Universität Hamburg

Faculty Economics
and Social Sciences
Chair for Economic Policy

SEBASTIAN BRANDT / WOLFGANG MAENNIG

PERCEIVED EXTERNALITIES OF CELL PHONE BASE STATIONS

THE CASE OF PROPERTY PRICES IN HAMBURG, GERMANY

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University of Hamburg
Faculty Economics and Social Science
Chair for Economic Policy
Von-Melle-Park 5
D-20146 Hamburg | Germany
Tel +49 40 42838 - 4622
Fax +49 40 42838 - 6251
http://www.uni-hamburg.de/economicpolicy/

Editor: Wolfgang Maennig

Sebastian Brandt
University of Hamburg
Faculty Economics and Social Science
Chair for Economic Policy
Von-Melle-Park 5
D-20146 Hamburg | Germany
sebastian_brandt@gmx.net

Wolfgang Maennig
University of Hamburg
Faculty Economics and Social Science
Chair for Economic Policy
Von-Melle-Park 5
D-20146 Hamburg | Germany
Tel +49 40 42838 - 4622
Fax +49 40 42838 - 6251
maennig@econ.uni-hamburg.de

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Sebastian Brandt & Wolfgang Maennig

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 pricing study on this subject for real estates in Europe and the first worldwide which examines the price impact of base stations within a whole metropolis. We distinguish between individual masts and groups of masts. Based on a data set 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, Eternalities, Residential Property Prices, Hamburg
Version: October 2010

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).[1] To ensure comprehensive network connections, cell phone service providers have set up cell phone base stations (CPBS) in over

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[1] Amounts in euro have been converted at the average spot rate of EUR/US$ in 2009, i.e., 1.39. The German market accounted for approx. $31 billion of worldwide sales in 2009 (HANDELSBLATT).

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, 2010a).[2]

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.[3] 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 enhance in 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.[4] 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 & BEAMISH

2 Rather than establish freestanding masts, the majority of cell phone antennas in Hamburg were installed on the roofs of existing buildings.

3 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.

4 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.

(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.

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 (BOND & WANG, 2005).[5] BOND & 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 200 m from newly-built CPBS. While BOND & 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.

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[5] Over the past decades studies on the effects of negative 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 traffic noise (e.g., ANDERSSON et al.), air and (drinking) water pollution (e.g., BAYER et al., 2009, KIMET et al., 2003, LEGGETT & BOCKSTAEL, 2000), high-voltage power lines (e.g., DES ROSIERS, 2002, SIMS & DENT, 2005), waste disposal sites (e.g., IHLANFELDT & TAYLOR, 2004, MCCLUSKEY & RAUSSER, 2003) and nuclear waste (e.g., GAWANDE & JENKINS-SMITH, 2001).

We study the price structure of condominiums in Hamburg, Germany, which were entirely offered for sale a few years after the population had been made aware of the possible health hazards stemming from EMFs.[6] 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 as well as further issues that, according to our knowledge, had not been discussed anywhere else to date.

1) Does the appearance of a CPBS have any effect on the price-distance gradient in the vicinity of such masts?

2) Do the type, appearance and height of buildings on which CPBS are erected also cause negative externalities?

3) How does the impact of CPBS change when we control for type, appearance and height of buildings on which CPBS are erected?

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

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[6] Table VI in the appendix serves as a proxy for the range of media attention on possible health risks in the vicinity of CPBS. As can be seen from the table, the media attention regarding this issue peaked in 2001. In subsequent years, media attention on the issue declined considerably.

(COMMITTEE OF VALUATION EXPERTS IN HAMBURG, 2008) and by using listing prices instead of sales prices.[7] 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 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.[8] As for the remaining 16 significant variables, the coefficient pairs do not deviate from each other by more than 12%. MERLO & 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 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.[9] 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

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[7] 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. (The possible consequences of non-public access to property transaction prices have been discussed in detail by BERRENS & MCKEE, 2004.)

[8] 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%.

[9] GRETHER & 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.

age, size or price category has been observed.[10] 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.

The study area comprises the entire city of Hamburg, which has an area of 755.2 km² 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.[11] 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. 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.[12] 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).

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[10] Unpublished study of F+B GmbH from the year 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.

[11] Initially 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.

[12] 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.

The BSU has also supplied us with a data set for all 1,034[13] locations known to the authorities[14] where CPBS were set up that required a permit[15] within the territory of the City of Hamburg. Among other attributes the data set 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.[16] Table III in the appendix shows that Hamburg, compared to other German states, has the second highest density of base stations (in terms of CPBS per km^2).

3 Empirical methodology

3.1 Hedonic approach and choice of functional form

To assess the effects of CPBS on condominium prices we use hedonic regression techniques (ROSEN, 1974). The hedonic price function can be written as

$$P = f(O, N, L, C), \quad (1)$$

[13] The deviation in the number of antenna locations according to BSU from the 1,343 locations reported by the FEDERAL NETWORK AGENCY, (http://www.bundesnetzagentur.de/cln_1931/DE/Sachgebiete/Telekommunikation/TechRegTelekommunikation/ElektromagnetischeFelderEMF/Statistik/statistik_node.html, Accessed September 13, 2010a). 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.

[14] One CPBS may have several antenna masts, for example, spread out across a rooftop.

[15] 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]).

[16] For CPBS consisting of groups of antenna masts, the distance was measured from the spatial center of the antennas.

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*. *C* is a vector that captures exposure to CPBS.

The choice of the proper parametric form of hedonic regression equation is the subject of several publications (e.g., CASSEL & MENDELSOHN, 1985, CROPPER et al., 1988, HALVORSEN & POLLAKOWSKI 1981, LINNEMAN, 1980). However, 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 & COX, 1964). But, so far, the literature has not overcome the problems of implementing flexible functional forms in the presence of spatial dependence (KIM et al., 2003, LEGGETT & BOCKSTAEL, 2000). As we consider spatial-lag terms in our models described below we use semi-logarithmic functional forms for our analysis.

3.2 Empirical models

Model 1

In model 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 1 can be written as:

$$\ln(P) = \alpha + \beta\ PROP + \gamma\ NEIGH + \delta\ ACCESS + \eta\ NOISE\_VIS\_DIS + \theta\ AUTOREG \quad (2)$$

$$+ \lambda\ TREND + \mu\ DIST\_CPBS + \varepsilon,$$

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.[17] In selecting the

[17] Descriptive statistics of the variables included in the final model specifications are listed in Table I.

variables, we rely on SIRMANS et al. (2005) and WILHELMSSON (2000), who evaluated the control variables most commonly used in hedonic studies.[18] *NEIGH* is a vector of neighborhood characteristics, consisting of the proportion of those aged 65 and older (*ELDERLYPOP*: e.g., AHLFELD & MAENNIG, 2009, AHLFELD & MAENNIG, 2010), the average income (*INCOME*: e.g., ANDERSSON et al., 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 & MACHIN, 2005).

[18] Since SIRMANS et al. (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.

Tab. 1 Variable names, definitions and summary statistics

Variable	Definition	Mean	Std. dev.
Dependent variable			
PRICE	Last asking price of property	185,520	75,474
	Property		
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 ≤ 250 m, 0 otherwise	0.09	0.28
DISTSTAT_250_750	1 if distance to next metro station > 250 m and ≤ 750 m, 0 otherwise	0.48	0.50
DISTSTAT_750_1250	1 if distance to next metro station > 750 m and ≤ 1,250 m, 0 otherwise	0.25	0.44
DISTSTAT_1250_1750	1 if distance to next metro station > 1,250 m and ≤ 1,750 m, 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

Tab. 1 (continued)

Variable	Definition	Mean	Std. dev.
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
	CPBS		
DIST_CPBS_100	1 if distance to next CPBS ≤ 100 m, 0 otherwise	0.11	0.31
DIST_CPBS_200	1 if distance to next CPBS > 100 m and ≤ 200 m, 0 otherwise	0.27	0.45
SMALL_CPBS	1 if height of next CPBS is 5 m or less as defined using aerial photography, 0 otherwise	0.17	0.37
BIG_CPBS	1 if height of next CPBS is more than 5 m 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 IV, 0 otherwise	0.08	0.28
BADVIEW	1 if next CPBS is located on building / construction as defined in column (7) of table IV, 0 otherwise	0.17	0.38
NOISYNEIGH	1 if next CPBS is located on building / construction as defined in column (8) of table IV, 0 otherwise	0.17	0.38

Access to jobs is measured by a gravity variable (BOWES & 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:

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

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, we also take into account a district-internal distance measure d_{ii} (cf. e.g., CRAFTS, 2005).[19] Access to public transport network (e.g., BAUM-SNOW & KAHN, 2000) is 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 & RAMIREZ, 2005) as well as from the nearest bodies of water (Inner and Outer Alster Lake and Elbe River, *DISTWATER*: e.g., GIBBONS & MACHIN, 2005).[20]. *ACCESS* is thus a vector to map the previously discussed accessibility indicators.

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[19] 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 non-graded weights.

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

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 et al., 2007) and that captures the distance to industrial sites (*DISTIND*: e.g., LI & 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 neighborhood (AHLFELDT & MAENNIG, 2009, AHLFELDT & MAENNIG, 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 et al., 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, when $1/d_{ij}$ is the reciprocal distance between the condominiums *i* and *j* [17]:[21]

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

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*.

DIST_CPBS 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 100 m (*DIST_CPBS_100*) or over 100 m and up to 200 m (*DIST_CPBS_200*); otherwise, the

[21] CAN & 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 10.0 km) and found the best fit of the model when we considered properties within a radius of 1 km. In contrast to CAN & 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.

value is 0. According to BOND (2007), we define our external cutoff as 200 m. In contrast to the suburban region analyzed by BOND (2007) (Orange County, Florida), 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 100 m was selected as a second (internal) cutoff.[22] 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.

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.[23] We have also excluded properties where the exact location and construction design of the nearest CPBS could not be identified clearly by means of aerial photography. CPBS installed in church towers or subway ducts (see also Table IV 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 the property prices in the surrounding areas. Therefore, such CPBS were excluded from the evaluations.

Model 2

In Model 2 we take into account the fact that no two CPBS are identical. As Table V in the appendix shows, the number of antenna masts per CPBS can differ consi-

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[22] 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.

[23] We did not have information on the time when each CPBS was brought online.

derably. 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 2 as follows:

$$\ln(P) = \alpha + \beta\ PROP + \gamma\ NEIGH + \delta\ ACCESS + \eta\ NOISE\_VIS\_DIS + \theta\ AUTOREG \quad (5)$$

$$+ \lambda\ TREND + \mu\ DIST\_CPBS + \sigma\ DIST\_CPBS \times STRCUTURE\ + \varepsilon\ ,$$

where *DIST_CPBS* is additionally multiplied by the vector *STRUCTURE*, which represents the dummy variables defined in Table I, *SMALL_CPBS, BIG_CPBS* and *GROUP_CPBS*, whose sum adds up to 1 for each data set. For example, the interactive *DIST_CPBS_100* x *GROUP_CPBS* takes the value 1 for properties within a radius of 100 m from such CPBS which consist of a group of antennas; otherwise, the value is 0.[24] μ and σ are vectors of the coefficients to be estimated.[25] All other terms in equation (5) have the meanings already explained for Model 1.

Model 3

Since CPBS are frequently set up on high-rise apartment buildings, commercial buildings, chimneys or freestanding masts (see also Table IV 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 as follows:

$$\ln(P) = \alpha + \beta\ PROP + \gamma\ NEIGH + \delta\ ACCESS + \eta\ NOISE\_VIS\_DIS + \theta\ AUTOREG \quad (6)$$

[24] The variable SMALL_CPBS and/or BIG_CPBS takes the value 1 if the nearest CPBS is not higher and/or higher than 5 m; otherwise, the value is 0 (see also Table I).

[25] The coefficient of the interactive *DIST_CPBS_100* x *GROUP_CPBS* indicates, for example, the price differential of properties within a radius of 100 m around a group of antennas compared to properties that are located more than 200 m from a CPBS.

$$+ \lambda\, TREND + \mu\, DIST\_CPBS + \sigma\, DIST\_CPBS \times STRUCTURE$$

$$+ \omega\, DIST\_CPBS \times LOCATION + \varepsilon\,,$$

where the vector *DIST_CPBS* is additionally multiplied by *LOCATION*, a vector of the dummy variables defined in Tables I and IV, *MULTISTOREY*, *MAST*, *BADVIEW* and *NOISYNEIGH*. In this context, 100 m and/or 200 m are also plausible cutoffs to capture visual and noise pollution. μ, σ and ω are vectors of the coefficients to be estimated.[26] All other terms in equation (6) 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 II).[27] 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.

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[26] The sum of the variables *MULTISTOREY*, *MAST*, *BADVIEW* & *NOISYNEIGH* does not have to amount to 1. The coefficient of the interactive *DIST_CPBS_100* x *MAST* thus indicates, for example, the price differential of properties within a radius of 100 m around a freestanding cell phone mast compared to properties that are up to 100 m from a non-freestanding mast.

[27] If the models are specified without the spatial lag term, the adjusted R^2 value is reduced by approximately 1.2%.

Tab. 2 Results

	Model 1	Model 2	Model 3
CONSTANT	8.5537***	8.5470***	8.5683***
Property			
SIZE	0.0131***	0.0131***	0.0131***
SIZESQ	-0.000009***	-0.000009***	-0.000009***
AGE	-0.0130***	-0.0130***	-0.0131***
AGESQ	0.0001***	0.0001***	0.0001***
ROOMS	0.0271*	0.0271*	0.0273*
GARAGE	0.0389***	0.0394***	0.0395***
BALCONY	0.0414***	0.0415***	0.0420***
TERRACE	0.0412***	0.0404***	0.0393***
KITCHEN	0.0486***	0.0484***	0.0479***
POOL	0.0385	0.0372	0.0364
FIREPLACE	0.0176	0.0139	0.0130
GOODCOND	0.0406***	0.0407***	0.0426***
BADCOND	-0.1114***	-0.1110***	-0.1109***
Neighborhood			
ELDERLYPOP	-0.0028***	-0.0027***	-0.0025***
INCOME	0.0029***	0.0030***	0.0029***
FOREIGNPOP	-0.0051***	-0.0050***	-0.0049***
SOCHOUSE	-0.0002**	-0.0002**	-0.0002**
Accessibility			
DISTCENT	-0.0194***	-0.0185***	-0.0173***
EMPGRAV	0.000002***	0.000002***	0.000002***
DISTSTAT 250	-0.0074	-0.0075	-0.0100
DISTSTAT 250 750	0.0325*	0.0340*	0.0361*
DISTSTAT 750 1250	0.0062	0.0050	0.0057
DISTSTAT 1250 1750	0.0056	0.0046	0.0063
DISTWATER	-0.0065***	-0.0066***	-0.0073***
DISTPARK	-0.0572***	-0.0544***	-0.0533***
Noise exposure / visual disamenities			
WIDEROAD	-0.0225	-0.0222	-0.0208
ROADNOISESQ	-0.000022***	-0.000021***	-0.000021***
AIRNOISE	-0.0015***	-0.0015***	-0.0015***
RAILNOISE	-0.0014***	-0.0014***	-0.0013***
DISTIND	0.0147	0.0156*	0.0162*

Tab. 2 (continued)

	Model 1	Model 2	Model 3
CPBS			
DIST CPBS 100	-0.0222*		
DIST CPBS 200	-0.0135		
DIST CPBS 100 x SMALL CPBS		0.0241	0.0257
DIST CPBS 200 x SMALL CPBS		-0.0079	0.0090
DIST CPBS 100 x BIG CPBS		0.0077	0.0098
DIST CPBS 200 x BIG CPBS		-0.0031	0.0229
DIST CPBS 100 x GROUP CPBS		-0.0559***	-0.0516**
DIST CPBS 200 x GROUP CPBS		-0.0193*	0.0122
DIST CPBS 100 x MULTISTOREY			-0.0560***
DIST CPBS 200 x MULTISTOREY			-0.0072
DIST CPBS 100 x MAST			0.0271
DIST CPBS 200 x MAST			-0.0130
DIST CPBS 100 x BADVIEW			-0.0463**
DIST CPBS 200 x BADVIEW			0.0286
DIST CPBS 100 x NOISYNEIGH			-0.0284
DIST_CPBS_200 x NOISYNEIGH			-0.0021
Spatial lag term	YES	YES	YES
Number of observations	4,348	4,348	4,348
White's correction	YES	YES	YES
R^2	0.87367	0.87403	0.87461
Adjusted R^2	0.87252	0.87277	0.87312

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. 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 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.[28] Among the neighborhood variables only the relationship between average income (*INCOME*) and condominium prices is positive. All other coefficients of neighborhood

[28] Following HALVORSEN & 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.

indicators show negative signs. While only properties within 250 m to 750 m 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 1,750 m 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[29]

The significantly negative coefficient of *DIST_CPBS_100* in Model 1 shows price discounts in the amount of 2.2% within a radius of 100 m around CPBS (compared to properties that are located at a distance of more than 200 m from the nearest CPBS). For distances of more than 100 m and up to 200 m around base stations (*DIST_CPBS_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 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 100 m and/or within a radius of 100 m to 200 m around groups of antenna masts (*DIST_CPBS_100 x GROUP_CPBS* and/or *DIST_CPBS_200*

[29] Since for all models the results are independent of whether the lag term is included or not, we do not adjust our estimates for spatial correlation (ANDERSSON et al., 2010).

x GROUP_CPBS) we observe condominium price discounts of 5.6% and/or 1.9% compared to properties that are located more than 200 m 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 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 100 m around groups of antenna masts (*DIST_CPBS_100 x GROUP_CPBS*). *DIST_CPBS_200 x GROUP_CPBS* is, in fact, insignificant. The regressors of the two interactives now represent price differences of properties within a radius of 100 m and/or 100 m to 200 m 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 200 m from a CPBS. In the immediate vicinity of base stations on high-rise buildings (*DIST_CPBS_100 x MULTISTOREY*) and/or close to locations exposed to a visual disamenity (*DIST_CPBS_100 x BADVIEW*), we observe further price discounts. These property price reductions amount to 5.6% and/or 4.6% when compared to properties at a distance of up to 100 m 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 100 m 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

Technical background

Cellular radio waves, like radio waves, are in the high-frequency range (10 MHz to 300 GHz). The transmitting power of CPBS is much lower than that of radio and TV broadcast transmitters. Their transmission frequency, however, is higher. UMTS[30] is the most recent cell phone standard and has been available commercially in Germany since 2004. Given its technical requirements, the UMTS network needs a relatively regular spatial arrangement of base stations. An even distribu-

[30] UMTS = Universal Mobile Telecommunications System

tion of CPBS also requires less transmitting power, thus reducing potential health risks to residents. Further criteria for the choice of location of CPBS are provided by BOND & WANG (2005).

EMF exposure standards

The maximum exposure limits for EMFs generated by CPBS in Germany are based, like in most other countries, on the recommendations of the "International Commission on Non-Ionizing Radiation Protection" (ICNIRP) issued in 1998 (ICNIRP, 1998). More restrictive limits than those recommended by the ICNIRP are currently in place, for example, in Belgium, China, Italy, New Zealand, Poland, Russia and Switzerland. The definition of maximum exposure limits is based on the Specific Absorption Rate (SAR), which indicates the energy absorption in watts per kilogram (W/kg). To ensure the protection of the population against the effects of high-frequency radiation, the base levels were defined in such a way that an additional warming of parts of the body by more than one degree Celsius can be excluded. This is guaranteed at a whole-body SAR of 1 to 4 W/kg over a period of 30 minutes (ICNIRP, 1998). To arrive at a limit value that also accounts for permanent exposure to high-frequency electromagnetic fields (e.g., in one's residential environment), a safety factor of 50 has been established. The whole-body SAR threshold for the general population is thus 0.08 W/kg. Readings will remain below such threshold, in the view of the ICNIRP, if the electric field strength and/or power flux density, depending on the frequency range of the cellular network, does not exceed 41 V/m to 61 V/m and/or 4.5 W/m^2 to 10 W/m^2 (ICNIRP, 1998).

Since 2003, the Federal Network Agency in Germany has conducted annual measurements at 2,000 locations to determine the overall exposure to EMF in a frequency range from 9 kHz to 300 GHz. The tests of the Federal Network Agency have shown that the EMF emissions in the frequency range of CPBS remained constant during the period under review and that, on average, only 0.07% of the statutory exposure limits have been exhausted in recent years, with a maximum utilization rate of 6.67%.[31]

Tab. 3 Number and density of CPBS (in Germany)

German Federal Land	Number of CPBS[1]	Number of CPBS[1] / area in km² [2]	Population[2] / number of CPBS[1]
Berlin	2,890	3.24	1,187
Hamburg	1,343	1.78	1,320
Bremen	419	1.04	1,580
North Rhine-Westphalia	13,610	0.40	1,318
Saarland	871	0.34	1,183
Baden-Württemberg	8,377	0.23	1,283
Hesse	4,901	0.23	1,237
Saxony	4,231	0.23	991
Rhineland-Palatinate	3,489	0.18	1,155
Bavaria	10,685	0.15	1,172
Thuringia	2,263	0.14	1,002
Schleswig-Holstein	2,035	0.13	1,393
Lower Saxony	6,004	0.13	1,324
Saxony-Anhalt	2,481	0.12	960
Brandenburg	2,674	0.09	943
Mecklenburg-West Pomerania	1,970	0.08	845
Germany	68,243	0.19	1,202

[1] Source: FEDERAL NETWORK AGENCY (December 31, 2009)

[2] Source: FEDERAL STATISTICAL OFFICE (December 31, 2008)

[31] Authors' own analysis, data based on: EMF database of the Federal Network Agency (FEDERAL NETWORK AGENCY, 2010b).

Tab. 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

Tab. 5 Number of cell phone antennas per location (in Germany)

Number of cell phone antennas per location	Proportion of locations
1	42%
2	30%
3	12%
4	8%
5	4%
6	2%
more than 6	2%

[1] Source: FEDERAL NETWORK AGENCY (December 31, 2009)

Tab. 6 Number of mentions of the terms 'mobile telephony' and 'health risks' in German national print media sources

Year	Number of mentions
1998	40
1999	71
2000	119
2001	269
2002	193
2003	86
2004	95
2005	58
2006	75
2007	54
2008	57

Notes: Source is GENIOS Pressequellen. Full text search for the terms 'mobile telephony' and 'health risks'. Results if an item contains combinations of the two terms.

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