSU 2001). In Greater Hamburg there are 9,295 bus stops (HVV 2009), with an average walking distance to the nearest bus station of only 5.5 minutes (Infas 2004). Premiums for residential properties can therefore be expected only in the vicinity of rapid transport system stops (Cervero and Duncan 2002).

This study complements the previous literature in a number of respects. This study examines the influence of rail infrastructure on residential property prices, not only of individual lines,

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[2] We owe this to an anonymous referee.

but for the entire rail network of a metropolitan region. Contrary to previous studies that have investigated mainly the effects of specific or few commuter rail lines on the structure of suburban residential property prices, we include in our analysis the entire Hamburg railway network, consisting of commuter rail as well as city trains ("S-Bahn") and underground rail ("U-Bahn") spread out across a total of 17 lines. The study uses a sensitivity analysis to examine the impact that the nature and scope of the control variables used have on the relation between access to railway stations and real estate prices.[3]

As regards funding for public transit, one should point out that possible public-transit-induced premiums on sales of real estate generate additional revenue from land transfer taxes. This effect of public transport has been largely filtered out in the discussion on funding for public transit, which might be due to the lack of empirical evidence so far regarding the influence of rail infrastructure on house prices in Germany. The present study is to help to close this gap, by analysing the contribution of rail-induced real estate price increases to the funding of public transport outside of America. Furthermore, the study contributes to an understanding of the hitherto little explored influence of income level on the connection between access to railway infrastructure and residential real estate prices.

Section 2 provides an overview of the current literature on the subject. Then Section 3 describes the data that formed the basis of the study. Section 4 illustrates the empirical models used. In Section 5 the results are presented and an approach is introduced to quantify the fiscal benefits of public transit for the city of Hamburg. The conclusions are presented in Section 6.

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[3] Löchl and Axhausen.(2010) also control for the distance to railway stations and provide sensitivity tests by OLS, spatial autoregressive, and geographically weighted regression (GWR) techniques.

2 Literature review

In the tradition of von Thünen (1826), Alonso (1964), Muth (1969) and Mills (1972) have improved upon the land rent theory by including the aspect of the relationship between property prices and access to jobs, which are to be found in a central location according to the model assumptions. Neighbourhoods in the vicinity of the Central Business District (CBD), accordingly, have lower commuting costs than peripheral locations, resulting in higher house prices in central locations. Where a residential area has a rail connection to the CBD, this implies relatively lower commuting costs and thus higher real estate prices along the railway corridor (Vessali 1996; Debrezion, Pels, and Rietveld 2007). These results are also transferable if the criticism of the assumption of a monocentric city is taken into account (e.g., McDonald 1987; Wheaton 1982; White 1988; Shin, Washington, and Choi 2007).

The proximity to train stations – as an important determinant of urban accessibility – has so far been examined using hedonic models mainly for U.S. regions (e.g., most recently, Armstrong and Rodríguez 2006; McMillen and McDonald 2004; Redfearn 2009) and for British markets (e.g., Forrest, Glen, and Ward 1996; Gibbons and Machin 2005; Henneberry 1998). For continental Europe there have been comparatively few studies, most recently, for example, by Debrezion, Pels, and Rietveld (2006) as well Löchl and Axhausen (2010).

The majority of studies find a positive impact of railway stations on property prices. Some authors have observed no significant effect (Cervero and Duncan 2002), while others may actually have noticed a negative effect (Forrest, Glen, and Ward 1996). The divergent results, including studies that investigate the same transport system, can be attributed to a number of causes: First, findings may be biased if the opposing externalities of railway stations (Bowes and Ihlanfeldt 2001) are neglected and/or if variables are ignored that correlate with the proximity to stations. Stations and railway tracks are sources of vibration; above-ground stations cause noise and visual nuisance. In addition, stations are often located near busy roads or intersections, which create noise pollution (Theebe 2004). Negative effects on property prices may also come from increased crime in the vicinity of stations (Poister 1996; Bowes and Ihlanfeldt 2001). On the other hand, train stops can encourage the establishment of retail stores (Green and James 1993), which in turn can have a positive impact on the surrounding real estate prices (Sirpal 1994). As a transportation system competing with rail transport, access to the road network should also be considered. If, for example, the distance of a property to the nearest motorway junction is neglected, the coefficients for access to railway stations can be biased (Debrezion, Pels, and Rietveld 2007).

Second, the size and type of a mass transit system can be significant for its effect on house prices. It is likely that the effect is particularly pronounced in cities with a well-developed rail network. It is likely also that rapid commuter rail systems have a greater impact on property prices than slower light-rail systems. As well, individual stations can generate different effects when they differ in terms of service frequency, connection to the transport network, aboveground or underground location as well as park-and-ride facilities. Third, the influence of railway stations may also depend on socio-demographic factors such as the income level of a region or a neighbourhood. The direction of effect does not seem to be unambiguous here. While Gatzlaff and Smith (1993) observe a positive relationship between income and the effects of railway stations on house prices, Nelson (1992) finds a negative relationship. Possible time savings due to good access to transport may be valued higher in high-income neighbourhoods, but this is in contrast to a higher proportion of public transport users in lower-income areas (Kim 2003).

The present study uses a cross-sectional hedonic approach to investigate the influence of the existing rail infrastructure on Hamburg condo prices. Gibbons and Machin (2005) criticise this method in that the results of the regression analysis are biased if variables that are correlated with access to railway stations are not included in the regression equation. However, the results of studies examining the transport infrastructure on the basis of longitudinal analyses may also be biased, as it seems unclear how long it takes a real estate market to reflect in its prices a change in the quality of the rail infrastructure (Henneberry 1998). McMillen and McDonald (2004) have observed that house prices react to new transport infrastructure as early as six years before and as many as six years after the opening of a new railway line. If one chooses too short a period of investigation, it is possible to underestimate the effect of a new transport system on the surrounding property prices. We take the criticism of Gibbons and Machin (2005) into account, by testing a number of positive and negative externalities of railway stations as well as potentially correlated variables. For a detailed review of the literature on the effects of railway stations on property prices, we refer to Wrigley and Wyatt (2001) and NEORail II (2001), and for a review on methodological problems to Löchl and Axhausen (2010).

3 Data

Most housing studies rely on sales prices for single- and two-family homes. We depart from this approach by using prices of condominiums, which make up the largest share of transactions involving residential properties in Hamburg (Committee of Valuation Experts in Hamburg 2008) and by using listing prices instead of sales prices.[4] Using listing prices may cause problems if the difference between offer and transaction price is correlated with the physical characteristics of the properties.

Williams (1995) analyses the prices of single-family homes in Queensland, Australia. By using linear functional forms two separate regressions are estimated, once on the basis of offer prices and, once on the basis of sales prices. In both equations the same coefficients are statistically significant, and all significant coefficients in both equations have the same sign.

[4] In fact, in Germany a Committee of Valuation Experts that collects sales prices of housing units is located in every county. But in practice strict data protection regulations and high fees make it difficult to get access to detailed datasets of actual sales prices containing information on property’s addresses.

However, the coefficients of two variables differ from each other significantly.[5] As for the remaining 16 significant variables, the coefficient pairs do not deviate from each other by more than 12%. Merlo and Ortalo-Magné (2004) as well as Knight (2002) show that the difference between offer and transaction prices is greater the longer a property is on the market. If we observed a correlation between time on market and distance to the closest train station with respect to our dataset, an unsystematic variance of the difference between listing and sales prices in relation to the distance to the closest station would, thus, be doubtful. In our case, the Pearson correlation coefficient for time on market and distance to next rail station, however, is small (0.006) and insignificant at conventional levels.[6] For the condominium market in Hamburg, where the average differential between listing and transaction prices is approximately 8%, no systematic variance of this difference for properties of different age, size or price category has been observed.[7] Since we use semi-logarithmic forms, which reflect relative – and not absolute – changes in property prices for an additional unit of a characteristic, it may be assumed that the offer prices should yield unbiased coefficients.[8]

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[5] In the regression that uses the sales price as a dependent variable, a tiled roof, as opposed to an iron roof, is valuated at A$4,800, while the regression where the offer price is the dependent variable arrives at a price premium of A$6,300. In addition, the coefficient of *SIZE* calculated on the basis of the offer prices exceeds the coefficient calculated on the basis of the sales prices by approximately 20%.

[6] Grether and Mieszkowski (1974) also note that it is reasonable to assume that missing information on property characteristics, which may be connected to the use of offer data, does not give rise to a systematic bias of coefficients.

[7] Cf. F+B (2002). To our knowledge, there have not been any further studies on the influence that property characteristics have on the difference between offer and transaction prices.

[8] By contrast, the linear form produces coefficients that represent absolute changes in property prices for an additional unit of a property characteristic. Since listing prices are systematically higher than sales prices, coefficients obtained from linear functional forms using listing prices as the dependent variable are likely to overestimate the effects on housing prices examined, independently from whether the difference between listing and transaction prices is correlated with the physical characteristics of a condominium or not.

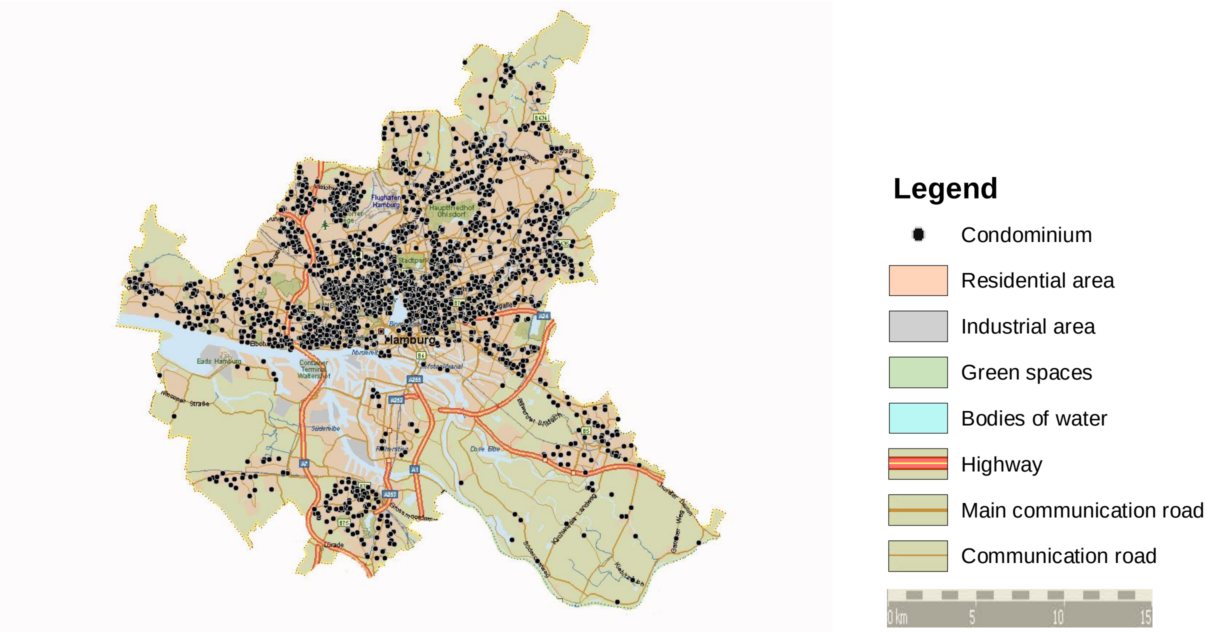
The study area comprises the entire city of Hamburg, which has an area of 755.2km² and at the end of the study period a population of 1.767 million (March 31, 2008). The primary source of data for this study is a dataset supplied by F+B GmbH that contains 4,832 listing prices for condominiums in Hamburg that were put up for sale on Internet portals between April 1, 2002, and March 31, 2008.[9] All datasets contain information on the year of construction, size of the condominium, listing price and date, time on market as well as the complete address of the property. In addition, information on the characteristics of the condominiums was extracted from the portals. We further considered the location of the properties by calculating a variety of variables related to neighbourhood and accessibility.[10] Using a directory supplied by the Hamburg Office for Urban Development and the Environment (BSU), each address was allocated to one of the 938 statistical districts of Hamburg. A statistical district is the smallest statistical unit for which the Statistics Office of Hamburg collects demographic and socioeconomic population data.[11] In addition, we used GIS to calculate distances between properties and train stations, public infrastructure (such as schools, kindergartens and shopping), water and green spaces as well as jobs. BSU has supplied us with further small-scale datasets on the noise pollution caused by road, air and rail traffic for the area of Hamburg, so that we were able to determine property-specific noise pollution levels in dB(A).

[9] Initially the service provider IDN ImmoDaten GmbH extracted the data from the portals automatically. Subsequently, the data were adjusted by IDN and F+B to remove duplications and implausible datasets.

[10] The distribution of the condominiums examined across the area of Hamburg can be seen in Fig. IV.1.

[11] All population data refer to the year in which the property was offered for sale most recently. The information regarding average income, however, was available only for 1995.

Fig. IV.1 Spatial distribution of condominiums



In 1965 the transit companies of the metropolitan region of Hamburg formed the Hamburg Transit Association (HVV) – one of the oldest transport associations in the world (HVV 2009). Nine of today's total of 33 transit companies provide their transportation services by rail. In 2008 they carried 554 million passengers, that is, 58.5% of all passengers within the transit network. Assuming for each passenger one round trip per day, there are on average approx. 750,000 people in the metropolitan region of Hamburg who use rail transport. About half of the approximately 3.37 million inhabitants in the HVV area live in Hamburg. Taking into account that the inhabitants of the city of Hamburg take public transport at least twice as often as the population of the surrounding countryside (Infas 2004), the daily average of the people in Hamburg who travel by train comes to more than 500,000, or more than 28%.[12] This demonstrates the substantial importance of rail transport in the city of Hamburg (Infas and DIW 2004). The 803km railway tracks in the network area are operated by 27 lines (HVV 2009). There is a total of 278 stations along the network, 134 of which are located in Hamburg.[13] By

[12] Determinants for the choice of means of transport, for example, have been described by Schwanen and Mokhtarian (2005) as well as Simma and Axhausen (2003).

[13] This leaves the number of stops and lines in the area of the city of Hamburg constant over the study period.

using the data made available by HVV, we were able to determine for each station the number of serving train and bus routes as well as the service frequency. We also collected information on whether a station is a transfer station, the stop is located above or underground, and whether it has a parking lot.

4 Empirical methodology

4.1 Hedonic approach and choice of functional form

To assess the effects that access to the rail network has on condominium prices we use hedonic regression techniques (Rosen 1974).[14]

$$P = f(O, N, L, R), \tag{IV.1}$$

where P is the listing price of the condominium. O is a vector of the property's physical characteristics. The neighbourhood and/or location characteristics are represented by vector N and/or L. R is a vector that captures rail access.

The choice of the proper parametric form of the hedonic regression equation is the subject of several publications (e.g., Cassel and Mendelsohn 1985; Cropper, Deck, and McConnell 1988; Halvorsen and Pollakowski 1981; Linneman 1980). However, since their advantage of allowing for non-linearity effects as well as intuitive interpretation of coefficients housing studies commonly rely on semi-logarithmic functional forms. In recent years, authors have tended to use flexible forms such as the Box-Cox transformation (Box and Cox 1964). But, so far, the literature has not overcome the problems of implementing flexible functional forms in the presence of spatial dependence (Kim, Phipps, and Anselin 2003; Leggett and Bockstael 2000). Thus we use semi-logarithmic functional forms for our analysis.

[14] We thank an anonymous referee for pointing out that Rosen (1974) suggests a two-step approach where the hedonic (the first stage) is used in a second stage to determine demand functions for housing characteristics. This study limits the analysis to a study of hedonic prices.

4.2 Empirical models

Basic model (Model 2.1)

In our basic model we use a hedonic cross-sectional approach that takes into account property and neighbourhood characteristics, accessibility and noise indicators as well as access to rail stations. For the semi-logarithmic form, the basic model (2.1) can be written as:

$$\ln(P) = \alpha + \beta\ PROP + \gamma\ NEIGH + \delta\ ACCESS + \eta\ NOISE\_VIS\_DIS + \theta\ AUTOREG \qquad \text{(IV.2)}$$
$$+ \lambda\ YEAR + \mu\ DISTSTAT + \varepsilon\ ,$$

where α is a constant and β, γ, δ, η, θ, λ and μ are representing the vectors of coefficients to be estimated and ε is an error term. *PROP* is a vector capturing the property characteristics, including information regarding age and size – that we have considered in both linear form and with an additional quadratic term (e.g., Voith 1993) – as well as dummy variables for the property's physical attributes.[15] In selecting the variables, we rely on Sirmans, Macpherson, and Zietz (2005) and Wilhelmsson (2000), who evaluated the control variables most commonly used in hedonic studies.[16] *NEIGH* is a vector of neighbourhood characteristics, consisting of the proportion of those aged 65 and older (*ELDERLYPOP*: e.g., Ahlfeldt and Maennig 2010), the average income (*INCOME*: e.g., Andersson, Shyr, and Fu 2010), the proportion of population with non-German passport (*FOREIGNPOP*: e.g., Theebe 2004) as

[15] Descriptive statistics of the variables included in the final model specifications are listed in Table IV.1.

[16] Since Sirmans, Macpherson, and Zietz (2005) and Wilhelmsson (2000) primarily used studies on U.S. housing markets in their analysis, it seemed meaningful for an analysis of a German market to differ in some respects. Given that Hamburg in Northern Germany has a moderate climate even in the summer, which essentially negates the use of air-conditioning for residential property, we have decided to drop this control variable. In contrast to the North-American housing markets, which are dominated mostly by single-family homes, the characteristics *BALCONY* and *KITCHEN* can have a considerable impact on the value of German condominiums.

well as the number of social housing units per 1,000 inhabitants (*SOCHOUSE*: e.g., Gibbons and Machin 2005).[17]

Table IV.1 Variable names, definitions and summary statistics

Variable	Definition	Mean	Std. dev.
Dependent variable			
PRICE	Last asking price of property	193,897	177,747
Property			
SIZE	Living area in square metres	81.78	47.10
AGE	Age of property in years	39.41	35.25
ROOMS	Number of rooms	2.79	1.71
GARAGE	1 if property has a garage, 0 otherwise	0.52	0.50
BALCONY	1 if property has a balcony, 0 otherwise	0.82	0.39
TERRACE	1 if property has a terrace, 0 otherwise	0.77	0.42
KITCHEN	1 if property has a built-in kitchen, 0 otherwise	0.65	0.48
POOL	1 if property has a pool, 0 otherwise	0.03	0.17
FIREPLACE	1 if property has a fireplace, 0 otherwise	0.04	0.20
GOODCOND	1 if property is in good condition, 0 otherwise	0.13	0.34
BADCOND	1 if property is in bad condition, 0 otherwise	0.06	0.24
Neighbourhood			
ELDERLYPOP	Proportion of population in census tract that is 65 years and older	18.93	6.73
INCOME	Mean income of population in census tract (in 1,000 €)	34.80	15.18
FOREIGNPOP	Proportion of population with non-German passport in census tract	13.06	6.64
SOCHOUSE	Number of social housing units per 1,000 inhabitants in census tract	40.65	62.27
Access			
DISTCENT	Distance to next central place according to zoning plan (in kilometres)	1.16	0.82
EMPGRAV	District proximity (air distance) to employment (measured by a gravity variable)	146,016	44,153
DISTWATER	Distance to closest of the bodies of water Elbe and Binnen-/Aussenalster (in kilometres)	4.68	3.67
DISTPARK	Distance to next park, forest or nature protection area (in kilometres)	0.69	0.51
BUS_NUMBER	Number of bus lines that stop at the next rail station in the peak	3.82	4.38

[17] In preliminary studies, we have further tested whether a change in the population (in the statistical district or the urban district) over the study period had any influence on condo prices. Since a significant effect had not been observed for any of the specifications tested, we decided to leave this aspect out of the final model specifications.

Table IV.1 (continued)

Variable	Definition	Mean	Std. dev.
Noise exposure / visual disamenities			
WIDEROAD	1 if property is located on a wide road (with at least two lanes per driving direction), 0 otherwise	0.08	0.27
ROADNOISE	Road noise in dB(A) as measured by a L_{DEN} index	56.67	11.69
AIRNOISE	Air noise in dB(A) as measured by a L_{DEN} index if property is located within noise protection zone two (≥ 67 dB(A)) or three (≥ 62 dB(A)) around Hamburg Airport, 0 otherwise	2.19	10.95
RAILNOISE	Rail noise in dB(A) as measured by a L_{DEN} index if property is located in the vicinity of rail tracks, 0 otherwise	9.36	20.93
DISTIND	Distance to next industrial site (in kilometres)	0.55	0.46
Station Accessibility			
DISTSTAT_250	1 if distance to next rail station ≤ 250m, 0 otherwise	0.09	0.29
DISTSTAT_250_750	1 if distance to next rail station > 250m and ≤ 750m, 0 otherwise	0.50	0.50
DISTSTAT_750_1250	1 if distance to next rail station > 750m and ≤ 1,250m, 0 otherwise	0.25	0.43
DISTSTAT_1250_1750	1 if distance to next rail station > 1,250m and ≤ 1,750m, 0 otherwise	0.11	0.31
UNDERGR	1 if next rail station is located underground, 0 otherwise	0.26	0.44

Access to jobs is measured by a gravity variable (Bowes and Ihlanfeldt 2001), which captures the distance between the urban district where the condominium is located and the jobs located in the metropolitan area of Hamburg. This applies to all 103 districts of Hamburg as well as the 307 surrounding communities in the metropolitan region of Hamburg:

$$EMPGRAV_i = \sum_j \frac{Emp_j}{d_{ij}} \qquad , d_{ii} = \frac{1}{3}\sqrt{\frac{area_i}{\Pi}} \, , \tag{IV.3}$$

where *Emp* represents all jobs subject to social insurance in an urban district or in one of the surrounding communities. *j* stands for all urban districts and communities other than *i*, and d_{ij} is the distance between the centroids of *i* and *j*. Since some of the urban districts cover relatively large areas, we also take into account a district-internal distance measure d_{ii} (cf., e.g., Crafts 2005).[18] Proximity to shopping and recreation has been captured by the distance to central locations (*DISTCENT*) according to the zoning plan of Hamburg (BSU 2003). These 35 locations are characterised by a differentiated supply of everyday goods as well as bars, restaurants, cinemas, etc., despite a scarcity of space. The zoning plan differentiates the central locations with decreasing diversification of supply and retail space into A Centre (city), B Centre (district centre) and C Centre (neighbourhood centre). Thus, depending on the type of the nearest central place one must expect different levels of price premiums for location proximity. We therefore introduce three dummy variables, each of which assumes the value 1 if the nearest central place is an A (*CBD*) or B (*B_CENT*) or C centre (*C_CENT*); otherwise, the value is 0. Then we multiply the variables by the distance between the property and the nearest central location (*DISTCENT)*. Consequently, the location of properties from shopping and leisure facilities can be considered separately for the different types of central places. Indicating the access to recreation we considered the distance from the closest green space (*DISTPARK*: e.g., Agostini and Palmucci 2008) as well as from the nearest bodies of water (Inner and Outer Alster Lake and Elbe River: *DISTWATER*). It is mostly North-American publications that tend to use the distance from highway on-ramps as an indicator of accessibility (e.g., McMillen 2004). This may be meaningful for metropolitan regions with an extensive network of city highways as in many U.S. American metropolises). The often-congested highways in Hamburg, due to transit and commuter traffic, however, are only rarely used by the inhabitants of Hamburg for their daily trips to work or to go shopping, which is why the distance from highway on-ramps as a measure of accessibility has been excluded from our models. *BUS_NUMBER*, that captures the number of bus lines that stop at the next rail station in the peak, is included to make sure that we do not positively bias the

[18] In order to avoid overestimation of Emp_j and/or Emp_i, we did not allow d_{ij} and/or d_{ii} to take on values smaller than 1. The regression coefficient of the gravity variable calculated from the graded weights shows a higher *t*-value than the coefficient of the variable calculated from nongraded weights.

effect of the train station accessibility. *ACCESS* is thus a vector to map the previously discussed accessibility indicators.[19]

NOISE_VIS_DIS is a vector that, in addition to noise pollution in the entry and exit lanes of the Hamburg Airport (*AIRNOISE*: e.g., Pope 2008), also takes into account noise and visual nuisances stemming from road traffic (*ROADNOISESQ*, *WIDEROAD*) as well as railway noise[20] near railway tracks (*RAILNOISE*) and that captures the distance to industrial sites (*DISTIND*: e.g., Li and Brown 1980). By introducing a spatial lag term (*AUTOREG*) we assume that listing prices also depend on the prices of the properties previously put up for sale in the neighbourhood (Ahlfeldt and Maennig 2010). Owing to the nature of listing prices, which are generally guided by neighbouring property prices, we favour the spatial lag model over the spatial error model, which assumes that spatial autocorrelation emerges from omitted variables that follow a spatial pattern (Kim, Phipps, and Anselin 2003). For condominium i the value of the term is equivalent to the prices weighted by $w_{ij} = (1/d_{ij})/\Sigma_j 1/d_{ij}$ of the surrounding j summed-up apartments, when $1/d_{ij}$ is the reciprocal distance between the condominiums i and j (Can and Megbolugbe 1997):[21]

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[19] Numerous studies have observed that part of the variability in property prices can be explained by the distance to the nearest school (e.g., Agostini and Palmucci 2008). However, as preliminary regressions did not yield significant coefficients for either linear or additional quadratic distance terms, we have excluded the distance to schools from the final model specifications.

[20] Other studies frequently use the distance to the rail tracks as an indicator of noise exposure (e.g., Strand and Vågnes 2001). However, shielding effects (e.g., because of the topography, noise barriers or the surrounding buildings) result in very different levels of noise pollution and visual nuisance for an identical distance to railway tracks.

[21] Can and Megbolugbe (1997) consider properties within a radius of 3 kilometres. However, their study area covers a large-area suburban county in the metropolitan region of Miami. As concerns the small-scale housing market in Hamburg, it is reasonable to assume that the offer price of a condominium is affected only by prices of properties that are located in the immediate vicinity. However, we computed *AUTOREG* using various critical distances (0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 7.5 and 10.0km) and found the best fit of the model when we considered properties within a radius of 2km. In contrast to Can and Megbolugbe (1997), who take into account surrounding properties if

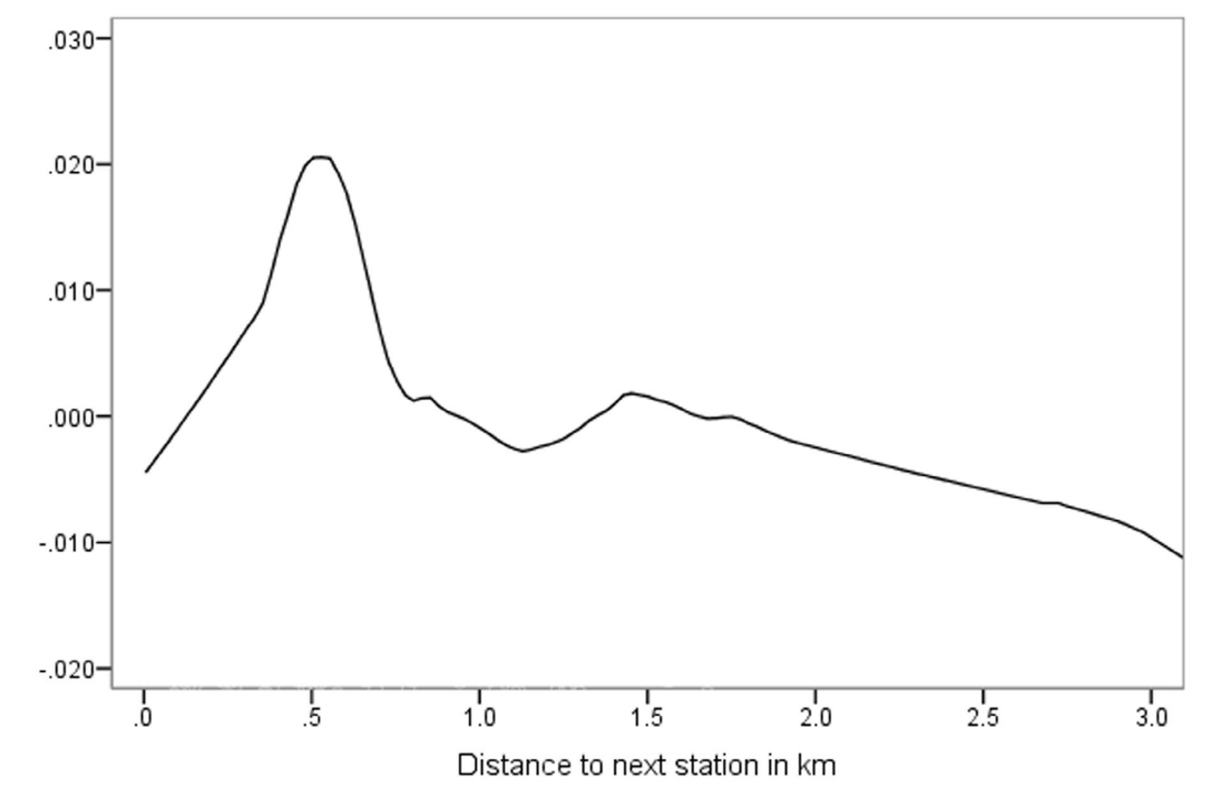
$$AUTOREG_i = \sum_j \frac{(1/d_{ij})}{\sum_j 1/d_{ij}} P_{j,t-m}, \; m = 1,...,12; \; j = 1,..., N; d_{ij} \leq 2\; km. \quad \text{(IV.4)}$$

The dummy variables representing the most recent year in which a property was offered for sale are captured by the vector *YEAR*.

The vector *DISTSTAT*, according to Bowes and Ihlanfeldt (2001), represents in the following a set of dummy variables that map the distance contours to the nearest train station. We have examined the price-distance trend first with kernel regressions using the residuals of Eq. IV.2, but without the term *μ DISTSTAT*. Fig. IV.2 shows that the price gradient is exclusively negative from a distance of about 1,750m, which is why we select properties with distances greater than 1,750m to the next station as the reference group. This also seems to be a possible maximum walking distance to the nearest station. In light of the price-distance trend determined by kernel regressions, we have defined four dummy variables that each take on the value of 1 if a property is up to 250m, more than 250m and up to 750m, more than 750m and up to 1,250m or more than 1,250m and up to 1,750m from the next train stop; otherwise the value is 0. While we expect to find decreasing premiums for condos for distances of 250m to 1,750m with increasing distance to a station, we think that relatively lower property prices are possible for distances up to 250m due to the negative externalities of stations.

they were sold in the previous six months, we believe, given the relatively low volatility of the condominium market in Hamburg, that it is reasonable to include properties in the neighbourhood that were offered for sale within the previous 12 months.

Fig. IV.2 Property price gradient, with distance to next railway station



Remark: Figure shows kernel regression of residuals from Eq. IV.2 omitting the term *λ DISTSTAT*. Kernel uses the Epanechnikov function.

Model with interactives (Model 2.2)

As already mentioned above, the influence of train stations on the surrounding housing prices may also depend on station characteristics and the income level of a neighbourhood. To investigate these factors, we have interacted *DISTSTAT* with the dummy variable *UNDERGR*, which takes on the value of 1 if the nearest railway station is located underground.[22] Furthermore, *DISTSTAT* is interacted with the dummy variable *HIGHINC* that takes

[22] Preliminary regressions have shown that other station characteristics, contrary to some observations such as by Gibbons and Machin (2005), do not affect the structure of condo prices in Hamburg. These include frequency of service, number of serving railway lines, whether the nearest station has a parking lot or whether it is a transfer station. Furthermore, it has no bearing on whether the next station is part of the light-rail or commuter rail system. We have also examined the effect of crime density and frequency on the surrounding property prices. Crime data, however, were only made available at the neighbourhood level and yielded insignificant results.

on the value of 1 if a property is located in a statistical area with incomes above the median income.[23] The model with interactives is thus:

$$\ln(P) = \alpha + \beta\ PROP + \gamma\ NEIGH + \delta\ ACCESS + \eta\ NOISE\_VIS\_DIS + \theta\ AUTOREG \\ + \lambda\ YEAR + \mu\ DISTSTAT + \sigma\ DISTSTAT \times UNDERGR + \omega\ DISTSTAT \times HIGHINC + \varepsilon\ , \tag{IV.5}$$

where *μ*, σ and ω are vectors of the regression coefficients to be estimated. While σ represents the price difference between underground and above-ground stops, ω captures the influence of the distance to the next station in neighbourhoods with incomes above the median income. For subterranean stations, we expect premiums for distances up to 250m to the next train station in comparison to above-ground stations. As for which income group access to train stations is deemed to be more important, we have no *a priori* expectations due to the conflicting results of previous studies already described. All other terms in Eq. IV.5 have the meanings already described for the basic model.

5 Results

Around 87.2% of the variance of listing prices can be explained by the hedonic pricing models used (Table IV.2).[24] This is an average value when compared to other hedonic housing price studies that control for spatial dependence. Since White’s test rejects homoscedasticity for both models, the standard errors were corrected using White’s Correction. All control variables have the expected signs and are predominantly highly significant, yielding values that are plausible also in terms of their amounts.

[23] We identify neighbourhoods with incomes above the median by splitting our random sample into two sub-samples of equal size on the basis of the median of the variable *INCOME*.

[24] If the models are specified without the spatial lag term, the adjusted R^2 value is reduced by approximately 1.0%.

Table IV.2 Results

	Basic model	Model with interactives
CONSTANT	8.3023***	8.3804***
YEAR_2002	–0.0336	–0.0316
YEAR_2003	0.0061	0.0048
YEAR_2004	–0.0256*	–0.0266*
YEAR_2005	–0.0624***	–0.0625***
YEAR_2006	–0.0384***	–0.0385***
YEAR_2007	–0.0229*	–0.0210*
Property		
SIZE	0.0131***	0.0131***
SIZESQ	–0.000009***	–0.000009***
AGE	–0.0129***	–0.0128***
AGESQ	0.000097***	0.000097***
ROOMS	0.0271***	0.0275***
GARAGE	0.0340***	0.0329***
BALCONY	0.0559***	0.0564***
TERRACE	0.0448***	0.0427***
KITCHEN	0.0446***	0.0415***
POOL	0.0345	0.0329
FIREPLACE	0.0119	0.0129
GOODCOND	0.0514***	0.0520***
BADCOND	–0.1040***	–0.1056***
Neighbourhood		
ELDERLYPOP	–0.0032***	–0.0033***
INCOME	0.0033***	0.0028***
FOREIGNPOP	–0.0055***	–0.0049***
SOCHOUSE	–0.0001**	–0.0001**
Access		
DISTCENT x CBD	–0.0545	–0.0543
DISTCENT x B_CENT	–0.0161**	–0.0158**
DISTCENT x C_CENT	–0.0361***	–0.0394***
EMPGRAV	0.000002***	0.000002***
DISTWATER	–0.0091***	–0.0095***
DISTPARK	–0.0342***	–0.0367***
BUS_NUMBER	0.0013	0.0014
Noise exposure / visual disamenities		
WIDEROAD	–0.0489***	–0.0498***
ROADNOISESQ	–0.000019***	–0.000020***
AIRNOISE	–0.0012***	–0.0014***
RAILNOISE	–0.0011***	–0.0011***
DISTIND	0.0156	0.0144

Table IV.2 (continued)

	Basic model	Model with interactives
Station Accessibility		
DISTSTAT_250	0.0178	–0.0355
DISTSTAT_250_750	0.0455**	0.0155
DISTSTAT_750_1250	0.0236	0.0092
DISTSTAT_1250_1750	0.0138	0.0042
DISTSTAT_250 x UNDERGR		0.0445*
DISTSTAT_250_750 x UNDERGR		0.0020
DISTSTAT_750_1250 x UNDERGR		–0.0051
DISTSTAT_1250_1750 x UNDERGR		0.0534
DISTSTAT_250 x HIGHINC		0.0655***
DISTSTAT_250_750 x HIGHINC		0.0526***
DISTSTAT_750_1250 x HIGHINC		0.0261
DISTSTAT_1250_1750 x HIGHINC		0.0114
Spatial lag term	YES	YES
Number of observations	4,832	4,832
White's correction	YES	YES
R^2	0.87286	0.87357
Adjusted R^2	0.87180	0.87230

Notes: The endogenous variable is the natural log of the last listing price of property. All models include yearly dummy variables. * indicates significance at the 10% level; ** indicates significance at the 5% level; *** indicates significance at the 1% level.

5.1 Control variables

The coefficients estimated for *SIZE* and *SIZESQ* show the expected positive, but less than proportional effect of property size on condominium prices. On the basis of the regressors *AGE* and *AGESQ*, we find a quadratic influence for the property's age, with the lowest prices for condominiums that are 66 years old. Regarding the other condominium's physical characteristics, only a generally bad condition of the property (*BADCOND*) has a negative effect on property prices.[25]

The effects of the proportion of the population with non-German passport as well as the proportion of those aged 65 and older on property prices are significantly negative. The relation-

[25] Following Halvorsen and Palmquist (1980), the coefficients of dummy variables used in the semi-log form were transformed by (e^a – 1), where *a* is the OLS coefficient.

ship between medium income in the statistical district (*INCOME*) and condominium prices is positive and statistically highly significant. While we do not observe any significant price premiums when the nearest central location is downtown (*DISTCENT x CBD*), the price-distance gradient is the steepest for C centres (*DISTCENT x C_CENT*). This is plausible insofar as there are few shopping opportunities for daily goods in the inner city, unlike in the B and C centres, but instead mostly clothing and electronics stores. Since the average resident rarely seeks out such goods, he or she tends to be less willing to pay a premium for a short route. The different results for B and C centres could be due to the fact that the B centres are located primarily in densely populated neighbourhoods where numerous retail shops with goods for daily needs are to be found even outside the central locations. Outside the predominantly peripheral C centres, however, there is likely to be significantly less retail space, which makes proximity to these centres an attractive aspect. While proximity to jobs, represented by *EMPGRAV*, is seen as positive, all variables that measure distance from local amenities have the expected negative signs. All the variables that capture noise or visual disturbances exhibit significant coefficients. If a flat, for example, is exposed to road noise of 75 dB(A) – as is the case in close proximity to heavy traffic road sections – its price will be discounted by approx. 4.5% compared to a flat with an average noise level of 57 dB(A). The variable *BUS_NUMBER* is not significantly different from zero.

5.2 Impact of railway stations[26]

Basic model results (Model 2.1) and sensitivity analysis

Our results show that it is attractive for residents to live near, but not in immediate proximity to, railway stations. Compared to properties that are located at a distance of more than 1,750m to the next station, condo prices rise with decreasing distance between 1,750 and 750m insignificantly at first, but then rise significantly coupled with maximum premiums of

[26] Since for both models the results are independent of whether the lag term is included or not, we do not adjust our estimates for spatial correlation (Andersson, Jonsson, and Ögren 2010).

4.6% in a radius of 250-750m to the nearest station. In immediate proximity to a station (≤ 250m), the premiums are not significantly different from zero. As Fig. IV.3 illustrates, a linear price-distance trend with a *t*-value of –3.190 would be significant, but would underestimate the premiums for properties in a radius of 250-750m and overestimate the premiums in the immediate vicinity of a station. The rail access premiums calculated by us are lower than those determined by most of the previous studies that have examined the effect of access to railway stations on residential property prices. Debrezion, Pels, and Rietveld (2006), for example, have identified premiums of up to 32.3% for residential properties near train stations in the Netherlands. In suburban locations of Chicago McMillen and McDonald (2004) have observed discounts of up to 19.4% for each mile that a property is located further away from a station. Grass (1992) has shown premiums in Washington, DC, of up to 38% for locations near train stations. In principle, (our) lower coefficients could be due to the generally high level of accessibility in the Hamburg area compared to the areas in other studies.[27] It should also be pointed out that the other studies mentioned control only for a few location and accessibility indicators.[28] As a result, the coefficients mapping access to train stations each represent all the location and accessibility criteria which are not controlled for.

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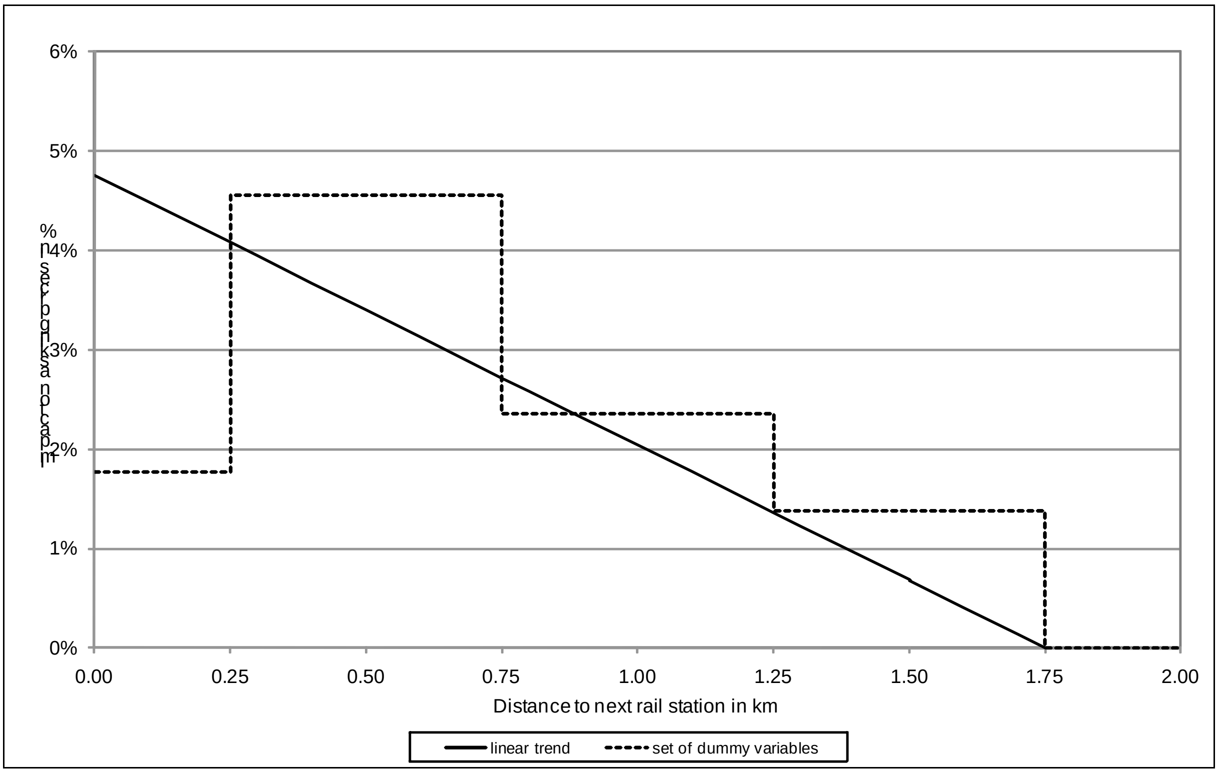
[27] We owe this comment to an anonymous referee.

[28] Debrezion, Pels, and Rietveld (2006) only consider the distance to railway tracks and the nearest motorway junction, McMillen and McDonald (2004) control for the distance to railway tracks and to CBD, and Grass (1992) only considers the distance to the CBD.

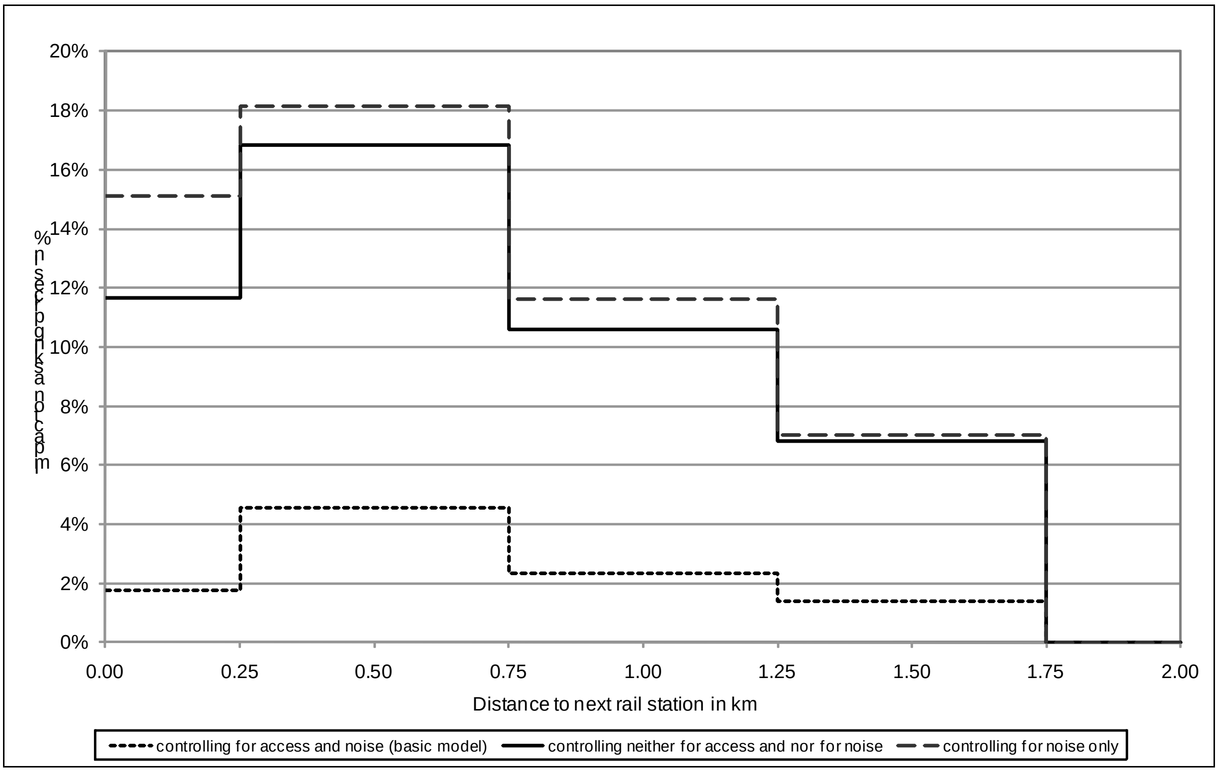
Fig. IV.3 Linear price-distance trend vs. set of dummy variables



Remark: Reference group of dummy variables are station distances > 1,750m. Dummy variable coefficients for distances ≤ 250m and > 750m are insignificant.

To be more specific, Fig. IV.4 indicates that higher coefficients in other studies may be biased if determinants are neglected that are correlated with access to train stations. In Fig. IV.4, the dotted line represents the coefficients calculated for the base model for access to train stations, of which, as mentioned above, only the coefficient for distances of 250-750m to the next station is significant. The black solid line shows estimates that would result for Model 2.1 if the vectors *ACCESS* and *NOISE_VIS_DIS* from Eq. IV.2 were excluded. All coefficients are significant and, depending on the distance to the nearest train station, are 5.4% to 12.3% higher than the coefficients calculated on the basis of Eq. IV.2. This can be explained by the fact that the vector *DISTSTAT* now represents all the location-specific factors. Since positive accessibility effects appear to weigh more strongly than negative externalities, higher price premiums are observed than for the basic model. If the vector *NOISE_VIS_DIS* is again added to Eq. IV.2, we obtain the coefficients shown by the dashed line (see Fig. IV.4). All regressors are significant and take on even higher values, as they now represent exclusively positive effects, namely, accessibility (*ACCESS*) and access to train stations (*DISTSTAT*). While the distance between the x-axis and dotted line can be interpreted as a price premium for access to train stations, the distance between the dotted and dashed line must be seen as a premium for other accessibility factors. The gap between the black and dashed line, however, can be interpreted as a price discount for noise exposure, which is highest in immediate proximity to train stations. Keeping in mind that stations are often located near busy roads or intersections, this result is plausible. That the influence of train stations, calculated from Eq. IV.2 and illustrated by the dotted line, is ultimately also a net effect, namely accessibility less negative externalities in the form of vibration, noise and visual nuisance, is borne out by the fact that the price premiums in the immediate vicinity of train stations, where the negative effects are strongest, are lower than for distances between 250m and 750m to the next station.

Fig. IV.4 Results with and without controlling for location-related variables



Remark: Reference group of dummy variables are station distances > 1,750m. Basic model coefficients for distances ≤ 250m and > 750m are insignificant. All other coefficients are statistically significant.

Results for model with interactives (Model 2.2)

The coefficients established for Model 2.2 indicate that prices for condominiums in the immediate vicinity (≤ 250m) of underground stations (*DISTSTAT_250 x UNDERGR*) are higher by 4.5% than for properties within a radius of 250m around above-ground stations. For longer distances, there are no significant price differences between above-ground and underground stations. This result is plausible insofar as the negative effects of stations decrease with increasing distance. Furthermore, the coefficients of the vector *DISTSTAT x HIGHINC* for distances of up to 750m are significantly positive and exhibit premiums that are up to 6.6% higher for access to stations in upper-income neighbourhoods (as compared to lower-income areas). Two opposing effects determine the impact of income on the price-distance gradient in the vicinity of stations. On the one hand, German households adjust their modal split, due to the well-developed public transport system, to their income situation more closely than, say, American households, which are often forced by the spatial structure of many metropolitan regions to rely on the car as a means of transport (Kim 2003). In Germany, lower-income households use mass transit more often than households with above-average incomes. This would suggest that access to railway infrastructure in residential areas with below-average income is valued higher. Our results, similar to those obtained by Bowes and Ihlanfeldt (2001), suggest that among the households that use public transit as a means of transport, potential time savings from good access to train stations are valued higher by high-income households. This is also evidenced by the fact that price premiums in upper-income neighbourhoods are significantly higher only for locations with good accessibility of train stations (at distances of up to 750m) compared to neighbourhoods with lower incomes.

Aggregated price effects of access to railway stations

As mentioned above, the possibility of additional tax revenues resulting from higher residential property prices in the vicinity of stations has so far been excluded from the discussion on the financing of public transport. For the estimation of additional tax revenues (*Δ TAX*) we use again the list of all addresses in Hamburg. For each address in Hamburg, we have calculated the corresponding urban district and, using GIS, the distance to the nearest railway station. Consequently, we determined for each urban district *i* the share of addresses per distance contour $PROP_{ic}$:

$$\Delta TAX = TAXRATE \times PROPSOLD \times \left(\sum_i \sum_c \mu_c \times V_{ic} \right) \text{ with} \qquad \text{(IV.6)}$$

$$V_{ic} = PROP_{ic} \times \left(\sum_u P_{iu} \times N_{iu} \right), u = 1, 2; i = 1,...,103; c = 1,...,4; \mu_c = 0, \textit{ if } \mu_c \textit{ is insignificant.}$$

The value of the residential properties per urban district and distance contour was then estimated by multiplying for each urban district *i* the average sales prices per type of use P_{iu} with the number of residential units per type of use N_{iu} and then summing them up via the types of use *u*. We obtain V_{ic} by multiplying this term by the share of addresses per distance contour $PROP_{ic}$.[29] Then we calculated for each urban district the price increases of properties due to access to train stations by multiplying V_{ic} with the significant coefficient μ_c from Model 2.1. For all 103 urban districts *i* the aggregate price increases resulting from access to stations amount to a total of EUR 2.33 billion.[30] If one considers that the purchase of a property in Hamburg is subject to a land transfer tax (*TAXRATE*) in the amount of 4.5% of the assessed value, which generally corresponds to the sales price, and if one further considers that every year about 4% of the residential properties are sold (*PROPSOLD*), proximity to train stations

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[29] Both the district data on average sales prices and the number of residential units per type of use were obtained from the Statistics Office of Hamburg (2009). We use the sales price data because our sample does not contain offer prices for all urban districts. We differentiate the types of use according to condominiums as well as single- and two-family houses.

[30] The method presented here implies some assumptions: In addition to an unsystematic distribution of residential and commercial properties over the area of the city of Hamburg, the transferability of the premiums for condominiums is also assumed for single- and two-family homes. Against the background of the aforementioned polycentric distribution of jobs, it is likely that the first assumption has been met at least approximately. Potential biases due to the transfer of the results for condominiums on to single- and two-family houses are minimised not least by the fact that single- and two-family houses account for only about 21% of all residential units in Hamburg (Statistikamt 2009).

increases the annual revenue from land transfer taxes in Hamburg (*Δ TAX*) by around EUR 4.20 million.[31] This calculation is a conservative figure for the effects of train stations on public revenues because some land is publicly owned. If some of this land is sold by public authorities, it would yield revenues.[32]

6 Conclusions

Using a hedonic approach, we show that access to local railway stations is priced by the housing market also in continental European cities like Hamburg. For condominiums close, but not too close to stations, we find premiums of approx. 4.6%. Furthermore, we observe significantly higher premiums for underground stops located in close proximity to a station. Our results also demonstrate that access to train stations is valued higher by residents with higher incomes. We also show that it is necessary, for a reliable estimate of access to stations, to control for potentially correlated variables such as accessibility indicators and noise pollution measures. We estimate that the gains in value of residential properties in Hamburg resulting from access to train stations amount to EUR 2.33 billion. The additional annual revenues from land transfer taxes due to such value increases come to about EUR 4.20 million.

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[31] Furthermore, good access to train stations may also increase the rent of a residential property (e.g., Benjamin and Sirmans 1996) and thus the taxable income of the landlord.

[32] We owe this idea to an anonymous referee.

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V The impact of rail access on condominium prices in Hamburg – Supplementary notes

1 Data collection and descriptive statistics of data

Using digital maps, every train station of the public transit system was initially identified in Hamburg and in the near surroundings of Hamburg. The following data were collected for each of these 141 stations on the basis of the maps:

1) Longitude and latitude
2) City district where the station is located
3) Existence of Park&Ride spaces at the station, and
4) Whether a station is located underground.

Based on a Hamburg Transit (HVV) route map, the rail network to which each station belonged was determined. The number of bus and train lines serving each station, as well as the number of departures per hour and direction, were obtained from the HVV website. Using MS MapPoint, MileCharter and MS Access, the nearest train station was allocated to each property's coordinates.

Table V.1 shows the distribution of the 4,832 residential properties under review across the four distance rings around the train stations. Accordingly, approx. half of all properties of the portfolio under review are located within a radius of more than 250m, but not more than 750m, around the train stations, that is, the area for which significant price premiums have been observed. The table also shows that the nearest station for approx. one in four condominiums is located underground and that, according to the variable definition of *HIGHINC*, half the properties are located in a neighborhood with higher incomes.

Table V.1 Properties located within distance rings around rail stations

Distance rings	DISTSTAT		DISTSTAT x UNDERGR		DISTSTAT x HIGHINC	
	Number	Proportion	Number	Proportion	Number	Proportion
DISTSTAT_250	434	9.0%	174	3.6%	202	4.2%
DISTSTAT_250_750	2,419	50.1%	816	16.9%	1,064	22.0%
DISTSTAT_750_1250	1,197	24.8%	172	3.6%	655	13.6%
DISTSTAT_1250_1750	511	10.6%	44	0.9%	343	7.1%
DISTSTAT_1750+	271	5.6%	37	0.8%	151	3.1%
Total	4,832	100.0%	1,243	25.7%	2,415	50.0%

2 Empirical methodology

Dealing with the subway line U4 currently under construction and the planned light rail (as of: 02.10.2011)

The paper does not deal with the potential influences on the study design and results exerted by the subway line U4 currently under construction and the planned light-rail system. The following account, thus, provides additional information on the study methodology described in the paper.

In December 2004, the city senate approved the current routing of the subway line U4 that has been under construction since August 3, 2007. The completion of the 4-km long line has been scheduled for September 2012 (Hochbahn 2011). At that time, the new city district "Hafencity" will be connected to the subway system of the City of Hamburg via the newly-built stations "Überseequartier" and "Hafencity Universität". An expansion of U4 to the south is still being debated, which could then go through the city districts Veddel and Wilhelmsburg and on to Harburg (Kossel 2010).

Upon completion of U4 to the station "Hafencity Universität" in the fall 2012, the distance from the nearest station will be reduced for eleven of the 4,832 condominiums of the portfolio under review. The two new U4 stations, however, were not considered for the study (study period 2nd quarter 2002 to first quarter 2008). As McMillen and McDonald (2004) have shown for Chicago's Midway Line, residential property prices can anticipate a new train line long before its completion.[1] The eleven properties with improved access to train stations were all offered for sale in 2007. It is thus possible that the reduced distance from the nearest station is already reflected in the property prices, which could lead to biased estimates.

A closer look at the data reveals that the eleven properties with improved access to the rail network will still be located within the same distance rings following the opening of the U4 line, but then around a new station. For ten properties, however, the nearest station is then underground, rather than above-ground. Consequently, the model with interactives was estimated again, but now in consideration of the two new U4 stations. The estimated coefficients differ from the results presented in Section IV.5 only minimally; all significance levels are identical. Given the minor deviations the results are not presented. The small number of affected properties made it also impossible to employ an intertemporal approach to examine the influence of the new U4 line (cf., e.g., Gibbons and Machin 2005).

As well, the expansion of the U4 line to the south must be kept in mind. However, since the expansion does not currently have a majority yet (press office of the city senate – Pressestelle des Senats 2010), which leaves the time of a possible opening in doubt, the influence of the expansion of the U4 line beyond the "Hafencity Universität" station was not studied.

The potential influence of the planned new light-rail system also requires further discussion. With a predicted average speed of approx. 23 kph[2], the planned light rail is about 3 kph faster than Hamburg buses. But it is considerably slower than the city trains (S-Bahn) and subway trains (U-Bahn) as well as motorized private transport (cf. Section IV.1). Thus, potential time savings for the light-rail are smaller than for the other rail-based transportation sys-

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[1] According to McMillen and McDonald (2004), residential property prices respond to improved public transit access as early as six years prior to the completion of a new rail line.

[2] Referring to the first construction phase from Bramfeld Dorfplatz to the subway at Kellinghusenstraße (Straßenbahn-Hamburg.de 2011); an expected average speed has not been published for other track sections.

tems in Hamburg, which, *ceteris paribus*, gives rise to the expectation that the light rail will affect residential property prices to a lesser degree.

The CDU, having had a majority government in Hamburg between October 2001 and March 2011, initially spoke up against the construction of a light-rail system in Hamburg. It was not until the coalition agreement between the CDU and GAL on April 17, 2008, that the introduction of a light-rail system was specified (Koalitionsvertrag 2008). On September 18, 2008, the Hamburg Office for Urban Development and the Environment presented its first draft of the planned rail system (BSU 2008). The current First Mayor of the City of Hamburg, Olaf Scholz, however, said on March 23, 2011, that the planning for the light rail was to be suspended and that the bus system ought to be expanded instead (Carini and Veit 2011).

Given the minor time savings of the light-rail system and due to the fact that a political expression of will regarding the introduction of a light-rail system was not issued until after the end of the study period, and that the planned route map was not released until a later point of time, the planned light-rail system was excluded from further examinations.

Influence of income on the effect of access to train stations

The effect that the average income of a neighborhood has on how residents assess access to public transit has been examined in the literature a few times, but with contradictory results (cf. Section IV.2). The findings on the effects of other externalities, such as noise or view, however, are clearer; deviations only concern the estimated intensity of the effect and not its direction. As a result, the influence of the socio-demographic factor income was looked at in more detail in the paper.

3 Results

For Models 2.1 and 2.2, the model adjustments also resulted in an increase in the adjusted R^2 by around 0.1 percentage points (see Table V.2). The coefficients of the station accessibility variables remain largely unchanged. In Model 2.1, the influence of *DISTSTAT_250_750* remains significant at the 5% level, with the coefficient rising by 0.0003. All other regressors capturing station accessibility continue to be insignificant. In Model 2.2, too, the coefficients of the station accessibility variables remain largely unchanged. The interactive *DISTSTAT_250 x UNDERGR*, however, is decreased by 0.0058 to 0.0387 and, with a *t*-value of 1.3607, is no longer significant at conventional levels. The effect of train stations on residential property prices for underground stations is, thus, not significantly different from the influence of above-ground train stations. *DISTSTAT_250 x UNDERGR*, thus, seems less robust with respect to changes to model assumptions than, say, *DISTSTAT_250 x HIGHINC*

Table V.2 Results

	Basic model *(Model 2.1)*	Model with interactives *(Model 2.2)*
CONSTANT	8.2534***	8.3416***
TOM	–0.0001***	–0.0001***
AUTOREG	0.2209***	0.2166***
YEAR_2002	–0.0480*	–0.0463*
YEAR_2003	–0.0025	–0.0041
YEAR_2004	–0.0328**	–0.0341**
YEAR_2005	–0.0669***	–0.0674***
YEAR_2006	–0.0400***	–0.0404***
YEAR_2007	–0.0245*	–0.0231*
QUARTER_1	0.0005	–0.0005
QUARTER_2	0.0162	0.0137
QUARTER_3	0.0091	0.0087
Property		
SIZE	0.0132***	0.0131***
SIZESQ	–0.000009***	–0.000009***
AGE	–0.0128***	–0.0128***
AGESQ	0.000096***	0.000096***
ROOMS	0.0265**	0.0269**
GARAGE	0.0320***	0.0309***
BALCONY	0.0531***	0.0537***
TERRACE	0.0453***	0.0434***
KITCHEN	0.0412***	0.0380***
POOL	0.0330	0.0321
FIREPLACE	0.0102	0.0116
GOODCOND	0.0507***	0.0511***
BADCOND	–0.1057***	–0.1073***
Neighbourhood		
ELDERLYPOP	–0.0035***	–0.0035***
INCOME	0.0034***	0.0029***
FOREIGNPOP	–0.0057***	–0.0050***
SOCHOUSE	–0.0001*	–0.0001*

Table V.2 (continued)

	Basic model *(Model 2.1)*	Model with interactives *(Model 2.2)*
Access		
DISTCENT x CBD	–0.0498	–0.0496
DISTCENT x B_CENT	–0.0142*	–0.0141*
DISTCENT x C_CENT	–0.0320***	–0.0358***
EMPGRAV	0.000001***	0.000001***
DISTWATER	–0.0094***	–0.0096***
DISTPARK	–0.0320***	–0.0349***
DISTSCH	0.1852***	0.1862***
DISTSCHSQ	–0.1617***	–0.1627***
DISTPOW_100	0.0355	0.0307
DISTPOW_100_200	0.0475**	0.0419*
DISTPOW_200_400	0.0245	0.0173
DISTPOW_400_600	0.0120	0.0037
DISTPOW_600_1000	0.0027	–0.0051
BUS_NUMBER	0.0011	0.0012
Noise exposure / visual disamenities		
WIDEROAD	–0.0478***	–0.0495***
ROADNOISESQ	–0.000019***	–0.000019***
AIRNOISE	–0.0012***	–0.0014***
RAILNOISE	–0.0011***	–0.0011***
DISTIND	0.0186*	0.0172*
DISTCPBS_100	–0.0106	–0.0125
DISTCPBS_100_200	0.0087	0.0073
Station Accessibility		
DISTSTAT_250	0.0122	–0.0382
DISTSTAT_250_750	0.0458**	0.0152
DISTSTAT_750_1250	0.0260	0.0138
DISTSTAT_1250_1750	0.0198	0.0181
DISTSTAT_250 x UNDERGR		0.0387
DISTSTAT_250_750 x UNDERGR		0.0000
DISTSTAT_750_1250 x UNDERGR		–0.0096
DISTSTAT_1250_1750 x UNDERGR		0.0487
DISTSTAT_250 x HIGHINC		0.0646**
DISTSTAT_250_750 x HIGHINC		0.0550***
DISTSTAT_750_1250 x HIGHINC		0.0234
DISTSTAT_1250_1750 x HIGHINC		0.0006
Spatial lag term	YES	YES
Number of observations	4,832	4,832
White's correction	YES	YES
R^2	0.87420	0.87491
Adjusted R^2	0.87280	0.87331

Notes: The endogenous variable is the natural log of the last listing price of property. * indicates significance at the 10% level; ** indicates significance at the 5% level; *** indicates significance at the 1% level.

or *DISTSTAT_250_750 x HIGHINC.* The coefficient of *DISTSTAT_250 x HIGHINC* has decreased by 0.0009 and is thus significant only at the 5% level. But the price premiums for good access to train stations are significantly higher in neighborhoods with higher incomes than in areas with lower income, even on the basis of the adjusted model specifications. That households with higher incomes value good access to train stations higher could also be due to the fact that employees with better incomes often work in the CBD where many financial service providers and consultancies are domiciled. The CBD is well accessible via public transit from almost all city districts, which is why people who work there may place a premium on living in proximity to train stations. The often-tight traffic and parking situation in the CBD may also contribute to public transit's popularity over driving.

Most of the studies conducted so far have found a positive effect of public transit train stations on adjacent residential property prices. This is documented by Table V.3, which summarizes the results of current studies on this subject. The comparison with results of previous studies shows that the price premiums observed in Hamburg are at the lower end of the range of previously reported premiums. But the effects demonstrated in Hamburg are also on a smaller scale. Both these aspects may be due to the dense rail-based public transit system in Hamburg, as well as the primarily urban location of the residential properties. While most of the previous studies examined the influence of commuter rail lines on the basis of single-family house prices in the suburbs of metropolises, where distances to be covered are typically greater, 59.1% of the condominiums in Hamburg studied are located no more than 750m from the nearest train station (cf. Table V.1).

Table V.3 Results of previous hedonic studies on the effects of rail transit access

Year and author(s)	Study region	Data	Valuation method	Results
2008, Agostini and Palmucci	Santiago, Chile	Transaction data of 6,804 residential properties	Before-after-comparison, difference-in-difference	Price premiums of 4.2% to 7.9% after announcement of construction; premiums of 3.1% to 5.5% after identification of station location
2006, Armstrong and Rodríguez	Boston metropolitan area, Massachusetts, USA	Transaction data of 1,806 single-family properties	Cross-sectional	Weak evidence of premiums of 10.1% within 0.5 miles around stations and a decrease of 1.6% in property values for an additional minute of drive time from next station
2006, Debrezion, Pels, and Rietveld	Netherlands	Transaction data of 663,024 dwellings	Cross-sectional	Dwellings that are located very close to a rail station sell on average at price premiums of 25%. A doubling of train frequency leads to an increase of housing values of 1.3% to 3.5%
2005, Gibbons and Machin	London, UK	Transaction data of 15,943 residential properties	Difference-in-difference, cross-sectional,	Difference-in-difference and/or cross-sectional: Discount of 2.1% and/or 8.5% following a 1km increase of distance to next station (within impact area of 2km)
2004, McMillen and McDonald	Chicago, Illinois, USA	Transaction data of 17,034 single-family properties	Hedonic index, repeat-sales regression	Hedonic index: House price gradient changed from –4.2% to –19,4% after opening for each additional mile from the nearest station. Repeat-sales: identical results
2004, Lin and Hwang	Taipeh, Taiwan	Transaction data of 317 residential properties	Before-after-comparison	Price premiums of approx. 20% after opening of a new line
2001, Bowes and Ihlanfeldt	Atlanta region, Georgia, USA	Transaction data of 22,388 single-family properties	Cross-sectional	Price discounts of 18.7% within 0.25 miles to next station; price premiums of 3.5% for distances of 1 to 3 miles

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Sebastian Brandt & Wolfgang Maennig

VI Perceived externalities of cell phone base stations – The case of property prices in Hamburg, Germany

Abstract: We examine the impact of cell phone base stations on prices of condominiums in Hamburg, Germany. This is the first hedonic study on this subject for housing prices in Europe and the first ever to examine the price impact of base stations within a whole metropolis. We distinguish between individual masts and groups of masts. Based on a dataset of over 1,000 base stations set up in Hamburg, we find that only immediate proximity to groups of antenna masts is perceived as harmful by residents of nearby condominiums. For individual masts, however, no effect on residential property prices in the surrounding areas has been observed indicating that cell phone service providers should prevent installation of groups of masts in a single location. We control for spatial dependence and show that the influence of cell phone base stations on adjacent residential property prices can be overestimated, if other negative externalities that are typically correlated with the proximity to base stations are neglected.

Keywords: Cell phone base stations, externalities, residential property prices, Hamburg
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1 Introduction

Mobile phone accessibility is perceived by most citizens as a gain in quality of life. For many business people not being reachable at any time – including outside their offices – is unimaginable in day-to-day business. Mobile telephony is one of the fastest growing sectors; in 2009, worldwide turnover amounted to about $803 billion (Handelsblatt 2009). To ensure comprehensive network connections, cell phone service providers have set up cell phone base stations (CPBS) in over 68,000 locations in Germany in the last two decades, with 1,343 locations in the territory of the City of Hamburg (Federal Network Agency 2010).

The transmission of mobile phone conversations produces high-frequency, electromagnetic radiation, which is at its highest near mobile phone masts. However, there is no scientifically unambiguous assessment of the effect of electromagnetic fields (EMFs) on the human body yet.[1] As a result, possible consequences of cellular phone radiation continue to be at the center of controversial debate. In general, CPBS are a source of uncertainty among tenants, experts and banks and in the past have been at the root of many court disputes resulting in a variety of outcomes. Some biased information and conflict situations enhanced by the media also contribute to such uncertainty (Bobka 2004). Those affected also include the owners of residential property, who fear for their rental income and property values. Property owners often find themselves in a predicament. Since owners are not shielded against the construction of cell phone antennas on adjacent properties, even if they withhold their consent, it is likely that antennas may often be installed on properties whose owners take a critical view of the cell phone technology but still receive at least rental income from cell phone service providers. Given the horizontal direction of radiation from most antennas, a cell phone transmitter on an adjacent property could also result in higher radiation levels on the property whose owners have objected to the erection of a CPBS on their land. The measurement of discounts on housing prices triggered by antenna masts, however, is seen as significant also by people outside this group of investors: The discounts can be viewed as an unbiased measure of the negative externalities of CPBS perceived by economic agents, which may help render the controversy more objective.

Against this background it is remarkable that the influence of CPBS on the prices of adjacent properties has been given such scant attention in scholarly studies. The few surveys and/or contingent valuation studies conducted have determined a devastating effect of CPBS on residential property prices. Eighty-nine percent of the questionnaires returned by the households surveyed by Bond and Beamish (2005) in Christchurch, New Zealand, indicated that they would buy or rent their residential property only at a discount if a cell phone mast were to be erected in the neighborhood, with approx. 34% of the respondents quantifying such price discounts as ranging from –10% to –19% or –20% and greater reduction in price/rent.

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[1] For a review of the possible health risks in connection with high-frequency, electromagnetic fields, see, for example, Ahlbom et al. (2009) and ICNIRP (2009).

Hedonic studies on the influence of CPBS on residential property prices have so far been provided by Bond (2007) as well as Bond and Wang (2005).[2] Bond and Wang (2005) observed for suburbs of Christchurch, New Zealand, insignificant results or value increases of 12% in two neighborhoods near base stations set up in 1994. After the construction of two CPBS in 2000, however, the authors noticed discounts of approx. 20% on the prices of adjacent residential properties. The authors concluded that the divergent results could be connected to the negative media attention in the area in the late 1990s regarding possible health risks in the vicinity of CPBS. Accordingly, property buyers were not sufficiently aware of potential health hazards until the construction of the masts in 2000, which had not been there at the time the base stations were built in 1994.

Analyzing the prices of single-family homes in Orange County, Florida, over the period between 1990 and 2000, Bond (2007) observed value decreases of 2% for properties within a radius of 200m from newly-built CPBS. While Bond and Wang (2005) introduce street name dummies, Bond (2007) incorporates Cartesian object coordinates as metric variables. It is possible that value-influencing location attributes such as access to infrastructure, water and green areas or the impact of traffic noise may not be captured, which can lead to biased coefficients. In another study on the impact of CPBS, Banfi, Filippini, and Horehájová (2008) examine apartment rents in Zurich, Switzerland, and find discounts of 1.8% within a radius of 200m around CPBS.

We study the price structure of condominiums in Hamburg, Germany, that were offered for sale a few years after the population had been made aware of the possible health hazards

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[2] Over the past decades studies on the effects of externalities have frequently relied on hedonic approaches. The impact on residential property prices has in recent years been analyzed using the hedonic pricing technique, e.g., for urban attraction (e.g., Osland and Thorsen 2008), a good view (e.g., Bourassa, Hoesli, and Sun 2004), traffic noise (e.g., Andersson, Jonsson, and Ögren 2010), air and (drinking) water pollution (e.g., Kim, Phipps, and Anselin 2003; Poor, Pessagno, and Paul 2007) and high-voltage power lines (e.g., Des Rosiers 2002; Sims and Dent 2005) and environmental hazards (e.g., Daniel, Florax, and Rietveld 2009).

stemming from EMFs in the years around the turn of the millennium. This way any temporary reactions in residential property prices in the vicinity of CPBS may be excluded. This study is the first hedonic paper on the effect of CPBS on residential property prices in Europe and the first for an entire metropolitan region. Based on detailed data on 1,034 locations of cell phone base stations in Hamburg – a number that no other study has been based on before – we were able to investigate the price-distance relation between CPBS and residential properties in the vicinity of such masts. In addition we are able to discuss

- whether the type, appearance and height of buildings on which CPBS are erected cause negative externalities themselves and
- how the impact of CPBS changes when we control for type, appearance and height of buildings on which CPBS are erected.

To the best of our knowledge, these issues have not been discussed anywhere else to date.

Section 2 describes the data on which the study is based. Section 3 introduces the empirical models that were used to examine the impact of CPBS on surrounding residential property prices. Section 4 describes the results. A final conclusion is presented in section 5.

2 Data

Most housing price studies rely on sales prices for single- and two-family homes. We depart from this approach by using prices of condominiums, which make up the largest share of transactions involving residential properties in Hamburg (Committee of Valuation Experts in Hamburg 2008) and by using listing prices instead of sales prices. Using list prices may cause problems if the difference between the offer and transaction price is correlated with a condominium's physical characteristic or groups of characteristics.

In a working paper, Williams (1995) analyses the prices of single-family homes in Queensland, Australia. By using linear functional forms two separate regressions are estimated, once on the basis of offer prices and, once on the basis of sales prices. In both equations the same coefficients are statistically significant, and all significant coefficients in both equations have the same sign. However, the coefficients of two variables differ from each other significantly.[3] As for the remaining 16 significant variables, the coefficient pairs do not deviate from each other by more than 12%. Merlo and Ortalo-Magné (2004) and Knight (2002, 2008) study the influence of market imperfections on transaction prices, such as the influence of time-on-market. If we observed a correlation between time-on-market and distance to the closest CPBS with respect to our dataset, an unsystematic variance of the difference between listing and sales prices in relation to the distance to the closest CPBS would, thus, be doubtful. In our case, the Pearson correlation coefficient for time-on-market and distance to next CPBS, however, is small (–0.012) and insignificant at conventional levels. For the condominium market in Hamburg, where the average differential between listing and transaction prices is approximately 8%, no systematic variance of this difference for properties of different age, size or price category has been observed (F+B 2002). To our knowledge, there have not been any further studies on the influence that property characteristics have on the difference between offer and transaction prices. Since we use semi-logarithmic forms, which reflect relative – and not absolute – changes in property prices for an additional unit of a characteristic, the offer prices should yield unbiased coefficients.

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[3] In the regression that uses the sales price as a dependent variable, a tiled roof, as opposed to an iron roof, is valuated at A$4,800, while the regression where the offer price is the dependent variable arrives at a price premium of A$6,300. In addition, the coefficient of *SIZE* calculated on the basis of the offer prices exceeds the coefficient calculated on the basis of the sales prices by approximately 20%.

Table VI.1 Variable names, definitions and summary statistics

Variable	Definition	Mean	Std. dev.
Dependent variable			
PRICE	Last asking price of property	185,520	159,474
Property			
TOM	Time-on-market in days	89.31	149.84
SIZE	Living area in square meters	80.24	45.03
AGE	Age of property in years	38.88	35.51
ROOMS	Number of rooms	2.75	1.74
GARAGE	1 if property has a garage, 0 otherwise	0.52	0.50
BALCONY	1 if property has a balcony, 0 otherwise	0.82	0.39
TERRACE	1 if property has a terrace, 0 otherwise	0.76	0.43
KITCHEN	1 if property has a built-in kitchen, 0 otherwise	0.65	0.48
POOL	1 if property has a pool, 0 otherwise	0.02	0.15
FIREPLACE	1 if property has a fireplace, 0 otherwise	0.04	0.21
GOODCOND	1 if property is in good condition, 0 otherwise	0.13	0.34
BADCOND	1 if property is in bad condition, 0 otherwise	0.06	0.23
Neighborhood			
ELDERLYPOP	Proportion of population in census tract that is 65 years or older	19.21	6.73
INCOME	Mean income of population in census tract (in 1,000 €)	34.34	14.44
FOREIGNPOP	Proportion of foreign population in census tract	13.19	6.80
SOCHOUSE	Number of social housing units per 1,000 inhabitants in census tract	42.25	61.80
Access			
DISTCENT	Distance to next sub center according to zoning plan (in kilometers)	1.18	0.81
EMPGRAV	District proximity to employment (measured by a gravity variable)	145,196	43,749
DISTSTAT_250	1 if distance to next metro station ≤ 250m, 0 otherwise	0.09	0.28
DISTSTAT_250_750	1 if distance to next metro station > 250m and ≤ 750m, 0 otherwise	0.48	0.50
DISTSTAT_750_1250	1 if distance to next metro station > 750m and ≤ 1,250m, 0 otherwise	0.25	0.44
DISTSTAT_1250_1750	1 if distance to next metro station > 1,250m and ≤ 1,750m, 0 otherwise	0.12	0.33
DISTWATER	Distance to closest of the bodies of water Elbe and Binnen-/Aussenalster (in kilometers)	4.72	3.64
DISTPARK	Distance to next park, forest or nature protection area (in kilometers)	0.70	0.51
Noise / visual disamenities			
WIDEROAD	1 if property is located on a wide road (with at least two lanes per driving direction), 0 otherwise	0.09	0.28
ROADNOISE	Road noise in dB(A) as measured by a L_{DEN} index	56.89	11.64
AIRNOISE	Air noise in dB(A) as measured by a L_{DEN} index if property is located within noise protection zone 2 (≥ 67 dB(A)) or 3 (≥ 62 dB(A)) around Hamburg Airport, 0 otherwise	1.99	10.42
RAILNOISE	Rail noise in dB(A) as measured by a L_{DEN} index if property is located in the vicinity of rail tracks, 0 otherwise	8.96	20.57
DISTIND	Distance to next industrial area (in kilometers)	0.55	0.45

Table VI.1 (continued)

Variable	Definition	Mean	Std. dev.
CPBS			
DISTCPBS_100	1 if distance to next CPBS ≤ 100m, 0 otherwise	0.11	0.31
DISTCPBS_100_200	1 if distance to next CPBS > 100m and ≤ 200m, 0 otherwise	0.27	0.45
SMALL_CPBS	1 if height of next CPBS is 5m or less as defined using aerial photography, 0 otherwise	0.17	0.37
BIG_CPBS	1 if height of next CPBS is more than 5m as defined using aerial photography, 0 otherwise	0.24	0.43
GROUP_CPBS	1 if next CPBS consists of more than one antenna as defined using aerial photography, 0 otherwise	0.59	0.49
MULTISTOREY	1 if next CPBS is located on multi-storey building (at least 7 storeys), 0 otherwise	0.26	0.44
MAST	1 if next CPBS is located on a freestanding mast as defined in column (6) of Table VI.4, 0 otherwise	0.08	0.28
BADVIEW	1 if next CPBS is located on building / construction as defined in column (7) of Table VI.4, 0 otherwise	0.17	0.38
NOISYNEIGH	1 if next CPBS is located on building / construction as defined in column (8) of Table VI.4, 0 otherwise	0.17	0.38

The study area comprises the entire city of Hamburg, which has an area of 755.2km² and at the end of the study period a population of 1.767 million (March 31, 2008). Hamburg is the second largest city in Germany, both in terms of its area and population. The primary source of data for this study is a dataset supplied by F+B GmbH that contains 6,332 listing prices for condominiums in Hamburg that were put up for sale on Internet portals between April 1, 2002, and March 31, 2008. All datasets contain information on the year of construction, size of the condominium, listing price and date, time-on-market in days as well as the complete address of the property. In addition, information on the characteristics of the condominiums was extracted from the portals. Using a directory supplied by the Hamburg Office for Urban Development and the Environment (BSU), each address was allocated to one of the 938 statistical districts of Hamburg. A statistical district is the smallest statistical unit for which the Statistics Office of Hamburg collects demographic and socioeconomic population data. All population data refer to the year in which the property was offered for sale most recently. The information regarding average income, however, was available only for 1995. In addition, we used GIS to calculate distances between properties and public infrastructure (such as train stations, schools, kindergartens and shopping), bodies of water, green spaces and jobs. BSU has supplied us with further small-scale datasets on the noise pollution caused by road, air and rail traffic for the area of Hamburg, so that we were able to determine property-specific noise pollution levels in dB(A).

The BSU has also supplied us with a dataset for all 1,034[4] locations known to the authorities where CPBS were set up that required a permit[5] within the territory of the City of Hamburg. Among other attributes the dataset includes the Cartesian coordinates of the CPBS. All coordinates were checked by the authors using aerial photography and supplemented to include data on the location as well as the type of base station. Each property was assigned the nearest CPBS on the basis of GIS.

We have limited our analysis to condominiums that were offered for sale after December 31, 2004, because the number of CPBS remained virtually constant after that date according to information received from BSU in Hamburg. We have also excluded properties for which the exact location and design of the nearest CPBS could not be identified clearly by means of aerial photography. This reduces the initial dataset from 6332 to 4348 observations. CPBS installed in church towers or subway ducts (see Table VI.4 in the appendix) are invisible to residents and usually unknown to interested buyers, which is why they can be expected to have no influence on property prices in the surrounding areas. Therefore, such CPBS were excluded from the evaluations.

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[4] The deviation in the number of antenna locations according to BSU from the 1,343 locations reported by the Federal Network Agency (2010) is caused by the following, according to BSU: The statistics of the Federal Network Agency capture all locations for which a permit has been issued. The Federal Network Agency, however, does not follow up to check whether a CPBS was actually built in each location or whether a CPBS still exists. Nor can it be ruled out that not all CPBS have been reported to BSU.

[5] In Germany, CPBS are subject to approval that have a transmitting power of 10 watts EIRP (equivalent isotropically radiated power) or more and that generate electromagnetic fields in the frequency range of 10 to 300,000 MHz (26. BImSchV [German Federal Immission Control Act]).

Descriptive statistics of the variables included in the final model specifications are listed in Table VI.1. The mean property price is €185,520 with a standard deviation of €159,474. The relatively high standard deviation can be explained by the heterogeneity of the housing stock, which is also confirmed by the high standard deviation for the variables *SIZE* and *AGE*. Another reason is the small-scale housing market in Hamburg that we consider by controlling for a rich set of location and neighborhood attributes. The mean time-on-market is approximately three months. Descriptive statistics also show that 38% of the properties are located within the impact area (at distances of up to 200 m) around CPBS. For the majority of the condominiums (59%) the next CPBS consists of a group of antennas.

3 Empirical methodology

Since their advantage of allowing for non-linearity effects as well as intuitive interpretation of coefficients housing price studies commonly rely on semi-logarithmic functional forms. In recent years, authors have tended to use flexible forms such as the Box-Cox transformation (Box and Cox 1964). But, so far, the literature has not overcome the problems of implementing flexible functional forms in the presence of spatial dependence (Kim, Phipps, and Anselin 2003). As we consider spatial lag terms in our models described below we use semi-logarithmic functional forms for our analysis.

Model 3.1

In Model 3.1 we use a hedonic approach that takes into account property and neighborhood characteristics, accessibility and noise indicators as well as proximity to CPBS. For the semi-logarithmic form, Model 3.1 can be written as:

$$\begin{aligned}\ln(P) &= \alpha + \beta\, PROP + \gamma\, NEIGH + \delta\, ACCESS + \eta\, NOISE\_VIS\_DIS + \theta\, AUTOREG \\ &\quad + \lambda\, TREND + \mu\, DIST\_CPBS + \varepsilon\,,\end{aligned} \tag{VI.1}$$

where α, β, γ, δ, η, θ, λ and μ are representing the set of coefficients to be estimated and ε is an error term. *PROP* is a vector capturing the property characteristics, including information regarding age and size – that we have considered in both linear form and with an additional quadratic term (e.g., Voith 1993) – as well as dummy variables for the property's physical attributes and a measure that captures the time-on-market. In selecting the variables, we rely on Sirmans, Macpherson, and Zietz (2005) and Wilhelmsson (2000), who evaluated the control variables most commonly used in hedonic studies. Since Sirmans, Macpherson, and Zietz (2005) and Wilhelmsson (2000) primarily used studies on U.S. housing markets in their analyses, it seemed meaningful for an analysis of a German market to differ in some respects. Given that Hamburg in Northern Germany has a moderate climate even in the summer, which essentially negates the use of air-conditioning for residential property, we have decided to drop this control variable. In contrast to the North-American housing markets, which are dominated mostly by single-family homes, the characteristics *BALCONY* and *KITCHEN* can have a considerable impact on the value of German condominiums. *NEIGH* is a vector of neighborhood characteristics, consisting of the proportion of those aged 65 and older (*ELDERLYPOP*: e.g., Ahlfeldt and Maennig 2009, 2010), the average income (*INCOME*: e.g., Andersson, Shyr, and Fu 2010), the proportion of foreign population (*FOREIGNPOP*: e.g., Theebe 2004) as well as the number of social housing units per 1,000 inhabitants (*SOCHOUSE*: e.g., Gibbons and Machin 2005).

Access to jobs is measured by a gravity variable (Bowes and Ihlanfeldt 2001), which captures the distance between the city district where the condominium is located and the jobs located in the metropolitan area of Hamburg. This applies to all 103 districts of Hamburg as well as the 307 surrounding communities in the metropolitan region of Hamburg:

$$EMPGRAV_i = \sum_j \frac{Emp_j}{d_{ij}} \qquad , d_{ii} = \frac{1}{3}\sqrt{\frac{area_i}{\Pi}} \, , \tag{VI.2}$$

where *Emp* represents all jobs subject to social insurance contributions in a city district or in one of the surrounding communities. *j* stands for all city districts and communities other than *i*, and d_{ij} is the distance between the centroids of *i* and *j*. Since some of the city districts cover relatively large areas, we also take into account a district-internal distance measure d_{ii} (e.g., Crafts 2005). In order to avoid overestimation of Emp_j and/or Emp_i, we did not allow d_{ij} and/or d_{ii} to take on values smaller than 1. Preliminary regressions suggested that access to public transport network (e.g., Baum-Snow and Kahn 2000) is best measured by a set of dummy variables (*DISTSTAT_250*, *DISTSTAT_250_750*, *DISTSTAT_750_1250* and *DISTSTAT_1250_1750*) that capture distance contours around railway stations. Proximity to shopping and recreation facilities has been captured by the distance to (sub-)centers (*DISTCENT*) according to the zoning plan of Hamburg (BSU 2003). These 35 locations are characterized by a differentiated supply of everyday goods as well as bars, restaurants, cinemas, etc., despite a scarcity of space. Indicating access to recreation we considered the distance from the closest green space (*DISTPARK*: e.g., Baranzini and Ramirez 2005) as well as from the nearest bodies of water (Inner and Outer Alster Lake and Elbe River, *DISTWATER*: e.g., Gibbons and Machin 2005). *ACCESS* is thus a vector to map the previously discussed accessibility indicators.

NOISE_VIS_DIS is a vector that, in addition to noise pollution in the entry and exit lanes of the Hamburg Airport (*AIRNOISE*: e.g., McMillen 2004), also takes into account noise and visual nuisances stemming from road traffic (*ROADNOISESQ*, *WIDEROAD*: e.g., Wilhelmsson 2000) as well as railway noise near railway tracks (*RAILNOISE*: e.g., Day, Bateman, and Lake 2007) and that captures the distance to industrial sites (*DISTIND*: e.g., Li and Brown 1980). By introducing a spatial lag term (*AUTOREG*) we assume that listing prices also depend on the prices of properties previously put up for sale in the neighborhood (Ahlfeldt and Maennig 2009, 2010). Owing to the nature of listing prices, which are generally guided by neighboring property prices, we favor the spatial lag model over the spatial error model, which assumes that spatial autocorrelation emerges from omitted variables that follow a spatial pattern (Kim, Phipps, and Anselin 2003). This is confirmed by the results of global tests[6] for spatial dependence that are shown in Table VI.2. Based on the results of Moran's I test, we can reject the possibility that there is no spatial dependence. From the results of the Lagrange multiplier tests, we conclude that our data are best described by the spatial lag model.

Table VI.2 Results of tests for spatial dependence

	Statistic	MI/DF	*p*-value
Spatial error			
Moran's I	37.9	0.274	0.000
Lagrange multiplier	1,334.1	1	0.000
Robust Lagrange multiplier	169.9	1	0.000
Spatial lag			
Lagrange multiplier	1,376.4	1	0.000
Robust Lagrange multiplier	212.1	1	0.000

Notes: MI, Moran's I test-value; DF, degrees of freedom in the Lagrange multiplier test. Results are based on a row-standardized inverse distance weight matrix; the critical distance is 1 km.

For condominium *i* the value of the lag term is equivalent to the prices weighted by $w_{ij} = (1/d_{ij}) / \Sigma_j 1/d_{ij}$ of the surrounding *j* summed-up apartments, when $1/d_{ij}$ is the reciprocal distance between the condominiums *i* and *j* (Can and Megbolugbe 1997):

$$AUTOREG_i = \sum_j \frac{(1/d_{ij})}{\sum_j 1/d_{ij}} P_{j,t-m}\,, \quad m=1,\ldots,12;\; j=1,\ldots,N;\; d_{ij} \le 1\,km\,. \tag{VI.3}$$

Can and Megbolugbe (1997) consider properties within a radius of 3 kilometers. However, their study area covers a large-area suburban county in the metropolitan region of Miami. Regarding the small-scale housing market in Hamburg, it is reasonable to assume that the offer price of a condominium is affected only by prices of properties that are located in the immediate vicinity. However, we computed *AUTOREG* using various critical distances (0.5, 0.75, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 7.5 and 10.0km) and found the best fit of the model when we

[6] Salvi (2008) discusses more detailed empirical strategies on the choice of the spatial models.

considered properties within a radius of 1km. In contrast to Can and Megbolugbe (1997), who take into account surrounding properties if they were sold in the previous six months, we believe, given the relatively low volatility of the condominium market in Hamburg during the study period, that it is reasonable to include properties in the neighborhood that were offered for sale within the previous 12 months. The dummy variables representing the most recent year and the most recent season in which a property was offered for sale are captured by the vector *TREND*.

DISTCPBS is a vector of two dummy variables that each take the value 1 when the property's distance to the nearest CPBS amounts to up to 100m (*DISTCPBS_100*) or over 100m and up to 200m (*DISTCPBS_100_200*); otherwise, the value is 0. According to Banfi, Filippini, and Horehájová (2008) and Bond (2007), we define our external cutoff as 200m. In contrast to the suburban region analyzed by Bond (2007), the development of a major city like Hamburg is higher and more dense. In Hamburg, CPBS are primarily set up on buildings where they are less likely to be noticed by residents than would be the case in a suburban area, where CPBS are mostly installed on freestanding masts due to the smaller height of buildings. Since the radius of potential price discounts in the vicinity of base stations in Hamburg might therefore be smaller, a distance of 100m was selected as a second (internal) cutoff. Land on which a CPBS has been installed might be subject to price premiums due to the rent to be paid by cell phone service providers. Throughout preliminary studies we have examined this aspect by introducing a dummy variable *CPBS_ON_ROOF* that takes the value 1 if there is a CPBS on the roof of a building that contains a condominium; otherwise, the value is 0. Since coefficients of *CPBS_ON_ROOF*, however, were insignificant for all of our models, this variable was excluded from the final model specifications. Similar to the results of Bond (2007), we expect to find price discounts for condominiums in the vicinity of base stations. However, given the relatively inconspicuous antenna installations in an urban setting, the price effects could also turn out to be insignificant.

Model 3.2

In Model 3.2 we take into account the fact that no two CPBS are identical as, for example, the number of antenna masts per CPBS can differ considerably. A group of antenna masts distributed across the entire rooftop of a building could trigger higher price discounts than a single mast. Whether an antenna is fairly small and inconspicuous or whether it is a rather large construction to which several smaller antennas are installed could also make a difference. In order to study the influence of CPBS in a differentiated manner based on their physical appearance, we have defined Model 3.2 as follows:

$$\begin{aligned}\ln(P) = {} & \alpha + \beta\, PROP + \gamma\, NEIGH + \delta\, ACCESS + \eta\, NOISE\_VIS\_DIS + \theta\, AUTOREG \\ & + \lambda\, TREND + \mu\, DIST\_CPBS + \sigma\, DIST\_CPBS \times STRUCTURE + \varepsilon\,,\end{aligned} \tag{VI.4}$$

where *DISTCPBS* is additionally multiplied by the vector *STRUCTURE*, which represents the dummy variables defined in Table VI.1, *SMALL_CPBS*, *BIG_CPBS* and *GROUP_CPBS*, whose sum adds up to 1 for each dataset. For example, the interactive *DISTCPBS_100* x *GROUP_CPBS* takes the value 1 for properties within a radius of 100m from such CPBS which consist of a group of antennas; otherwise, the value is 0 (see Table VI.1). μ and σ are vectors of the coefficients to be estimated. The coefficient of the interactive *DISTCPBS_100* x *GROUP_CPBS* indicates, for example, the price differential of properties within a radius of 100m around a group of antennas compared to properties that are located more than 200m from a CPBS. All other terms in Eq. VI.4 have the meanings already explained for Model 3.1.

Model 3.3

Since CPBS are frequently set up on high-rise apartment buildings, commercial buildings, chimneys or freestanding masts (see Table VI.4 in the appendix), potential price discounts in the vicinity of CPBS – at least partially – could be due to visual or noise pollution originating from the buildings or structures on which they are installed. In order to differentiate for the influence of CPBS as well as for the impact of visual or noise pollution, we introduce further interactives, rendering Model 3.3 as follows:

$$\ln(P) = \alpha + \beta\ PROP + \gamma\ NEIGH + \delta\ ACCESS + \eta\ NOISE\_VIS\_DIS + \theta\ AUTOREG \\ + \lambda\ TREND + \mu\ DIST\_CPBS + \sigma\ DIST\_CPBS \times STRUCTURE \\ + \omega\ DIST\_CPBS \times LOCATION + \varepsilon, \quad \text{(VI.5)}$$

where the vector *DISTCPBS* is additionally multiplied by *LOCATION*, a vector of the dummy variables defined in Table VI.1 and Table VI.4, *MULTISTOREY*, *MAST*, *BADVIEW* and *NOISYNEIGH*. In this context, 100m and/or 200m are also plausible cutoffs to capture visual and noise pollution. The sum of the variables *MULTISTOREY*, *MAST*, *BADVIEW* and *NOISYNEIGH* does not have to amount to 1. The coefficient of the interactive *DISTCPBS_100* x *MAST* thus indicates, for example, the price differential of properties within a radius of 100m around a freestanding cell phone mast compared to properties that are up to 100m from a non-freestanding mast. μ, σ and ω are vectors of the coefficients to be estimated. All other terms in Eq. VI.5 have been described previously.

4 Results

Since White's test rejects homoscedasticity for all models, the standard errors were corrected using White's Correction. Around 87.3% of the variance of listing prices can be explained by the hedonic pricing models used (Table VI.3). This is an average value when compared to other hedonic housing price studies that control for spatial dependence. All control variables have the expected signs and are predominantly highly significant, yielding values that are plausible also in terms of their amounts.

Table VI.3 Results

	Model 3.1	Model 3.2	Model 3.3
CONSTANT	8.5521***	8.5474***	8.5687***
Property			
TOM	–0.000112***	–0.000113***	–0.000112***
SIZE	0.0131***	0.0131***	0.0131***
SIZESQ	–0.000009***	–0.000009***	–0.000009***
AGE	–0.0131***	–0.0130***	–0.0131***
AGESQ	0.0001***	0.0001***	0.0001***
ROOMS	0.0269*	0.0269*	0.0271*
GARAGE	0.0360***	0.0364***	0.0365***
BALCONY	0.0395***	0.0397***	0.0402***
TERRACE	0.0430***	0.0422***	0.0411***
KITCHEN	0.0469***	0.0466***	0.0461***
POOL	0.0363	0.0350	0.0342
FIREPLACE	0.0151	0.0115	0.0105
GOODCOND	0.0401***	0.0403***	0.0421***
BADCOND	–0.1101***	–0.1096***	–0.1096***
Neighborhood			
ELDERLYPOP	–0.0030***	–0.0028***	–0.0027***
INCOME	0.0030***	0.0030***	0.0030***
FOREIGNPOP	–0.0051***	–0.0049***	–0.0048***
SOCHOUSE	–0.0001*	–0.0001*	–0.0001*
Accessibility			
DISTCENT	–0.0181***	–0.0172***	–0.0159***
EMPGRAV	0.000002***	0.000002***	0.000002***
DISTSTAT_250	–0.0036	–0.0032	–0.0056
DISTSTAT_250_750	0.0360*	0.0377**	0.0399**
DISTSTAT_750_1250	0.0102	0.0090	0.0097
DISTSTAT_1250_1750	0.0092	0.0081	0.0099
DISTWATER	–0.0066***	–0.0067***	–0.0073***
DISTPARK	–0.0551***	–0.0525***	–0.0514***
Noise exposure / visual disamenities			
WIDEROAD	–0.0241	–0.0239	–0.0226
ROADNOISESQ	–0.000021***	–0.000021***	–0.000020***
AIRNOISE	–0.0015***	–0.0015***	–0.0015***
RAILNOISE	–0.0014***	–0.0014***	–0.0013***
DISTIND	0.0168*	0.0178*	0.0184*

Table VI.3 (continued)

	Model 3.1	Model 3.2	Model 3.3
CPBS			
DISTCPBS_100	–0.0227*		
DISTCPBS_100_200	–0.0135		
DISTCPBS_100 x SMALL_CPBS		0.0262	0.0280
DISTCPBS_100_200 x SMALL_CPBS		–0.0081	0.0088
DISTCPBS_100 x BIG_CPBS		0.0051	0.0073
DISTCPBS_100_200 x BIG_CPBS		–0.0049	0.0210
DISTCPBS_100 x GROUP_CPBS		–0.0567***	–0.0519**
DISTCPBS_100_200 x GROUP_CPBS		–0.0183*	0.0133
DISTCPBS_100 x MULTISTOREY			–0.0560***
DISTCPBS_100_200 x MULTISTOREY			–0.0076
DISTCPBS_100 x MAST			0.0258
DISTCPBS_100_200 x MAST			–0.0204
DISTCPBS_100 x BADVIEW			–0.0473**
DISTCPBS_100_200 x BADVIEW			0.0352
DISTCPBS_100 x NOISYNEIGH			–0.0271
DISTCPBS_100_200 x NOISYNEIGH			–0.0082
Spatial lag term	YES	YES	YES
Number of observations	4,348	4,348	4,348
White's correction	YES	YES	YES
R^2	0.87429	0.87466	0.87524
Adjusted R^2	0.87312	0.87338	0.87373

Notes: The endogenous variable is the natural log of the last listing price of property. All models include yearly and seasonal dummy variables. * indicates significance at the 10% level; ** indicates significance at the 5% level; *** indicates significance at the 1% level.

Control variables

Following Halvorsen and Palmquist (1980), the coefficients of dummy variables used in the semi-log form were transformed by (e^a – 1), where *a* is the estimated coefficient. Listing prices are slightly lower the longer a property is on the market. The coefficients estimated for *SIZE* and *SIZESQ* show the expected positive, but less than proportional effect of property size on condominium prices. On the basis of the regressors *AGE* and *AGESQ*, we find a quadratic influence for the property's age, with the lowest prices for condominiums that are 65.5 years old. Regarding the other condominium's physical characteristics, only a generally bad condition of the property (*BADCOND*) has a negative effect on condominium prices. Among the neighborhood variables only the relationship between average income (*INCOME*) and condominium prices is positive. All other coefficients of neighborhood indicators show negative signs. While only properties within 250m to 750m distance to the next railway station (*DISTSTAT_250_750*) experience a premium compared to housing units that are located at a distance of more than 1,750m to the next station, coefficients of all other variables that measure distance from local amenities have the expected negative signs. Furthermore, access to jobs, measured by *EMPGRAV*, is seen as positive. While condominiums located next to a major road (*WIDEROAD*) do not experience any price discounts, the coefficients of all traffic-noise indices (*ROADNOISESQ*, *AIRNOISE*, *RAILNOISE*) are negative and statistically highly significant.

Impact of CPBS

The significantly negative coefficient of *DISTCPBS_100* in Model 3.1 shows price discounts in the amount of 2.3% within a radius of 100m around CPBS (compared to properties that are located at a distance of more than 200m from the nearest CPBS). For distances of more than 100m and up to 200m around base stations (*DISTCPBS_100_200*) we do not observe any significant price discounts. CPBS in a metropolis like Hamburg, where they are mostly installed on top of buildings, are obviously perceived as less intrusive by residents than they would be by the residents in suburban or rural areas. Consequently, moderate price discounts in the immediate vicinity of base stations that quickly diminish with increasing distance are plausible.

A more subtle picture on the influence of CPBS on residential property prices in Hamburg emerges from the results for Model 3.2. The coefficients of the interactives show that the only CPBSs which have a negative impact on the prices of adjacent residential properties are those which consist of a group of antenna masts. For distances of up to 100m and/or within a radius of 100m to 200m around groups of antenna masts (*DISTCPBS_100 x GROUP_CPBS* and/or *DISTCPBS_100_200 x GROUP_CPBS*) we observe condominium price discounts of 5.7% and/or 1.8% compared to properties that are located more than 200m from CPBS. In the vicinity of individual masts, however, we do not find any discounts, regardless of whether they are small or large. It seems that only the proximity to groups of antenna masts is perceived as harmful by the residents of nearby condominiums.

However, Model 3.3 shows that a portion of the price discounts in the vicinity of groups of masts can be attributed to the location where the masts have been installed. If the dummies for the distance contours are additionally interacted with the vector *LOCATION*, we observe slightly diminished discounts of 5.2% within a radius of 100m around groups of antenna masts (*DISTCPBS_100 x GROUP_CPBS*). The impact within 200m (*DISTCPBS_100_200 x GROUP_CPBS*) is, in fact, not significant. The regressors of the two interactives now represent price differences of properties within a radius of 100m and/or 100m to 200m around such groups of antennas that are not set up on high-rise buildings (*MULTISTOREY*) or freestanding masts (*MAST*), nor in noisy areas (*NOISYNEIGH*) or around locations exposed to a visual disamenity (*BADVIEW*), compared to properties that are more than 200m from a CPBS. In the immediate vicinity of base stations on high-rise buildings (*DISTCPBS_100 x MULTISTOREY*) and/or close to locations exposed to a visual disamenity (*DISTCPBS_100 x BADVIEW*), we observe further price discounts. These property price reductions amount to 5.6% and/or 4.7% when compared to properties at a distance of up to 100m from CPBSs not installed on high-rise buildings and/or in locations exposed to a visual disamenity. The proximity to high-rise buildings and a poor view in Hamburg has therefore a similarly impact on prices of adjacent residential properties as do (groups of) antennas.

5 Conclusions

Being the first hedonic study that examines the impact of cell phone base stations on residential property prices for a metropolis we find price discounts of 5.2% within a radius of 100m to groups of antenna masts for condominiums in Hamburg, Germany. Thus, the amount of price discounts is similar to discounts that we have observed in the immediate vicinity of high-rise buildings and/or properties with a poor view. However, we have not found any impact of individual antenna masts on the prices of nearby residential properties in Hamburg. Cell phone service providers should therefore avoid installation of groups of masts in a single location and, instead, opt for a more even spatial distribution of antenna masts.

Our findings can be transferred to rural areas only to a limited extent. Cell phone base stations are ubiquitously found in metropolitan areas and attract less attention, because they are mostly installed on rooftops, as opposed to peripheral areas, where most antennas are installed on freestanding masts.

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Appendix

Table VI.4 Location of CPBS and classification of variables *MAST*, *BADVIEW* and *NOISYNEIGH*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	City of Hamburg		Next to portfolio		Classification of dummies		
Location of CPBS	Number	Of which multi-storey	Number	Of which multi-storey	MAST	BAD-VIEW	NOISY-NEIGH
Arena	3	0	7	0			X
Bunker	7	0	97	0		X	
Education	14	2	44	2			X
Fair hall	4	0	0	0			X
Fire station	3	0	25	0			X
Freestanding mast	66	0	330	0	X		
Hospital	9	3	54	33			X
Hotel	15	5	55	10			
Industrial site	55	0	68	0		X	X
Logistics	12	0	5	0		X	X
Office	124	30	379	64			
Other com. use	114	0	470	0		X	X
Radio tower	4	0	35	0	X		
Residential use	398	162	2,614	1,043			
Retail	26	0	59	0			X
Smokestack	19	0	19	0		X	
Steeple	36	0	-	-		-	-
Swimming pool	1	0	1	0			X
Traffic infrastructure	13	0	13	0		X	X
Transmission line pylon	46	0	69	0		X	
Underground rail	48	0	-	-		-	-
Warehouse	5	0	4	0		X	
Wind farm	12	0	0	0		X	X
Total	1,034	202	4,348	1,152	2	9	12

VII Perceived externalities of cell phone base stations – The case of property prices in Hamburg, Germany – Supplementary notes

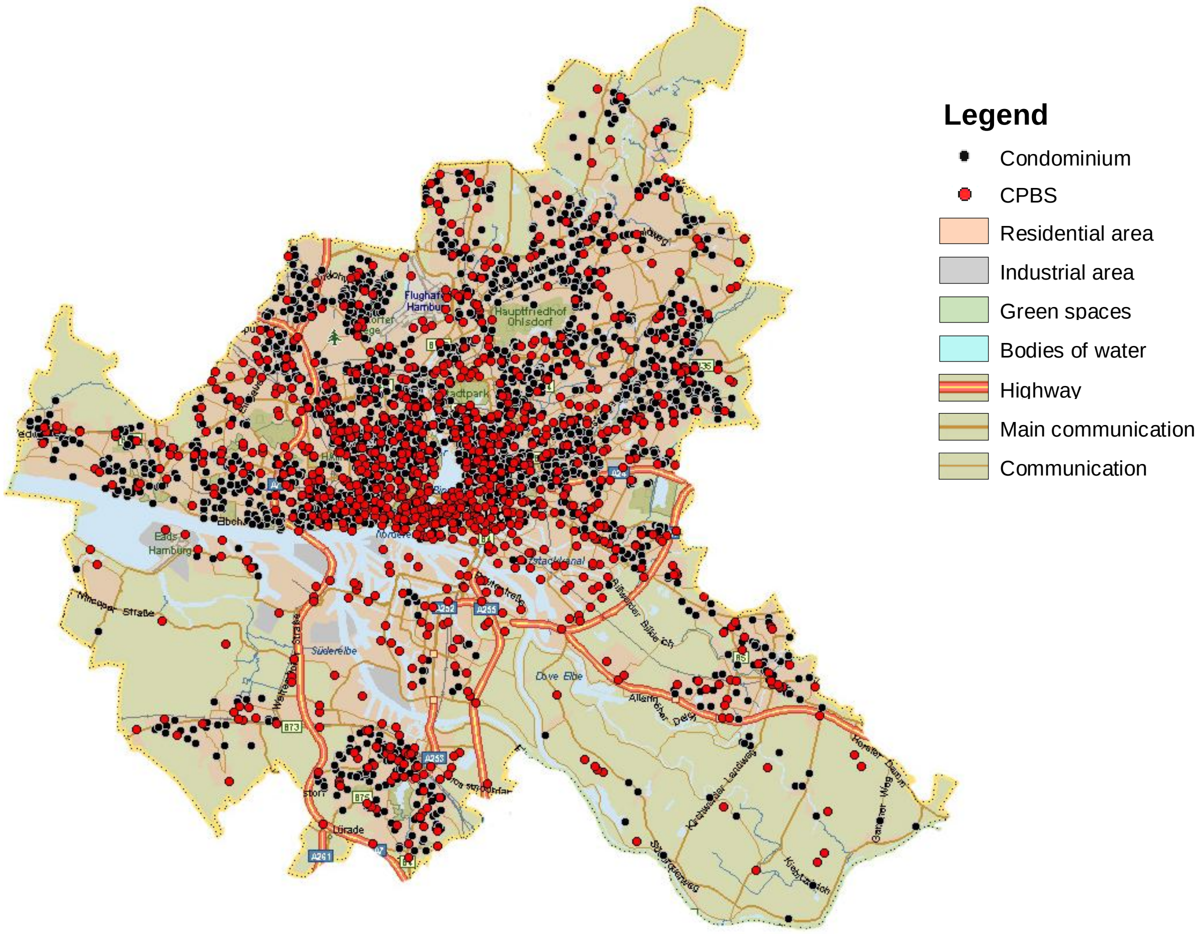
1 Data collection and descriptive statistics of data

BSU supplied a dataset containing the 1,034 cell phone base stations known to the authorities that are subject to approval. The Gauss-Krüger coordinates were at first converted to longitudes and latitudes using the software TRANSDAT Coordinate Transformations. Then, the locations of all cell towers were checked manually and corrected where necessary by means of digital maps. Using MS MapPoint, MileCharter and MS Access, the nearest CPBS was allocated to each property's coordinates.

In addition, the exact address was determined for each CPBS erected on a rooftop. For this, BSU also supplied a dataset containing the coordinates of all Hamburg addresses. Thus, all properties of the portfolio studied could be identified that have CPBS on the roof. Using the digital maps, the type of building and/or type of design were identified manually on which CPBS were erected. The appearance of antennas was also documented by way of aerial photography. A distinction was made between small (≤ 5m) and large (> 5m) antennas. CPBS installed on several masts were classified as *GROUP_CPBS*. Transmitters in subway shafts or on church spires were classified as not visible. CPBS that could not be classified clearly on the basis of digital aerial photography were excluded from further studies.

Fig. VII.1 shows the spatial distribution of CPBS as well as the condominiums studied across the territory of the City of Hamburg.

Fig. VII.1 Spatial distribution of condominiums and CPBS



In addition to the descriptive statistics in the paper (see Section VI, Table VI.1 and Table VI.4), Table VII.1 shows the distribution of the condominiums studied across the defined distance rings around CPBS. 38.4% of the properties are located no more than 200m from the nearest CPBS. The nearest CPBS for about 60% of the properties is a group of antennas.

Table VII.1 Proportion of properties located within distance rings around cell phone base stations

Distance rings	DISTCPBS	DISTCPBS x SMALL_CPBS	DISTCPBS x BIG_CPBS	DISTCPBS x GROUP_CPBS
DISTCPBS_100	11.0%	2.6%	2.8%	5.6%
DISTCPBS_100_200	27.4%	4.6%	7.5%	15.4%
DISTCPBS_200+	61.6%	9.7%	13.6%	38.2%
Total	100.0%	16.8%	23.9%	59.3%
Distance rings	DISTCPBS x MULTISTOREY	DISTCPBS x MAST	DISTCPBS x BADVIEW	DISTCPBS x NOISYHEIGH
DISTCPBS_100	4.0%	0.2%	0.6%	0.7%
DISTCPBS_100_200	7.2%	0.5%	4.0%	4.1%
DISTCPBS_200+	15.3%	7.7%	12.5%	12.4%
Total	26.5%	8.4%	17.1%	17.2%

2 Results

The changes to the model specifications of Models 3.1 - 3.3, again, have resulted in an increase of the adjusted R^2 by approx. 0.15 percentage points (see Table VII.2). The results presented in Section VI.4 generally also apply to the adjusted models. But when looked at in greater detail, there are deviations from the initial models. In Model 3.1, the coefficient of *DISTCPBS_100* increases by 0.0062 to –0.0165, and is thus no longer significant. By contrast, the coefficient of *DISTCPBS_100_200* decreases by 0.0022 and is now significant at the 10% level. Further tests were conducted to examine, on the basis of the variable *DISTCPBS_200_300*, whether the influence of CPBS exceeds the distance of 200m. But since condominium prices at distances between 200m and 300m from the nearest CPBS are not significantly different from prices at a distance > 300m, the impact area of 200m was maintained. In Models 3.2 and 3.3, the same coefficients remain significant that also showed significant relations for the initial models (cf. Section IV.4). The biggest change in value is in the coefficients *DISTCPBS_100 x BADVIEW* (from –0.0473 to –0.0571). In summary, it can be established that the CPBS variables are quite robust vis-à-vis the model adjustments made.

Table VII.2 Results

	Model 3.1	Model 3.2	Model 3.3
CONSTANT	8.5304***	8.5320***	8.5532***
TOM	–0.0001***	–0.0001***	–0.0001***
AUTOREG	0.1986***	0.1980***	0.1963***
YEAR_2005	–0.0573***	–0.0556***	–0.0530***
YEAR_2006	–0.0336**	–0.0319**	–0.0311**
YEAR_2007	–0.0221*	–0.0215*	–0.0203
QUARTER_1	–0.0063	–0.0043	–0.0042
QUARTER_2	0.0145	0.0154	0.0142
QUARTER_3	–0.0001	0.0014	–0.0003
Property			
SIZE	0.0131***	0.0131***	0.0131***
SIZESQ	–0.000009***	–0.000009***	–0.000009***
AGE	–0.0131***	–0.0131***	–0.0131***
AGESQ	0.000100***	0.000100***	0.000100***
ROOMS	0.0272*	0.0271*	0.0275*
GARAGE	0.0342***	0.0346***	0.0351***
BALCONY	0.0378***	0.0380***	0.0387***
TERRACE	0.0435***	0.0428***	0.0415***
KITCHEN	0.0459***	0.0455***	0.0450***
POOL	0.0398	0.0385	0.0373
FIREPLACE	0.0168	0.0135	0.0128
GOODCOND	0.0403***	0.0403***	0.0424***
BADCOND	–0.1076***	–0.1072***	–0.1074***
Neighborhood			
ELDERLYPOP	–0.0032***	–0.0030***	–0.0029***
INCOME	0.0032***	0.0032***	0.0032***
FOREIGNPOP	–0.0055***	–0.0053***	–0.0052***
SOCHOUSE	–0.0001	–0.0001	–0.0001
Accessibility			
DISTCENT x CBD	0.0206	0.0265	0.0108
DISTCENT x B_CENT	–0.0003	–0.0004	0.0023
DISTCENT x C_CENT	–0.0238***	–0.0228***	–0.0221***
EMPGRAV	0.000001***	0.000001***	0.000001***
DISTSTAT_250	0.0105	0.0101	0.0085
DISTSTAT_250_750	0.0537***	0.0538***	0.0582***
DISTSTAT_750_1250	0.0278	0.0255	0.0280
DISTSTAT_1250_1750	0.0235	0.0215	0.0247
DISTWATER	–0.0086***	–0.0086***	–0.0093***
DISTPARK	–0.0445***	–0.0425***	–0.0412***
DISTSCH	0.1273**	0.1157*	0.1160*
DISTSCHSQ	–0.1120*	–0.1031	–0.1048
DISTPOW_100	0.0723***	0.0706**	0.0776***
DISTPOW_100_200	0.0823***	0.0795***	0.0777***
DISTPOW_200_400	0.0433**	0.0411*	0.0400*
DISTPOW_400_600	0.0322	0.0286	0.0308
DISTPOW_600_1000	0.0380*	0.0375*	0.0380*

Table VII.2 (continued)

	Model 3.1	Model 3.2	Model 3.3
Noise exposure / visual disamenities			
WIDEROAD	–0.0252	–0.0250	–0.0239
ROADNOISESQ	–0.000021***	–0.000021***	–0.000021***
AIRNOISE	–0.0014***	–0.0014***	–0.0014***
RAILNOISE	–0.0014***	–0.0014***	–0.0014***
DISTIND	0.0216**	0.0218**	0.0232**
CPBS			
DISTCPBS_100	–0.0165		
DISTCPBS_100_200	–0.0157*		
DISTCPBS_100 x SMALL_CPBS		0.0279	0.0266
DISTCPBS_100_200 x SMALL_CPBS		–0.0079	0.0088
DISTCPBS_100 x BIG_CPBS		0.0067	0.0080
DISTCPBS_100_200 x BIG_CPBS		–0.0076	0.0193
DISTCPBS_100 x GROUP_CPBS		–0.0467**	–0.0462*
DISTCPBS_100_200 x GROUP_CPBS		–0.0209*	0.0104
DISTCPBS_100 x MULTISTOREY			–0.0557***
DISTCPBS_100_200 x MULTISTOREY			0.0005
DISTCPBS_100 x MAST			0.0352
DISTCPBS_100_200 x MAST			–0.0203
DISTCPBS_100 x BADVIEW			–0.0571**
DISTCPBS_100_200 x BADVIEW			0.0259
DISTCPBS_100 x NOISYNEIGH			–0.0210
DISTCPBS_100_200 x NOISYNEIGH			0.0008
Spatial lag term	YES	YES	YES
Number of observations	4,348	4,348	4,348
White's correction	YES	YES	YES
R^2	0.87562	0.87590	0.87652
Adjusted R^2	0.87420	0.87437	0.87476

Notes: The endogenous variable is the natural log of the last listing price of property. * indicates significance at the 10% level; ** indicates significance at the 5% level; *** indicates significance at the 1% level.

Table VII.3 summarizes the results of previous studies on the influence of CPBS on residential property prices. The results observed in Model 3.1 are comparable to the results based on hedonic pricing of Bond (2007) as well as Banfi, Filippine, and Horehájová (2008). The price discounts reported by Bond and Wang (2005), however, are significantly higher. But the findings of Bond and Wang (2005) could be biased due to insufficient controlling for spatial factors (cf. Section VI.1). The other empirical findings on the effect of CPBS on property prices are generally based on opinion surveys and/or contingent valuation. The results based on these methods are quite varied. Overall, the studies, though, seem to arrive at the same outcome that in close proximity of CPBS, the willingness to pay for residential property is lower.[1]

Table VII.3 Results of previous studies on the impact of cell phone towers on property prices

Year and author(s)	Study region	Data	Valuation method	Results
2008, Banfi, Filippini, and Horehájová	Zurich, Switzerland	6,204 apartment rents	Hedonic regression	In the profit submarket rents decrease by 1.8% when a CPBS is located within 200m. In the non-profit submarket no effects have been observed.
2007, Bond	Orange County, Florida, USA	Transaction data of 5,783 single-family properties	Hedonic regression	Erections of new CPBS reduce neighboring housing prices by 2%; effect diminishes beyond 200m.
2005, Bond and Wang	Christchurch (suburbs), New Zealand	Transaction data of 4,283 housing units	Hedonic regression	Price discounts of 20% in the vicinity of cell phone sites after media attention on potential health effects of cell phone systems. Prior to media publicity in close proximity to cell phone sites no significant effects have been observed.
2005, Bond and Wang, 2005 Bond and Beamish	Christchurch (suburbs), New Zealand	370 respondents	Opinion survey and contingent valuation among both residents affected and not affected by CPBS	For 79% and/or 93% of respondents (impact group and/or control group) willingness to pay is less for properties affected by cell phone sites ranging from 0% to -20% or less.
2005, Sims and Reed	4 study areas in the UK	161 respondents	Opinion survey and contingent valuation among both residents affected and not affected by CPBS	Health concerns and visual impact are the most frequently mentioned negative externalities of CPBS.
2004, Hughes & Associates	London, Ontario, Canada	Transaction prices of 362 side-split dwellings	Comparison of adjusted means of different distance contours around CPBS	Distance to communication tower has little or no influence on either the sales price or the marketability of the properties examined.
2004, Hughes & Associates	London, Ontario, Canada	256 respondents	Opinion survey among both residents affected and not affected by CPBS	18% of residents would be/are concerned of neighboring cell phone tower. 2% of residents thought that proximity of communication tower would decrease market value of their property.
2003, Bond et al.	Auckland, New Zealand	72 respondents	Opinion survey and contingent valuation among both residents affected and not affected by CPBS	For 50% of respondents willingness to pay is less for properties affected by nearby CPBS (ranging from 0% to -20% or less) with lower WTP for residents not exposed to CPBS.

[1] The weaknesses of opinion-based surveys and contingent valuation in the context of assessing environmental externalities are explained more thoroughly in Section I.2.

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VIII Do places of worship affect housing prices? Evidence from Germany *

Abstract: Using hedonic pricing models, this paper analyzes the impact of places of worship on the prices of adjacent condominiums in Hamburg, Germany. This is the first study on this subject to have been conducted outside the United States. It is also the first work to examine the externalities of places of worship of all five world religions. Furthermore, it is the first study that analyzes the effect of bell ringing on the adjacent residential property prices. Controlling for spatial dependence and by using potentiality variables positive externalities of places of worship within a radius of 1,000m were identified. Compared to properties beyond this threshold, price premiums of 4.8% were detected for condominiums at distances of 100m to 200m to the next place of worship. The results also show that the positive externalities near mosques do not differ from those of places of worship of other religions and that the positive effect of churches continues to be felt even after they have been deconsecrated. The influence of church bell ringing on the prices of surrounding residential properties, however, could not be substantiated.

Keywords: Hedonic pricing, places of worship, external effects, residential property prices, Hamburg
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1 Introduction

The fact that places of worship (POWs) create externalities is not disputed in the literature or by local residents. However, there is disagreement on whether the externalities are positive or negative. While Do, Wilbur, and Short (1994) have identified a negative effect of churches on adjacent residential property prices, Carroll, Clauretie, and Jensen (1996) find a positive effect of churches on the prices of nearby single-family houses. While complaints from local residents against liturgical ringing or the marking of time by bells keep the courts busy, the

* The author would like to thank F+B Forschung und Beratung für Wohnen, Immobilien und Umwelt GmbH, particularly Bernd Leutner, for providing the dataset on condominium prices in the city of Hamburg. The author would also like to thank numerous religious congregations in Hamburg for supplying information on their places of worship and the seminar participants at the University of Hamburg for their comments on earlier versions of this paper.

discussion on the construction of minarets and the muezzin's call have triggered political debates. Possible further negative externalities of places of worship, such as noise caused by the arrival or departure of visitors or through community and cultural events, as well as architectural disharmony with the surrounding buildings are also being considered (Do, Wilbur, and Short 1994). Possible positive externalities are visual amenities that originate in Hamburg from the many old churches built in the 19th century and the green belt that surrounds many of these places of worship. Other positive effects could be created by access to services, community events and recreational activities for the young and old (Carroll, Clauretie, and Jensen 1996; Do, Wilbur, and Short 1994), as well as by the reduction in crime rates (Lee and Ousey 2005).

The fact that residential property markets value externalities of churches has been confirmed on the basis of hedonic pricing only in a few studies on U.S. markets.[1] Do, Wilbur, and Short (1994) observed a negative influence of churches on the prices of neighboring single-family homes within a radius of approx. 850 feet in a community in the metropolitan region of San Diego, California. Maximum price discounts identified amount to 3.0%. These findings are contradicted by Carroll, Clauretie, and Jensen (1996), who found a positive influence of churches on the prices of single-family homes in the neighborhood in Henderson, Nevada, where the primary effect was felt at a distance of up to 2,910 feet. Properties that are only 100 feet, rather than 2,910 feet, from the nearest church experience price premiums of 3.1%. Bielefeld et al. (2006) observed price increases of 5.1% for residential properties in Marion County, Indiana, if they were located within a radius of one mile of at least four religious non-

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[1] However, over the past decades studies on the effects of externalities have commonly relied on the hedonic pricing technique. The impact on residential property prices has in recent years been analyzed using the hedonic framework, e.g., for air noise (e.g., Cohen and Coughlin 2009; McMillen 2004), road noise (e.g., Wilhelmsson 2000), rail noise (e.g., Clark 2006), (air) pollution (e.g., Decker, Nielsen, and Sindt 2005; Kim, Phipps, and Anselin 2003), rail transit stations (Bowes and Ihlanfeldt 2001), built heritage (e.g., Ahlfeldt and Maennig 2010) and school attributes (e.g., Clark and Herrin 2000).

profits. In Cleveland, Ohio, Ottensmann (2000) noted for census tracts with, or close to, a building of the Catholic diocese higher mean values of owner-occupied housing by 6.4%. One reason for the divergent results of different studies may lie in the different levels of religiosity of the local population.[2] The findings of Do, Wilbur, and Short (1994), which differ from other studies, could also be explained by methodological shortcomings of their study (for details, see Carroll, Clauretie, and Jensen (1996)). The author is not aware of studies on the externalities of places of worship other than churches.

Hamburg today is a cosmopolitan metropolis, where followers of all five world religions have settled and built their places of worship. Churches dating back to two construction periods characterize the cityscape of Hamburg. On the one hand, there are a large number of churches from the late 19th century and early 20th century, reflecting the quick economic development of the port city. Accordingly, four of the fifteen tallest churches in the world are located in Hamburg. On the other hand, the two post-war decades between 1950 and 1970 resulted in a number of churches being built in the city. Today, however, it is mostly Lutheran communities that now experience difficulty in paying the operating costs for their churches from their community budgets. This has to do with the high number of people leaving the Lutheran church in recent years and decades, resulting in lower revenue from the church tax, as well as with the increase in energy and maintenance costs of church buildings (Konerding 2007).[3] Consequently, as many as eleven Lutheran churches have been deconsecrated and then taken over by other denominations, rededicated or demolished (Ulrich 2010a). Numerous church buildings will likely meet the same fate in coming years (Benedict 2007).

After the Christians, Jews have lived the longest in Hamburg. The first arrived at the end of the 16th century (Bauche 1991). During Nazi rule, all synagogues in Hamburg were vandal-

[2] For a comparison of the proportion of regular churchgoers in U.S. states, cf. Newport (2010).

[3] Particularly the buildings of the two post-war decades constructed with concrete and its new structural possibilities show a high structural sensitivity (Konerding 2007), which necessitates high maintenance costs over the short and medium term.

ized and subsequently rededicated, torn down or destroyed in the war. In 1960, the reconstituted Jewish community opened a new – and to date, the only – synagogue in Hamburg. After the Jews came the Buddhists, who founded their first association in 1906 (den Hoet 2006). Today there are six temples in Hamburg, where followers of the different Buddhist schools congregate. The first mosque in Hamburg was built in 1957, followed by many others over the following decades. Of the more than fifty mosques in Hamburg, during the study period only three had a dome and/or minarets that clearly identified them as mosques to the outside world. Most mosques in Hamburg are housed in former commercial facilities or warehouses. The muezzin's call cannot be heard outside the Hamburg mosques. The last of the five world religions to settle in Hamburg were the Hindus in 1969 (Ulrich 2010a). They have set up two temples in former commercial facilities.

This study examines three current issues regarding the externalities of places of worship, which, to the authors` knowledge, have not been studied in the literature yet:

1) Against the background of the current political and social debate on the building of new minarets and the public call of the muezzin, the answer to the question whether mosques affect prices of adjacent residential properties differently than the places of worship of other religions could provide new stimulus for the debate.
2) In recent years, a number of churches have had to be closed down due to declining congregations. In light of the fact that more communities will have to abandon their church buildings in coming years (Benedict 2007), the question whether the externalities of buildings used for worship have different effects than deconsecrated church buildings was addressed. The answer to this question might be of useful help in deciding whether to tear down or rededicate a former church building.
3) Third, the question whether church bells affect the prices of residential properties was examined. The results can form the basis of a solution for some of the disputes being fought in court over bell ringing in residential areas.

Section 2 describes the data on which the study is based. Section 3 provides a description of the hedonic models used. The results are presented in Section 4. A summary and conclusion are provided in Section 5.

2 Data

Housing price studies widely rely on sales prices for single- and two-family homes. This paper departs from this approach by using prices of condominiums, which make up the largest share of transactions involving residential properties in Hamburg (Committee of Valuation Experts in Hamburg 2009) and by using listing prices instead of sales prices.[4] Using list prices may cause problems if the difference between the offer and transaction price is correlated with a condominium's physical characteristic or groups of characteristics.

Knight (2002) as well as Merlo and Ortalo-Magné (2004) show that the difference between offer and transaction prices is greater the longer a property is on the market. If I observed a correlation between time on market and distance to the closest place of worship, an unsystematic variance of the difference between listing and sales prices in relation to the distance to the closest place of worship would, thus, be doubtful. Here the Pearson correlation coefficient for time on market and distance to next place of worship, however, is small (0.015) and insignificant at conventional levels.[5] For the condominium market in Hamburg, where the average differential between listing and transaction prices is approx. 8%, no systematic variance of this difference for properties of different age, size or price category has been ob-

[4] In fact, in Germany a Committee of Valuation Experts that collects sales prices of housing units is located in every county. But in practice strict data protection regulations and high fees make it difficult to get access to detailed datasets of actual sales prices containing information on property's addresses.

[5] Grether and Mieszkowski (1974) also note that it is reasonable to assume that missing information on property characteristics, which may be connected to the use of offer data, does not give rise to a systematic bias of coefficients.

served.[6] Since this paper uses semi-logarithmic forms, which reflect relative – and not absolute – changes in property prices for an additional unit of a characteristic, the offer prices should yield unbiased coefficients.

The study area comprises the entire city of Hamburg, which has an area of 755.2km² and at the end of the study period a population of 1.767 million (March 31, 2008). Hamburg is the second largest city in Germany, both in terms of its area and population. The primary source of data for this study is a dataset supplied by F+B GmbH that contains 4,832 listing prices for condominiums in Hamburg that were put up for sale on Internet portals between April 1, 2002 and March 31, 2008. All datasets contain information on the year of construction, size of the condominium, listing price and date, time on market, the complete address of the property as well as information on the characteristics of the condominium. Using a directory supplied by the Hamburg Office for Urban Development and the Environment (BSU), each address was allocated to one of the 938 statistical districts of Hamburg. A statistical district is the smallest statistical unit for which the Statistics Office of Hamburg collects demographic and socioeconomic population data.[7] In addition, GIS was used to calculate distances between properties and public infrastructure (such as train stations, schools, kindergartens and shopping), bodies of water, green spaces and jobs. Employing small-scale datasets on the noise pollution caused by road, air and rail traffic supplied by the BSU, property-specific noise pollution levels in dB(A) were determined.

Data on the addresses, religious affiliations and heights of Hamburg places of worship were collected in numerous sources. Using GIS, I geo-coded the locations of places of worship, assigned to each condominium the nearest place of worship and measured the distance be-

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[6] Unpublished study of F+B GmbH from the year 2002. To the authors` knowledge, there have not been any further studies on the influence that property characteristics or the location of a property have on the difference between offer and transaction prices.

[7] All population data refer to the year in which the property was offered for sale most recently. The information regarding average income, however, was available only for 1995.

tween the two. Also, the floor space of each place of worship was estimated by means of aerial photographs. In addition, all church communities in Hamburg were contacted to determine whether or not a church has bells. For each church with bells, information was collected on whether they are used to mark the time (hourly, half-hourly or every fifteen minutes) and whether the marking of time of the church clock is turned off at night.[8]

3 Empirical methodology

Choice of functional form

The choice of the proper parametric form of the hedonic regression equation is the subject of several publications (e.g., Bartik 1987; Cassel and Mendelsohn 1985; Cropper, Deck, and McConnell 1988; Halvorsen and Pollakowski 1981). However, since their advantage of allowing for non-linearity effects as well as intuitive interpretation of coefficients housing studies commonly rely on semi-logarithmic functional forms. In recent years, authors have tended to use flexible forms such as the Box-Cox transformation (Box and Cox 1964). But, so far, the literature has not overcome the problems of implementing flexible functional forms in the presence of spatial dependence (Kim, Phipps, and Anselin 2003). As the models described below consider spatial lag terms, this paper relies on semi-logarithmic functional forms.

Spatial dependence

By introducing a spatial lag term (*AUTOREG*) it is assumed that listing prices also depend on the prices of the properties previously put up for sale in the neighborhood (Ahlfeldt and Maennig 2010). Owing to the nature of listing prices, which are generally guided by neighboring property prices, the spatial lag model is favored over the spatial error model, which assumes that spatial autocorrelation emerges from omitted variables that follow a spatial pattern (Kim, Phipps, and Anselin 2003). For condominium *i* the value of the lag term is equivalent to the prices weighted by $w_{ij} = (1/d_{ij}) / \Sigma_j 1/d_{ij}$ of the surrounding *j* summed-up apartments,

[8] For descriptive statistics of POW indicators see Table VIII.3 and Table VIII.4 in the appendix.

when $1/d_{ij}$ is the reciprocal distance between the condominiums *i* and *j* (Can and Megbolugbe 1997):[9]

$$AUTOREG_i = \sum_j \frac{(1/d_{ij})}{\sum_j 1/d_{ij}} P_{j,t-m}, \; m = 1,...,12; \; j = 1,...,N; \; d_{ij} \leq 1\,km\,. \qquad \text{(VIII.1)}$$

Model 4.1

All models employ hedonic approaches that control for property, neighborhood, accessibility and noise indicators. Furthermore, Model 4.1 takes into account the proximity to POWs measured by a potentiality variable and can be written as:

$$\ln(P) = \alpha + \beta\ PROP + \gamma\ NEIGH + \delta\ ACCESS + \eta\ NOISE\_VIS\_DIS + \theta\ AUTOREG \qquad \text{(VIII.2)}$$
$$+ \lambda\ TREND + \mu\ POW\_POTENTIALITY + \varepsilon\,,$$

where α, β, γ, δ, η, θ, λ and μ are the coefficients to be estimated and ε is an error term. Property characteristics are captured by the vector *PROP* that includes information regarding age and size – which are considered in both linear form and with an additional quadratic term (e.g., Rickman 2009) – as well as dummy variables for the property's physical attributes.[10] *NEIGH* is a vector of neighborhood characteristics, consisting of the proportion of those aged 65 and older (*ELDERLYPOP*), the average income (*INCOME*), the proportion of foreign population (*FOREIGNPOP*) as well as the number of social housing units per 1,000 inhabitants

[9] Can and Megbolugbe (1997) consider properties within a radius of 3 kilometers if the surrounding properties were sold in the previous six months. However, their study area covers a large-area suburban county in the metropolitan region of Miami. Regarding the small-scale housing market in Hamburg, it is reasonable to assume that the offer price of a condominium is affected only by prices of properties that are located in the immediate vicinity. However, *AUTOREG* was computed using various critical distances (0.5, 0.75, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 7.5 and 10.0km) and the best fit of the model was found when considering properties within a radius of 1km. In contrast to Can and Megbolugbe (1997), who take into account surrounding properties if they were sold in the previous six months, given the relatively low volatility of the condominium market in Hamburg during the study period, it is reasonable to include properties in the neighborhood that were offered for sale within the previous 12 months.

[10] In selecting the property variables, I widely follow Sirmans, Macpherson, and Zietz (2005) as well as Wilhelmsson (2000), who evaluated the control variables most commonly used in hedonic studies.

(*SOCHOUSE*). Descriptive statistics of the variables included in the final model specifications are listed in Table VIII.1.

Table VIII.1 Variable names, definitions and summary statistics

Variable	Definition	Mean	Std. dev.
Dependent variable			
PRICE	Last asking price of property	193,897	177,747
Property			
SIZE	Living area in square meters	81.78	47.10
AGE	Age of property in years	39.41	35.25
ROOMS	Number of rooms	2.79	1.73
GARAGE	1 if property has a garage, 0 otherwise	0.52	0.50
BALCONY	1 if property has a balcony, 0 otherwise	0.82	0.38
TERRACE	1 if property has a terrace, 0 otherwise	0.77	0.42
KITCHEN	1 if property has a built-in kitchen, 0 otherwise	0.65	0.48
POOL	1 if property has a pool, 0 otherwise	0.03	0.16
FIREPLACE	1 if property has a fireplace, 0 otherwise	0.04	0.20
GOODCOND	1 if property is in good condition, 0 otherwise	0.13	0.34
BADCOND	1 if property is in bad condition, 0 otherwise	0.06	0.24
Neighborhood			
ELDERLYPOP	Proportion of population in statistical district that is 65 years or older	18.93	6.73
INCOME	Mean income of population in statistical district (in 1,000 €)	34.80	15.18
FOREIGNPOP	Proportion of foreign population in statistical district	13.06	6.64
SOCHOUSE	Number of social housing units per 1,000 inhabitants in statistical district	40.65	62.27
Access			
DISTCENT	Distance to next sub center according to zoning plan (in kilometers)	1.16	0.82
EMPGRAV	District proximity to employment (measured by a gravity variable)	145,867	43,925
DISTSTAT	Distance to next metro station (in kilometers)	0.78	0.54
DISTWATER	Distance to closest of the bodies of water Elbe and Binnen-/Aussenalster (in kilometers)	4.68	3.67
DISTPARK	Distance to next park, forest or nature protection area (in kilometers)	0.69	0.51
DISTSCH	Distance to next school (in kilometers)	0.40	0.22
Noise exposure / visual intrusions			
WIDEROAD	1 if property is located on a wide road (with at least two lanes per driving direction), 0 otherwise	0.08	0.27
ROADNOISE	Road noise in dB(A) as measured by a L_{DEN} index	56.67	11.69
AIRNOISE	Air noise in dB(A) as measured by a L_{DEN} index if property is located within noise protection zone 2 (≥ 67 dB(A)) or 3 (≥ 62 dB(A)) around Hamburg Airport, 0 otherwise	2.19	10.95
RAILNOISE	Rail noise in dB(A) as measured by a L_{DEN} index if property is located in the vicinity of rail tracks, 0 otherwise	9.20	20.78
DISTIND	Distance to next industrial area (in kilometers)	0.55	0.46

Table VIII.1 (continued)

Variable	Definition	Mean	Std. dev.
Place of worship			
POW_POTENTIALITY	POW potentiality variable as defined in Eq. VIII.4	196.01	228.48
DISTPOW_100	1 if distance to next POW ≤ 100m, 0 otherwise	0.05	0.21
DISTPOW_100_200	1 if distance to next POW > 100m and ≤ 200m, 0 otherwise	0.14	0.35
DISTPOW_200_400	1 if distance to next POW > 200m and ≤ 400m, 0 otherwise	0.35	0.48
DISTPOW_400_600	1 if distance to next POW > 400m and ≤ 600m, 0 otherwise	0.24	0.43
DISTPOW_600_1000	1 if distance to next POW > 600m and ≤ 1,000m, 0 otherwise	0.18	0.39
MOSQUE	1 if next POW is a mosque, 0 otherwise	0.04	0.19
DECON	1 if next POW is a deconsecrated church, 0 otherwise	0.05	0.21
CHIME_DAY_POTENTIALITY	Index of chime during day as defined in Eq. VIII.8	0.00063	0.00920
CHIME_NIGHT_POTENTIALITY	Index of chime during day as defined in Eq. VIII.9	0.00029	0.00741

Access to jobs is measured by a gravity variable (Bowes and Ihlanfeldt 2001) that weights the number of jobs located in the 103 districts of Hamburg and the 307 surrounding communities in the metropolitan region of Hamburg each with their reciprocal distance to the city district where a condominium is located.[11] To measure the access to public transport network the distance to the next railway station (*DISTSTAT*) was included – which is considered in both linear form and with an additional quadratic term (Agostini and Palmucci 2008). Proximity to shopping and recreation facilities has been captured by the distance to (sub-)centers (*DISTCENT*) according to the zoning plan of Hamburg (BSU 2003) as well as the distance from the closest green space (*DISTPARK*) and from the nearest bodies of water

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11 $$EMPGRAV_i = \sum_j \frac{Emp_j}{d_{ij}} \quad , d_{ii} = \frac{1}{3}\sqrt{\frac{area_i}{\Pi}} , \qquad \text{(VIII.3)}$$

where *Emp* represents all jobs subject to social insurance in a city district or in one of the surrounding communities. j stands for all city districts and communities other than i, and d_{ij} is the distance between the centroids of i and j. Since some of the city districts cover relatively large areas, a district-internal distance measure d_{ii} is employed (e.g., Crafts 2005). In order to avoid overestimation of Emp_j and/or Emp_i, d_{ij} and/or d_{ii} was not allowed to take on values smaller than 1. The regression coefficient of the gravity variable calculated from the graded weights shows a higher t-value than the coefficient of the variable calculated from non-graded weights.

(*DISTWATER*).[12] Since schools and kindergartens are often located near places of worship, the models also capture the distance to such educational establishments.[13] *ACCESS* is thus a vector to map the previously discussed accessibility indicators.

NOISE_VIS_DIS is a vector that, in addition to noise pollution in the entry and exit lanes of the Hamburg Airport (*AIRNOISE*), also takes into account noise and visual nuisances stemming from road traffic (*ROADNOISESQ*, *WIDEROAD*) as well as railway noise near railway tracks (*RAILNOISE*) and that captures the distance to industrial sites (*DISTIND*). The vector *TREND* stands for a set of dummy variables that capture the most recent year and the most recent season in which a property was offered for sale.

$$POW\_POTENTIALITY_i = \sum_j A_j \, e^{-zd_{ij}} \qquad \text{(VIII.4)}$$

First, the spatial extent of the effect of places of worship is examined using a potentiality variable, which is estimated as an exponential spatial weight function (Ahlfeldt and Maennig 2010). For condo *i* *POW_POTENTIALITY* corresponds to the sum of the floor space *A* weighted with the term exp($-zd_{ij}$) of all places of worship *j* in Hamburg. d_{ij} is the distance between property *i* and the place of worship *j*, and *z* is a spatial weight used to weight the floor space[14] of the places of worship in relation to their distance from property *i*. By calculating

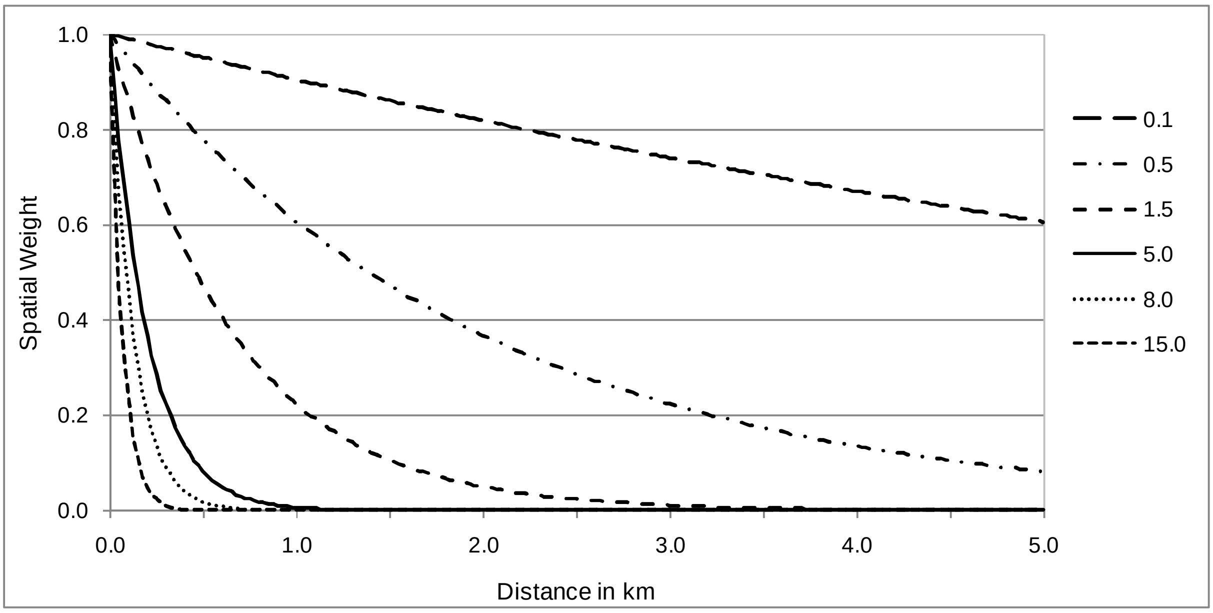
[12] All distance variables are stated as straight-line distances.

[13] The best fitting model was retrieved when considering the distance to the closest school both in linear and quadratic form. The influence of the distance to the nearest kindergarten was insignificant for all tested terms, which is why this indicator has been excluded from the final model specifications.

[14] In preliminary estimations, not only the floor space but also the height of places of worship was tested. Also, the volume of places of worship was approximated using various terms. However, the height and/or volume of places of worship was insignificant for all tested terms, which is why these indicators were excluded from the final models. One reason for the insignificant findings could be found in the deficient data quality of height information. For many buildings, it was impossible to research the height, which then had to be estimated from photographs of the properties. Another reason for the insignificant coefficients could lie in the variety of building structures of places of worship, which probably can be approximated only insufficiently using uniform terms.

POW_POTENTIALITY for different values of *z* (0.1 to 15) the best fit is found for *z* = 5 (cf. also Fig. VIII.1).[15] The spatial effect of places of worship in Hamburg is thus halved approx. every 140m and is limited to a radius of approx. 1km.[16] This is also plausible when compared to the findings of Ahlfeldt and Maennig (2010), who, using potentiality variables, have observed a spatial effect of built heritage at distances of up to 600m. Since places of worship are normally taller than heritage-listed properties, they may also have a stronger spatial effect on the prices of surrounding residential properties.

Fig. VIII.1 Selection of estimated spatial weight functions for different *z (0.1 - 15.0)*



Model 4.2

Taking into account the findings gained from Model 4.1, in Model 4.2 the influence of places of worship is examined by means of a conventional approach. That is, by introducing a set of dummy variables that capture distance contours around POWs. Model 4.2 can thus be written as follows:

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[15] *POW_POTENTIALITY* was tested with *z* = 0.1, 0.25, 0.5, 0.75, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 15.0.

[16] For d_{ij} = 1.0, the weight $\exp(-5d_{ij})$ = 0.0067.

$$\ln(P) = \alpha + \beta\ PROP + \gamma\ NEIGH + \delta\ ACCESS + \eta\ NOISE\_VIS\_DIS + \theta\ AUTOREG \\ + \lambda\ TREND + \sigma\ DIST\_POW + \varepsilon\ , \tag{VIII.5}$$

where σ is a vector of the coefficients to be estimated. *DISTPOW* is a vector of five dummy variables that each take on the value of 1 if a property is located at a distance of up to 100m (*DISTPOW_100*), more than 100m and up to 200m (*DISTPOW_100_200*), more than 200m and up to 400m (*DISTPOW_200_400*), more than 400m and up to 600m (*DISTPOW_400_600*) or more than 600m and up to 1,000m (*DISTPOW_600_1000*) from the next POW; otherwise the value is 0.[17] Accounting for the findings from Model 4.1, 1,000m is defined as the maximum cutoff, using properties at distances of more than 1,000m to the next POW as the reference group. The use of dummy variables has the advantage that their coefficients, in contrast to those of spatial weight terms, are easy to interpret and present an intuitive measure of the influence of POWs on residential property prices.

Model 4.3

In Model 4.3, I first analyze whether the externalities of mosques are different than those of other places of worship. In answering this question, I hope to obtain new input for the social debate on the construction of minarets and/or the public muezzin's call. Secondly, it is examined whether the externalities of deconsecrated churches differ from those of buildings used as places of worship. Taking into account the uncertain future of many – primarily Lutheran – churches, answering this question may supply impulses for the debate on the future use of former places of worship.

DISTPOW is additionally interacted with the variables *MOSQUE* and *DECON*. Thus, Model 4.3 is as follows:

$$\ln(P) = \alpha + \beta\ PROP + \gamma\ NEIGH + \delta\ ACCESS + \eta\ NOISE\_VIS\_DIS + \theta\ AUTOREG \\ + \lambda\ TREND + \sigma\ DIST\_POW + \varphi\ DIST\_POW \times MOSQUE \\ + \psi\ DIST\_POW \times DECON + \varepsilon\ , \tag{VIII.6}$$

[17] All other terms in Eq. VIII.5 have the meanings previously described for Model 4.1.

where φ and ψ are the coefficients to be estimated. *MOSQUE* and/or *DECON* take on the value of 1 if the next POW is a mosque and/or a deconsecrated church; otherwise the value is 0.[18] For example, the interactive variable *DISTPOW_100_200* x *MOSQUE* takes on the value of 1 if the next POW is a mosque that is located within a radius of 100m to 200m from the property; otherwise the value is 0. The coefficient of the interactive variable *DISTPOW_100_200* x *MOSQUE* thus indicates, for example, the price differential of properties within a radius of 100m to 200m around mosques compared to properties that are located at distances between 100m and 200m around POWs of other religions that were not deconsecrated.

Model 4.4

Finally, in Model 4.4, the extent to which residential property prices are influenced by the bell ringing of nearby churches is examined. First, a distinction must be made between liturgical bell ringing – e.g., on church holidays, to mark services and official church acts such as baptisms, weddings or funerals – and the secular marking of time of the church clock at quarterly, half-hourly or hourly intervals. In preliminary analyses, various terms were included to test whether it makes a difference that adjacent church spires have bells or not. However, the variables did not yield any significant results, which may primarily be due to the fact that bells are rung with varying frequency and intensity in each community. However, data on the frequency and intensity of liturgical bell ringing in the various communities was not available, because the variety of ringing could be quantified – if at all – only with disproportionate effort for the entire metropolitan area of Hamburg. Besides, the regular marking of time, which is more frequent than liturgical bell ringing and can be heard even at nighttime in many communities, probably creates greater noise pollution anyway. Therefore, for each church in Hamburg it is considered whether the church marks the time and if so, at what frequency and at what time of day this occurs. Model 4.4 can thus be written as follows:

---

[18] Deconsecrated churches are properties that were not used as places of worship anymore during the study period but whose buildings still existed.

$$\ln(P) = \alpha + \beta\ PROP + \gamma\ NEIGH + \delta\ ACCESS + \eta\ NOISE\_VIS\_DIS + \theta\ AUTOREG + \lambda\ TREND + \sigma\ DIST\_POW + \varphi\ DIST\_POW \times MOSQUE + \psi\ DIST\_POW \times DECON + \omega\ CHIME + \varepsilon, \tag{VIII.7}$$

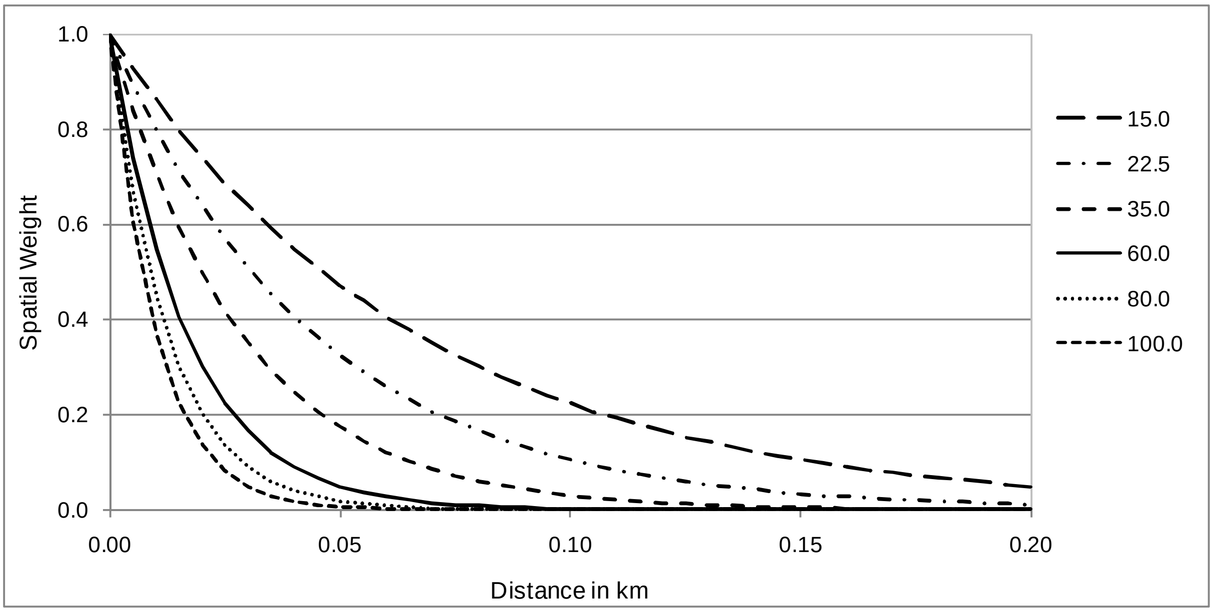
where ω is a vector of the coefficients to be estimated. *CHIME* is a vector of the two potentiality variables *CHIME_DAY_POTENTIALITY* and *CHIME_NIGHT_POTENTIALITY*, which, using exponential spatial weight functions, account for the marking of time of all church clock towers in Hamburg in relation to frequency, time of day and distance to the respective condominium. The variable *CHIME_DAY_INDEX* takes on the value 4 for church *j* if time is marked at quarterly intervals, or the value 2 if time is marked every half-hour, or the value 1 if time is marked hourly; otherwise the value is 0.

$$CHIME\_DAY\_POTENTIALITY_i = \sum_j CHIME\_DAY\_INDEX_j\ e^{-zd_{ij}} \tag{VIII.8}$$

For condominium *i* *CHIME_DAY_POTENTIALITY* corresponds to the sum of the *CHIME_DAY_INDEX* values of all Hamburg churches *j* weighted with the term $\exp(-zd_{ij})$. d_{ij} is the distance between property *i* and church *j*, and *z* is a spatial weight used to weight the values of *CHIME_DAY_INDEX* in relation to d_{ij}. For the calculation of *CHIME_DAY_POTENTIALITY* *z* is considered to take on values from 15 to 100 (see also Fig. VIII.2).[19]

[19] *CHIME_DAY_POTENTIALITY* and *CHIME_NIGHT_POTENTIALITY* were tested each with $z =$ 15.0, 16.0, 17.0, 18.0, 20.0, 22.5, 25.0, 30.0, 35.0, 40.0, 50.0, 60.0, 70.0, 80.0, 90.0, 100.0.

Fig. VIII.2 Selection of estimated spatial weight functions for different *z (15.0 - 100.0)*



$$CHIME\_NIGHT\_POTENTIALITY_i = \sum_j CHIME\_NIGHT\_INDEX_j \, e^{-zd_{ij}} \quad \text{(VIII.9)}$$

The calculation of the variable *CHIME_NIGHT_POTENTIALITY* follows the same principle. For church *j CHIME_NIGHT_INDEX* is equal to the value of *CHIME_DAY_INDEX* when the marking of time occurs also at night (at least from 12:00 AM to 6:00 AM); otherwise the value is 0.

4 Results

About 87.2% of the variance of listing prices can be explained by the hedonic models used (Table VIII.2).[20] This is an average value when compared to other hedonic housing price studies. Since White's test rejects homoscedasticity for all models, the standard errors were corrected using White's Correction. All control variables have the expected signs and are predominantly highly significant, yielding values that are plausible also in terms of their amounts.

[20] If the models are specified without the spatial lag term, the adjusted R^2 value is reduced by approx. 1.0%.

Table VIII.2 Results

	Model 4.1	Model 4.2	Model 4.3	Model 4.4
CONSTANT	8.4549***	8.4323***	8.4384***	8.4445***
Property				
SIZE	0.0132***	0.0132***	0.0132***	0.0132***
SIZESQ	–0.000009***	–0.000009***	–0.000009***	–0.000009***
AGE	–0.0130***	–0.0129***	–0.0129***	–0.0130***
AGESQ	0.000098***	0.000097***	0.000098***	0.000098***
ROOMS	0.0267**	0.0268**	0.0267**	0.0265**
GARAGE	0.0328***	0.0334***	0.0334***	0.0347***
BALCONY	0.0592***	0.0583***	0.0574***	0.0571***
TERRACE	0.0396***	0.0395***	0.0401***	0.0399***
KITCHEN	0.0409***	0.0411***	0.0414***	0.0421***
POOL	0.0337	0.0357	0.0366	0.0366
FIREPLACE	0.0111	0.0104	0.0104	0.0099
GOODCOND	0.0503***	0.0507***	0.0504***	0.0504***
BADCOND	–0.1052***	–0.1057***	–0.1047***	–0.1049***
Neighborhood				
ELDERLYPOP	–0.0033***	–0.0034***	–0.0034***	–0.0034***
INCOME	0.0031***	0.0031***	0.0031***	0.0032***
FOREIGNPOP	–0.0057***	–0.0056***	–0.0058***	–0.0057***
SOCHOUSE	–0.0002***	–0.0002***	–0.0002***	–0.0002***
Access				
DISTCENT	–0.0247***	–0.0245***	–0.0240***	–0.0242***
EMPGRAV	0.000002***	0.000002***	0.000002***	0.000002***
DISTSTAT	0.0374*	0.0394*	0.0395*	0.0343*
DISTSTATSQ	–0.0211**	–0.0215**	–0.0216**	–0.0195***
DISTWATER	–0.0077***	–0.0076***	–0.0077***	–0.0076***
DISTPARK	–0.0444***	–0.0444***	–0.0445***	–0.0446***
DISTSCH	0.1598***	0.1557***	0.1577***	0.1572***
DISTSCHSQ	–0.1367***	–0.1292***	–0.1290***	–0.1304***
Noise exposure / visual intrusions				
WIDEROAD	–0.0460***	–0.0461***	–0.0470***	–0.0468***
ROADNOISESQ	–0.000019***	–0.000020***	–0.000020***	–0.000020***
AIRNOISE	–0.0011***	–0.0011***	–0.0011***	–0.0011***
RAILNOISE	–0.0011***	–0.0011***	–0.0011***	–0.0011***
DISTIND	0.0178*	0.0225**	0.0237**	0.0234**

Table VIII.2 (continued)

	Model 4.1	Model 4.2	Model 4.3	Model 4.4
Place of worship				
POW_POTENTIALITY	0.000065***			
DISTPOW_100		0.0381	0.0384	0.0466
DISTPOW_100_200		0.0480**	0.0470**	0.0475**
DISTPOW_200_400		0.0262	0.0254	0.0259
DISTPOW_400_600		0.0090	0.0084	0.0093
DISTPOW_600_1000		0.0003	0.0019	0.0028
DISTPOW_100 x MOSQUE			0.0397	0.0292
DISTPOW_100_200 x MOSQUE			0.0383	0.0363
DISTPOW_200_400 x MOSQUE			0.0334	0.0325
DISTPOW_400_600 x MOSQUE			–0.0209	–0.0225
DISTPOW_600_1000 x MOSQUE			–0.0336	–0.0334
DISTPOW_100 x DECON			–0.0279	–0.0365
DISTPOW_100_200 x DECON			–0.0099	–0.0094
DISTPOW_200_400 x DECON			0.0059	0.0063
DISTPOW_400_600 x DECON			0.0214	0.0217
DISTPOW_600_1000 x DECON			–0.0966	–0.0961
CHIME_DAY_POTENTIALITY				0.1992
CHIME_NIGHT_POTENTIALITY				–1.6556
Number of observations	4,832	4,832	4,832	4,832
White's Correction	YES	YES	YES	YES
Spatial lag term	YES	YES	YES	YES
R^2	0.873	0.873	0.874	0.874
Adjusted R^2	0.872	0.872	0.872	0.872

Notes: The endogenous variable is the natural log of the last listing price of property. All models include yearly and seasonal dummy variables. * indicates significance at the 10% level; ** indicates significance at the 5% level; *** indicates significance at the 1% level.

Control variables

The coefficients estimated for *SIZE* and *SIZESQ* show the expected positive, but less than proportional effect of property size on condominium prices. The estimates of *AGE* and *AGESQ* indicate a quadratic influence for the property's age, with the lowest prices for condominiums that are 66 years old. Regarding the other condominium's physical characteristics, only a generally bad condition of the property (*BADCOND*) has a negative effect on condominium prices.[21] Among the neighborhood variables only the relationship between average income (*INCOME*) and condominium prices is positive. All other coefficients of neigh-

[21] The coefficients of dummy variables used in the semi-log form were transformed by (e^a – 1), where *a* is the estimated coefficient (Halvorsen and Palmquist 1980).

borhood indicators have negative signs. The coefficients of *DISTSTAT* and *DISTSTATSQ* show that the highest prices for properties can be found at a distance of approx. 900m from the next rail station. Also the estimates of *DISTSCH* and *DISTSCHSQ* indicate a quadratic relation between distance from next school and housing prices. Coefficients of all other variables that measure distance from local amenities have the expected negative signs. Furthermore, access to jobs, measured by *EMPGRAV*, is seen as positive. While condominiums located next to a major road (*WIDEROAD*) experience price reductions of 4.6%, the coefficients of all traffic-noise indices (*ROADNOISESQ*, *AIRNOISE*, *RAILNOISE*) are negative and statistically highly significant.

Impact of POWs

As mentioned above, tests with the potentiality variable *POW_POTENTIALITY* in Model 4.1 have shown that the spatial effect of places of worship is limited to around 1,000m. Model 4.2 now shows that the price premiums for the proximity to places of worship increase between 1,000m and 100m with declining distance, resulting in maximum premiums of 4.8% for locations between 100m and 200m from the nearest place of worship (*DISTPOW_100_200*). Compared to the property prices at a distance of more than 1,000m from the nearest place of worship, however, only premiums at a distance of 100m to 200m are significant. This result is plausible insofar as 200m also represents a plausible cutoff for a high visual perception of the buildings. In immediate proximity to places of worship, that is, at a distance of up to 100m (*DISTPOW_100*), price premiums are lower and not significantly different from residential property prices at a distance of more than 1,000m from the nearest place of worship. The lower premiums in close proximity to places of worship may result from noise pollution, for example, from community or cultural events, visitor traffic or church bell ringing. This topic will be further discussed when presenting the findings of Model 4.4. In summary, the estimated premiums near places of worship are comparable to previously reported premiums in the vicinity of churches that range from 3.1% (Carroll, Clauretie, and Jensen 1996) to 6.4% (Ottensmann 2000). Also, the estimated spatial extent of externalities of places of worship is comparable to the spatial effect of church buildings observed by Do, Wilbur, and Short (1994) and Ottensmann (2000). However, Carroll, Clauretie, and Jensen (1996) and Bielefeld et al. (2010) reported more far-reaching spatial effects.

In Model 4.3, the insignificant coefficients of the interactive vectors *DISTPOW* x *MOSQUE* and *DISTPOW* x *DECON* give rise to the conclusion that the condominium prices in Hamburg, either near mosques or in the vicinity of deconsecrated churches, do not differ significantly from property prices in the neighborhood of places of worship of other religions and/or in the vicinity of actively-used places of worship. Given the positive – albeit insignificant – coefficients of the interactive terms *DISTPOW_100* x *MOSQUE*, *DISTPOW_100_200* x *MOSQUE* and *DISTPOW_200_400* x *MOSQUE*, one could speculate that easy access to a place of worship matters more to Muslims than it does to believers of other religions. In fact, approx. 36% of Hamburg Muslims attend a mosque regularly (Ulrich 2010b), while, for example, only around 12% of Catholics in Hamburg attend church mass regularly (Ulrich 2010a). The fact that prices of residential properties near rededicated churches are not statistically different from prices in the vicinity of actively-used places of worship leads to the conclusion that, seemingly, the visual amenities of churches are key to price premiums, rather than easy access to church services and/or community and cultural events.

In Model 4.4, the potentiality variables *CHIME_DAY_POTENTIALITY* and *CHIME_NIGHT_POTENTIALITY* are calculated for z values from 15 to 100. For both variables the best fit is obtained for z = 60 (see also Fig. VIII.2).[22] However, the coefficients of both variables are insignificant even for z = 60. Therefore, an effect of bell ringing on the prices of nearby residential properties cannot be proved. At least with respect to bell ringing at night, price reductions in the immediate neighborhood would have been expected. A weakness of the model is certainly that the level of noise exposure from church bells de-

[22] Accordingly, the spatial effect of bell ringing is reduced by half approx. every 12m and is limited to a radius of approx. 80m (for d_{ij} = 0.08, the weight $\exp(-60d_{ij})$ = 0.0082).

pends on further factors that the model does not control for. Thus, the volume of the bells of different churches can vary greatly. Many church towers still have steel bells from the post-war years. Their sound is rather shrill. By contrast, later cast steel bells and bronze bells tend to produce a warm sound. Furthermore, bells are suspended at different heights, which could result in different noise levels at the same distance from the nearest church tower. Although the model controls for the frequency and time of day of bell ringing as well as the distance from residential properties, the aforementioned constraints may lead to biased results. An interesting aspect is, however, that the coefficient of *DISTPOW_100* rises by almost a percentage point compared to Model 4.3 and is now more or less equivalent to the coefficient of *DISTPOW_100_200*. *DISTPOW_100* is now also significant at least at the 11% level. The lower price premiums reported for Models 4.2 and 4.3 in immediate proximity to places of worship, therefore, can largely be explained by the noise exposure to church bells even if the influence of the noise itself is not statistically significant.

5 Conclusions

Applying hedonic pricing techniques this study examines the impact of places of worship on residential property prices in Hamburg, Germany. Controlling for spatial dependence and employing potentiality variables places of worship are found to have positive external effects on neighboring condominium prices within a distance of approx. 1,000m. Compared to properties beyond this threshold, price premiums of 4.8% are obtained for condominiums at distances of 100m to 200m to the next place of worship. As a result of noise exposure, however, price premiums in immediate proximity to places of worship (≤ 100m) are lower and not significantly different from property prices at a distance of more than 1,000m from the nearest place of worship. Condominium prices in Hamburg, either near mosques or in the vicinity of deconsecrated churches, are not significantly different from prices in the neighborhood of places of worship of other religions and/or in the vicinity of actively-used places of worship. Thus, no price discounts for residential properties have been observed in the vicinity of mosques that would account for local residents feeling bothered by Islamic places of worship. The findings also imply that churches should be preserved as buildings, because they continue to have positive externalities on adjacent residential property prices even after they have been deconsecrated. The influence of church bell ringing on the prices of surrounding residential properties, however, could not be substantiated.

It should be noted, however, that the study was conducted in a metropolis known for its liberalism and open-mindedness. The findings may be different for conservative and/or rural regions. This warrants further research.

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Appendix

Table VIII.3 Descriptive statistics of POW indicators

Denomination	Number of POWs	Mean year of construction	Mean floor space	Mean *CHIME _DAY_INDEX*	Mean *CHIME _NIGHT_INDEX*	Number of parishioners [a]
Lutheran church	175	1903.2	520.8	1.43	0.76	530,000
Free church	71	1968.4	338.1	0.00	0.00	20,000
Mosque	54	1968.3	282.8	0.00	0.00	140,000
Catholic church	42	1940.2	590.8	0.17	0.00	181,000
Other church	22	1950.8	361.5	0.00	0.00	20,000
Deconsecrated church	8	1933.8	508.4	0.88	0.00	-
Buddhist center/temple	6	1976.5	191.2	0.00	0.00	5,000
Hindu temple	2	1975.0	415.0	0.00	0.00	5,000
Synagogue	1	1960.0	400.0	0.00	0.00	5,000
Total	381	1933.7	445.2	0.70	0.35	906,000

[a] Source: Ulrich (2010a), author's own investigations.

Table VIII.4 Descriptive statistics of POW indicators for property portfolio

Denomination	Number of properties	Mean year of construction	Mean floor space	Mean *CHIME _DAY_INDEX*	Mean *CHIME _NIGHT_INDEX*	Mean *DISTPOW* (in kilometers)
Lutheran church	2,842	1922.2	483.4	1.40	0.72	0.467
Free church	716	1965.1	361.0	0.00	0.00	0.368
Catholic church	473	1934.7	699.3	0.21	0.00	0.388
Deconsecrated church	222	1931.7	615.9	0.85	0.00	0.354
Other church	212	1942.0	339.9	0.00	0.00	0.289
Mosque	186	1963.0	409.5	0.00	0.00	0.395
Buddhist center/temple	161	1974.8	176.9	0.00	0.00	0.421
Synagogue	17	1960.0	400.0	0.00	0.00	0.211
Hindu temple	3	1975.0	272.0	0.00	0.00	0.216
Total	4,832	1934.6	472.7	0.89	0.43	0.426

IX Do places of worship affect housing prices? Evidence from Germany – Supplementary notes

1 Data collection and descriptive statistics of data

First, the inventory of houses of worship in place during the study period was determined from monographs and Internet sources for the entire city territory. Then, the longitude and latitude of each of the 381 houses of worship identified were checked and/or determined manually on the basis of digital aerial photography. In a next step, each property was allocated the nearest house of worship by means of the programs MS MapPoint, MileCharter and MS Access.

The digital aerial photos were also used to estimate the floor space of each house of worship. The maps were then used to find out which mosques had a minaret. Where monographs and Internet sources did not contain information on construction years and building heights of Hamburg houses of worship, that information was obtained via a three-step procedure:

1) Survey via e-mail: Each congregation was surveyed by e-mail. This way, it was possible to collect the data for approx. 40% of the church buildings.
2) Survey via phone: Congregations that did not reply by e-mail were contacted by phone. This way, it was possible to collect the data for an additional approx. 50% of the churches.
3) Collection on site: Any still outstanding data were collected in person on site.

As part of the survey, it was also established for each church building whether it had church bells and whether it marked time, and if so, when the bells were sounded. The author wrote a Visual Basic program to calculate different potential variables that capture for each property the proximity to all houses of worship in Hamburg (cf. Section VIII.3).

For information on descriptive statistics, refer to Section VIII.3 and the appendix of Chapter VIII.

2 Results

First, it has to be mentioned that the modified Models 4.1 - 4.4 capture the variance of condominium prices better than the initial models, which is reflected by an increase in the adjusted R^2 by around 0.05 percentage points. The variable *POW_POTENTIALITY* that measures the extent of the spatial effect of houses of worship (cf. Section VIII.3) results in – as it

Table IX.1 Results

	Model 4.1	Model 4.2	Model 4.3	Model 4.4
CONSTANT	8.4621***	8.4460***	8.4543***	8.4589***
TOM	–0.0001***	–0.0001***	–0.0001***	–0.0001***
AUTOREG	0.2050***	0.2054***	0.2044***	0.2040***
YEAR_2002	–0.0481*	–0.0491*	–0.0487*	–0.0480*
YEAR_2003	–0.0083	–0.0064	–0.0058	–0.0046
YEAR_2004	–0.0313**	–0.0327**	–0.0325**	–0.0314**
YEAR_2005	–0.0632***	–0.0641***	–0.0635***	–0.0638***
YEAR_2006	–0.0399***	–0.0400***	–0.0402***	–0.0403***
YEAR_2007	–0.0253*	–0.0259*	–0.0259*	–0.0262*
QUARTER_1	0.0003	0.0010	0.0011	0.0003
QUARTER_2	0.0177	0.0184*	0.0188*	0.0188*
QUARTER_3	0.0092	0.0103	0.0099	0.0090
Property				
SIZE	0.0132***	0.0132***	0.0132***	0.0132***
SIZESQ	–0.000009***	–0.000009***	–0.000009***	–0.000009***
AGE	–0.0130***	–0.0129***	–0.0129***	–0.0129***
AGESQ	0.000097***	0.000097***	0.000097***	0.000098***
ROOMS	0.0264**	0.0265**	0.0265**	0.0263**
GARAGE	0.0319***	0.0324***	0.0324***	0.0338***
BALCONY	0.0542***	0.0535***	0.0525***	0.0521***
TERRACE	0.0455***	0.0460***	0.0466***	0.0460***
KITCHEN	0.0408***	0.0408***	0.0410***	0.0418***
POOL	0.0334	0.0330	0.0335	0.0337
FIREPLACE	0.0120	0.0115	0.0115	0.0109
GOODCOND	0.0512***	0.0514***	0.0511***	0.0512***
BADCOND	–0.1049***	–0.1052***	–0.1040***	–0.1043***
Neighborhood				
ELDERLYPOP	–0.0035***	–0.0036***	–0.0036***	–0.0036***
INCOME	0.0034***	0.0033***	0.0033***	0.0033***
FOREIGNPOP	–0.0059***	–0.0059***	–0.0061***	–0.0059***
SOCHOUSE	–0.0001	–0.0001	–0.0001	–0.0001

Table IX.1 (continued)

	Model 4.1	Model 4.2	Model 4.3	Model 4.4
Access				
DISTCENT x CBD	–0.0751**	–0.0384	–0.0384	–0.0377
DISTCENT x B_CENT	–0.0155**	–0.0156**	–0.0148**	–0.0139**
DISTCENT x C_CENT	–0.0333***	–0.0333***	–0.0330***	–0.0332***
EMPGRAV	0.000001***	0.000002***	0.000002***	0.000002***
DISTSTAT_250	0.0177	0.0157	0.0167	0.0209
DISTSTAT_250_750	0.0477**	0.0478**	0.0490**	0.0510**
DISTSTAT_750_1250	0.0312	0.0299	0.0310	0.0328*
DISTSTAT_1250_1750	0.0219	0.0230	0.0241	0.0255
DISTWATER	–0.0089***	–0.0089***	–0.0091***	–0.0090***
DISTPARK	–0.0352***	–0.0358***	–0.0358***	–0.0355***
DISTSCH	0.1906***	0.1853***	0.1885***	0.1843***
DISTSCHSQ	–0.1680***	–0.1606***	–0.1617***	–0.1597***
Noise exposure / visual intrusions				
WIDEROAD	–0.0470***	–0.0473***	–0.0486***	–0.0485***
ROADNOISESQ	–0.000018***	–0.000018***	–0.000019***	–0.000019***
AIRNOISE	–0.0011***	–0.0011***	–0.0011***	–0.0011***
RAILNOISE	–0.0011***	–0.0011***	–0.0011***	–0.0011***
DISTIND	0.0186*	0.0219**	0.0227**	0.0233**
DISTCPBS_100	–0.0112	–0.0097	–0.0098	–0.0100
DISTCPBS_100_200	0.0099	0.0092	0.0101	0.0099
Place of worship				
POW_POTENTIALITY	0.000061***			
DISTPOW_100		0.0355	0.0345	0.0427
DISTPOW_100_200		0.0464**	0.0444*	0.0442*
DISTPOW_200_400		0.0234	0.0222	0.0220
DISTPOW_400_600		0.0111	0.0112	0.0114
DISTPOW_600_1000		0.0031	0.0048	0.0049
DISTPOW_100 x MOSQUE			0.0497	0.0376
DISTPOW_100_200 x MOSQUE			0.0386	0.0368
DISTPOW_200_400 x MOSQUE			0.0292	0.0285
DISTPOW_400_600 x MOSQUE			–0.0332	–0.0345
DISTPOW_600_1000 x MOSQUE			–0.0436	–0.0440
DISTPOW_100 x DECON			–0.0335	–0.0444
DISTPOW_100_200 x DECON			–0.0171	–0.0165
DISTPOW_200_400 x DECON			–0.0044	–0.0041
DISTPOW_400_600 x DECON			0.0095	0.0103
DISTPOW_600_1000 x DECON			–0.1200	–0.1191
CHIME_DAY_POTENTIALITY				0.3252
CHIME_NIGHT_POTENTIALITY				–2.0273
Number of observations	4,832	4,832	4,832	4,832
White's Correction	YES	YES	YES	YES
Spatial lag term	YES	YES	YES	YES
R^2	0.87403	0.87412	0.87425	0.87459
Adjusted R^2	0.87277	0.87275	0.87262	0.87291

Notes: The endogenous variable is the natural log of the last listing price of property. * indicates significance at the 10% level; ** indicates significance at the 5% level; *** indicates significance at the 1% level.

did for the initial model – the best fit of the data in terms of the highest adjusted R^2 if the spatial weight *z* takes on the value of 5. The spatial effect of houses of worship thus extends to a radius of approx. 1km also on the basis of the modified model assumptions. The impact area of 1km implied in Models 4.2 - 4.4, therefore, continues to be appropriate. Among the variables that measure the influence of houses of worship in the Models 4.2 - 4.4 – as in the initial models – only the coefficient of *DISTPOW_100_200* is significant, with the value of the regressor decreasing by a maximum of 0.0033. Also on the basis of the adjusted model assumptions, the influence of mosques and/or deconsecrated churches is not significantly different from the effect of the other houses of worship. The influence of bell ringing continues to be not significant.

Table IX.2 summarizes the results of all empirical studies known to the author on the effect of houses of worship on residential property prices. As already established in Section VIII.1, so far, only the influence of churches has been examined, with the findings of previous studies having been contradictory. While Do, Wilbur, and Short (1994) have observed a negative influence of churches on residential property prices, Babawale and Adewunmi (2011) reported contradictory results, and Kinney and Winter (2006) found no significant effects. By contrast, Bielefeld et al. (2006), Carroll, Clauretie, and Jensen (1996) as well as Ottensmann (2000) have observed price premiums between 5.1% and 6.4% in the vicinity of churches. The premiums presented by the author are slightly below that range. Also, the extend of the spatial effect of Hamburg houses of worship is on a smaller scale, which may be explained by the high density of houses of worship in Hamburg.

Table IX.2 Results of previous studies on the effects of places of worship on residential property prices

Year and author(s)	Study region	Data	Valuation method	Results
2011, Babawale and Adewunmi	Lagos, Nigeria	Rents of 450 apartments	Hedonic regression	Neighboring properties around 3 churches are examined: impact of church is positive for one neighborhood, negative for another, and not significant for the third.
2006, Kinney and Winter	St. Louis, Missouri, USA	Census data on median housing values	One-way analysis of variance	Church and church type have no influence on median housing values (impact area = 250 ft).
2006, Bielefeld et al.	Marion County, Indiana, USA	Transaction data of 9,346 residential properties	Hedonic regression	If 4 religion nonprofits or more are located within a radius of 1 mile properties experience price premiums of 5.1%.
2000, Ottensmann	Cleveland, Ohio, USA	Mean values of owner-occupied housing in 858 census tracts	Hedonic regression	Presence of a property of the catholic diocese other than elementary school increases housing values within 0.25 miles by 6.4%.
1996, Carroll, Clauretie, and Jensen	Henderson, Nevada, USA	Transaction data of 4,858 single-family properties	Hedonic regression	Price premiums within 5.5 miles are reported. Properties that are only 100 ft, rather than 1 mile, from the nearest church experience price premiums of 5.5%. Within a radius of 0.43 miles the positive impact of churches is positively affected by church size.
1994, Do, Wilbur, and Short	San Diego metropolitan region, California, USA	Transaction data of 469 single-family properties	Hedonic regression	Negative impact of churches within a radius of 850 ft is reported with maximum price discounts of 3.0%

References

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Carroll, T. M., Clauretie, T. M., & Jensen, J. (1996). Living next to godliness: Residential property values and churches. *The Journal of Real Estate Finance and Economics*, 12(3), 319–330.

Do, A. Q., Wilbur, R. W., & Short, J. L. (1994). An empirical examination of the externalities of neighborhood churches on housing values. *The Journal of Real Estate Finance and Economics*, 9(2), 127–136.

Kinney, N. T., & Winter, W. E. (2006). Places of worship and neighborhood stability. *Journal of Urban Affairs*, 28(4), 335–352.

Ottensmann, J. R. (2000). *Economic value of selected activities of the catholic diocese of Cleveland: Final report*. Center for Urban Policy and the Environment, School of Public and Environmental Affairs, Indiana University–Purdue University Indianapolis.

X Robustness of results

As discussed in Sections III.2, V.3, VII.2 and IX.2, the results of the papers are robust with respect to the modifications to the initial models described in Section I.4. The adjusted R^2 of the modified models is between 0.05 and 0.15 percentage points higher than the R^2 of the initial models. If the spatial lag term is not included, the coefficients generally remain unchanged also for the modified models. For the assumed pecuniary spatial externalities (cf. Section I.4), this means that the implicit price on the basis of OLS and the direct effect for the spatial lag model are virtually identical (Andersson, Jonsson, and Ögren 2010).

Table X.1 summarizes the range of results of all twelve model specifications introduced in the previous sections. In the "No." column, for each variable the number of models are stated in which it is significant at least at the 10% level, as well as the number of models in which it is applied. Furthermore, minimum and maximum coefficients of the statistically significant variables are stated for all models. As can be seen in the table, the spatial lag term *AUTOREG* is significant in each of the models, with the coefficient being at around 0.2 in each case. The object and neighborhood variables are highly robust with respect to the model modifications, as is confirmed by the relatively low variance of the results.

The access and noise control variables, too, are characterized by a fairly high robustness. However, the influence of the proximity to the CBD and/or B centers is more difficult to assess; the variance of the significant coefficients is low, but the coefficients are significant only in 4 of 12 and/or 8 of 12 cases. A decrease in the distance from one of the C centers, usually located on the city's periphery, however, results for all models in significant price premiums. The other access indicators (*EMPGRAV, DISTWATER, DISTPARK, DISTSCH* and *DISTSCHSQ*), too, are largely robust with respect to the model changes. As for the noise control variables *AIRNOISE, RAILNOISE,* and *DISTIND*, they are statistically significant in all models.

The road noise variables are significant at the 1% level both in linear form (*ROADNOISE*) and in square form (*ROADNOISESQ*). As discussed in Section III.2, the interactives *ROADNOISE x AIRNOISEZONE* and *ROADNOISE x RAILNOISEZONE* in Model 1.2 are not significant, which is why they were excluded in other models. Overall, the results presented in the first paper have been confirmed by the findings in the other papers.

The results for the four station accessibility variables (*DISTSTAT_250, DISTSTAT_250_750, DISTSTAT_750_1250,* and *DISTSTAT_1250_1750*) indicate that – as already mentioned in Section V.3 – significant price premiums can be achieved only at distances between 250m and 750m from train stations. The only model in which *DISTSTAT_250_750* is not significant is Model 2.2, where the vectors *DISTSTAT x UNDERGR* and *DISTSTAT x HIGHINC* already capture most of the variance. *DISTSTAT_750_1250*, however, is significant only for Model 4.4, with a *t*-value of 1.7117, but only at the 9% level. As already described in Section V.3, among the interactives, only *DISTSTAT_250 x HIGHINC* and *DISTSTAT_250_750 x HIGHINC* are statistically significant. In summary, it must be said that the results outlined in the second paper are confirmed by the results of the other articles.

As already mentioned in Section VII.2, the coefficient of *DISTCPBS_100* at –0.0165 for Model 3.1 is negative, but not significant. As can be seen in Table X.1, *DISTCPBS_100* is not significant for any of the other models either. The significant negative influence captured by *DISTCPBS_100_200* and described in Section VII.2 on the basis of Model 3.1, however, is not confirmed by any of the other models. A negative influence of individual mobile phone masts can be questioned following the robustness check. The results for the interactive vector *DISTCPBS x STRUCTURE*, however, confirm the negative influence from groups of antenna masts (*DISTCPBS_100 x GROUP_CPBS* and *DISTCPBS_100_200 x GROUP_CPBS*) on the surrounding residential property prices in Hamburg.[1]

[1] In further tests, the vector *DISTCPBS x STRUCTURE* was incorporated with all the models of the other papers, and *DISTCPBS_100 x GROUP_CPBS* was always significantly negative, and

The influence of houses of worship on surrounding residential property prices in Hamburg, as reported in Section IX.2, has generally been confirmed by the findings of the other models. The coefficient of *DISTPOW_100_200* is significantly positive for all models. In contrast to the results presented in Section IX.2, the coefficients of further distance contours are significantly positive for some models. In each case, the robustness check supports the statement that houses of worship affect adjacent residential property prices positively. As reported in Section IX.2, the other places of worship variables do not have any significant influence.

DISTCPBS_100_200 x GROUP_CPBS was significantly negative only for one model. The other coefficients of the vector were insignificant for all models.

Table X.1 Summary of results

Variable	Significant No.	Significant Min.	Significant Max.	Variable	Significant No.	Significant Min.	Significant Max.
TOM	12/12	–0.0001	–0.0001	DISTSTAT_250_750	11/12	0.0434	0.0582
AUTOREG	12/12	0.1963	0.2215	DISTSTAT_750_1250	1/12	0.0328	0.0328
YEAR_2002	9/9	–0.0546	–0.0463	DISTSTAT_1250_1750	0/12	-	-
YEAR_2003	0/9	-	-	DISTSTAT_250 x UNDERGR	0/1	-	-
YEAR_2004	9/9	–0.0341	–0.0304	DISTSTAT_250_750 x UNDERGR	0/1	-	-
YEAR_2005	12/12	–0.0674	–0.0530	DISTSTAT_750_1250 x UNDERGR	0/1	-	-
YEAR_2006	12/12	–0.0404	–0.0311	DISTSTAT_1250_1750 x UNDERGR	0/1	-	-
YEAR_2007	8/12	–0.0262	–0.0215	DISTSTAT_250 x HIGHINC	1/1	0.0646	0.0646
QUARTER_1	0/12	-	-	DISTSTAT_250_750 x HIGHINC	1/1	0.0550	0.0550
QUARTER_2	3/12	0.0184	0.0188	DISTSTAT_750_1250 x HIGHINC	0/1	-	-
QUARTER_3	0/12	-	-	DISTSTAT_1250_1750 x HIGHINC	0/1	-	-
SIZE	12/12	0.0131	0.0133	DISTCPBS_100	0/10	-	-
SIZESQ	12/12	–0.000009	–0.000009	DISTCPBS_100_200	1/10	–0.0157	–0.0157
AGE	12/12	–0.0131	–0.0126	DISTCPBS_100 x SMALL_CPBS	0/2	-	-
AGESQ	12/12	0.000094	0.000100	DISTCPBS_100_200 x SMALL_CPBS	0/2	-	-
ROOMS	12/12	0.0263	0.0275	DISTCPBS_100 x BIG_CPBS	0/2	-	-
GARAGE	12/12	0.0296	0.0351	DISTCPBS_100_200 x BIG_CPBS	0/2	-	-
BALCONY	12/12	0.0378	0.0542	DISTCPBS_100 x GROUP_CPBS	2/2	–0.0467	–0.0462
TERRACE	12/12	0.0415	0.0467	DISTCPBS_100_200 x GROUP_CPBS	1/2	–0.0209	–0.0209
KITCHEN	12/12	0.0380	0.0459	DISTCPBS_100 x MULTISTOREY	1/1	–0.0557	–0.0557
POOL	3/12	0.0434	0.0439	DISTCPBS_100_200 x MULTISTOREY	0/1	-	-
FIREPLACE	0/12	-	-	DISTCPBS_100 x MAST	0/1	-	-
GOOD COND	12/12	0.0403	0.0514	DISTCPBS_100_200 x MAST	0/1	-	-
BAD COND	12/12	–0.1084	–0.1040	DISTCPBS_100 x BADVIEW	1/1	–0.0571	–0.0571
ELDERLYPOP	12/12	–0.0037	–0.0029	DISTCPBS_100_200 x BADVIEW	0/1	-	-
INCOME	12/12	0.0029	0.0034	DISTCPBS_100 x NOISYNEIGH	0/1	-	-
FOREIGNPOP	12/12	–0.0061	–0.0050	DISTCPBS_100_200 x NOISYNEIGH	0/1	-	-
SOCHOUSE	2/12	–0.0001	–0.0001	POW_POTENTIALITY	1/1	0.000061	0.000061
DISTCENT x CBD	4/12	–0.0751	–0.0567	DISTPOW_100	3/11	0.0706	0.0776
DISTCENT x B_CENT	8/12	–0.0156	–0.0124	DISTPOW_100_200	11/11	0.0419	0.0823
DISTCENT x C_CENT	12/12	–0.0358	–0.0221	DISTPOW_200_400	3/11	0.0400	0.0433
EMPGRAV	12/12	0.000001	0.000002	DISTPOW_400_600	0/11	-	-
DISTWATER	12/12	–0.0096	–0.0086	DISTPOW_600_1000	3/11	0.0375	0.0380
DISTPARK	12/12	–0.0445	–0.0290	DISTPOW_100 x MOSQUE	0/2	-	-
DISTSCH	12/12	0.1157	0.1906	DISTPOW_100_200 x MOSQUE	0/2	-	-
DISTSCHSQ	10/12	–0.1680	–0.1045	DISTPOW_200_400 x MOSQUE	0/2	-	-
WIDEROAD	9/12	–0.0495	–0.0470	DISTPOW_400_600 x MOSQUE	0/2	-	-
AIRNOISE	12/12	–0.0014	–0.0010	DISTPOW_600_1000 x MOSQUE	0/2	-	-
RAILNOISE	12/12	–0.0014	–0.0007	DISTPOW_100 x DECON	0/2	-	-
DISTIND	12/12	0.0172	0.0233	DISTPOW_100_200 x DECON	0/2	-	-
ROADNOISE	2/2	–0.0022	–0.0022	DISTPOW_200_400 x DECON	0/2	-	-
ROADNOISE x AIRNOISEZONE	0/1	-	-	DISTPOW_400_600 x DECON	0/2	-	-
ROADNOISE x RAILNOISEZONE	0/1	-	-	DISTPOW_600_1000 x DECON	0/2	-	-
ROADNOISESQ	10/10	–0.000021	–0.000018	CHIME_DAY_POTENTIALITY	0/1	-	-
BUS_NUMBER	0/2	-	-	CHIME_NIGHT_POTENTIALITY	0/1	-	-
DISTSTAT_250	0/12	-	-				