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External productivity and utility effects of city airports

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Abstract: This paper uses a micro-level data set for residential and commercial property transactions to investigate external utility and productivity effects for three (city) airports in Berlin, Germany in a spatial hedonic analysis. We find strong evidence of adverse noise effects on property prices and a discontinuity at approximately 55dB. Marginal price effects decrease significantly in the presence of alternative noise sources, which can lead to biased estimates if the interaction effect is not accounted for appropriately. Given that there is less evidence of positive accessibility effects, our result questions the justification for locating airports in citycentres.

Keywords: Accessibility, aircraft noise, commercial properties, residential properties, hedonic analysis

FORTHCOMING IN REGIONAL STUDIES

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1.0 INTRODUCTION

While large cities depend on major airports carrying out hub functions to provide various international non-stop connections, smaller downtown business airports are much appreciated by businessmen due to their accessibility. Neighbourhood activists usually oppose these airports, mainly because of extensive noise pollution and emissions. Opposition obviously becomes stronger the more central airports are located, since population density is typically found to be much higher in downtown areas. As a consequence, local authorities are confronted with two conflicting interests, emphasizing the role of downtown airports as a location factor to attract businesses on the one hand and the necessity of protecting local residents' living quality on the other. The case of Berlin stands exemplarily for such conflicts. Political opposition to the scheduled closure of city-airport

Tempelhof became large enough to enforce a public referendum, which finally failed. To make appropriate decisions, politicians have to rely on valid information about the extent to which residents and businesses are effectively exposed to the external effects mentioned.

Quantifying (city) airport externalities, however, is difficult in practice as residents and firms have no incentive to reveal the true (dis)amenties they incur from a nearby airport. Instead, they exaggerate (perceived) benefits and costs in a political bargaining process in order to seek rents.(Social) cost benefit analyses rely on large sets of assumptions regarding the cost of travel time and noise, which are difficult to ascertain. Spatial property market analyses offer a way to circumvent these problems. Following bid-rent theory, all kind of positive and negative accessibility effects and environmental externalities can be assumed to capitalize into property prices as they affect the willingness to pay of the marginal buyer. An evaluation of urban property markets therefore qualifies as a natural starting point of a welfare analysis of airport externalities based on the revealed preferences of market participants.

Property price effects of airports have, therefore, attracted scholars' attention. Bell (2001) provides a survey on the impact on residents' physical condition and introduces effects on property prices. Most empirical studies available so far focus on North America (Mieszkowski&Saper, 1978; Nelson, 1979; Uyeno, Hamilton, & Biggs, 1993) or United Kingdom, where Manchester Airport has attracted much attention (Collins & Evans, 1994; Pennington, Topham, & Ward, 1990; Tomkins, Topham, Twomey, & Ward, 1998). For Continental Europe evidence is available for airports located in Oslo, Basel, Paris and Amsterdam (Navrud, 2002). However, with the exception of Weigt (2007), there is still little evidence available for German Airports. Surveys on the empirical literature reveal that airports are clearly found to adversely affect property values (Nelson, 1980; Van Praag& Baarsma, 2005). Meta-analyses on hedonic price aircraft noise studies are provided by Schipper, Nijkamp, &Rietveld(2002) and Nelson (2004). An alternative approach to the evaluation of airport externalities was used by Nitsch(2009), who analysed residents' preferences as stated in a public poll conducted by opponents to the closure of Tempelhof Airport in Berlin, one of the airports analysed in this study.

This article adds to the existing literature in numerous important ways: First, it analyses the effects of three airports, Tegel (IATACode: TXL), Tempelhof (IATACode: THF) and Schönefeld (IATA Code: SXF) in one city. Two of the three airports (TLX and THF)are clearly city airports, whereas most airports in the studies mentioned above are outside cities. Second, it investigates the impact of airport externalities on three different submarkets. Two residential submarkets are considered to assess airport effects on household utility: typically owner-occupied detached and semi-detached houses and typically renter-occupied multi-family houses. The third submarket comprises commercial properties. This facilitates the evaluation of external productivity effects, which have been the focus of less attention in the literature. Third, we assess not only negative effects related to aircraft noise, but also positive externalities arising from access to flight connections, which we approximate using(weighted average) road network distances to airports. Although we find strong evidence of adverse productivity and utility effects arising from noise exposure, the evidence is less compelling for positive accessibility effects. Nevertheless, estimated noise effects can be biased if accessibility effects are not accounted for in empirical models. Fourth, the impact of aircraft noise is estimated not only conditional on alternative noise sources, but also in interaction with other sources. We show that estimated noise effects may be severely biased if these interactions are not accounted for appropriately. Finally, we show how a simple regression-based interpolation approach can help to overcome data limitations by generating a continuous noise surface where only limited (discrete) data are available.

We use GIS tools and projected GIS maps to analyse a highly disaggregated dataset covering a broad range of structural, location and neighbourhood characteristics. Our models use potentiality variables and include attributes such as neighbourhood historic quality, which has received little attention in the literature until recently. Where appropriate, we correct for a spatial auto-regressive structure in the price-generating process or a spatial structure in the error term by applying SAR models. The remainder of this article is organized as follows. In the next section we discuss the airports within the study area in more detail. Section 3 discusses the empirical strategy and data issues. Results are presented in Section 4 and conclusions in the final section.

2.0 BERLIN AIRPORTS

The official inauguration of Tempelhof airport was in 1923. After complete redevelopment during the national socialist regime, Tempelhof was clearly Germany's most important air hub with a maximum capacity of 6 million passengers a year, exceeding the effective 1934 numbers by a factor of thirty. These dimensions, the facility design and architectural and historical particularities have frequently been discussed (Carré, 2000; Demps& Paeschke, 1998; Meuser, 2000; Schmitz, 1997). Tempelhof later became internationally prominent as Berlin's most important access point for the 1948-49 airlift established to supply West Berlin residents during the Berlin Blockade. To provide the necessary capacity, two more airports were conceptualised, one of which was Tegel Airport, jointly operated by the French since 1948.

By the mid 20th century, Berlin possessed a decent infrastructure for air traffic and was preparing itself to benefit from the rapidly growing market. However, Berlin soon lost its status as Germany's pre-eminent hub, mainly due to the loss of market access following Germany's division(Redding, Sturm, & Wolf, in press). West Berlin became completely surrounded by the Soviet zone of occupation. While the most important West Germany counterpart of the airlift – Frankfurt – emerged as Germany's new pre-eminent hub, generating more and more traffic and continuously expanding facilities, improvements in air traffic infrastructure in West Berlin remained relatively modest.

As no reserve space for extension of facilities was available in Tempelhof due to its downtown location, Tegel Airport was opened for civilian air traffic in 1960 to meet the demands generated by increasing national and international air traffic, and the fact that a flight connection was the only way of travelling between West Berlin and West Germany avoiding border controls. In 1974,a new civilian terminal in the south of Tegel airfield replaced the existing facilities which subsequently have been used for military and governmental purposes only.

Following the inauguration of the new Tegel Airport, Tempelhof Airport was closed until 1984 when it was reopened mainly for smaller airplanes utilized by business travellers. Despite minor extensions during the following decades, Tegel Airport kept moderate size. Even experiencing a considerable capacity overload (Steinke, 2006), the number of served passengers at Berlin's Tegel Airport has hardly exceeded 13 million per year, a relatively small number compared to 52 million at Fankfurt or even over 67 million at London Heathrow in 2005. Figure 1 shows passenger traffic at Berlin airports since reunification in 1990.

[Figure 1 about here]

As noted above, the capacity of both airports is restricted by their central location and good accessibility. Compared to the city airports at Tegel and Tempelhof, the location of Schönefeld, which served East Berlin and its surroundings during the division period, is remote. In recent years, Schönefeld, which will be redeveloped as the new Berlin Brandenburg International (BBI) Airport, has become much appreciated by low-cost carriers due to low operating costs. However, Tegel continues being the most important airport for business flights and the only airport in Berlin to offer intercontinental connections.

While Tegel Airport will continue in operation until 2011, when the new BBI Airport is scheduled to be inaugurated, Tempelhof airport was closed on October 31, 2008. The external effects of Tempelhof Airport were judged differently by citizens: Some neighbourhood activist movements favoured the final shutdown, while the Interest Group of City Airport Tempelhof (ICAT) successfully held a referendum in favour of Tempelhof Airport remaining in operation. The poll was held on April 27, 2008 and won the approval of the majority of voters, but failed to achieve the minimum quorum of 25% ‘Yes’ votes of the total electorate. Legal claims of airlines opposing Tegel’s closure have not been successful.

3.0 EMPIRICAL STRATEGY

Following standard rent theory, spatial variation in the value of urban land, net of commuting cost, reflects productivity or utility differentials that drive bid rent functions of residents and firms. In principle, access to airports may be expected to increase the productivity of firms by providing fast access to other regions and national markets and reducing transaction, communication and information costs. If accessibility to other regions’ markets significantly impacts on the economic performance of regions and cities, then city areas close to transportation nodes such as airports should particularly benefit from regional integration given that journeys to and from airports are time-consuming. If productivity effects are significant we would, all other factors being equal, expect increasing bids and equilibrium land prices in closer proximity to airports. Within air corridors, however, the exposure to aircraft noise should exhibit an adverse effect on worker productivity and therefore decrease bids and equilibrium prices, conditional on access to fight connections and other factors. Similarly, households living closer to airports may experience an increase in utility due to fast access to flight connections and travel opportunities and a decline in utility from the exposure to aircraft noise, which is a clear disamenity. The proximity effect of an airport is a net-effect of both, which following conventional praxis in the real estate economics literature can be identified in a hedonic regression analysis (Rosen, 1974).

Our empirical analyses are conducted for three distinct submarkets, a) one/two family houses, town houses and villas, b) multi-family houses and c) commercial properties. While submarkets a) and b) serve as a basis for an evaluation of household utility, submarket c) analogically yields insights into productivity effects. Distinguishing the residential market into submarket a) and b) potentially yields further interesting insights, given the very distinct tenure structure. Sub-market a) is closest to the vast majority of the existing literature on the impact of air-craft noise, which has focused on owner occupied detached housing. A particularly interesting characteristic of the multi-family housing market in Berlin (submarket b) is the very low rate of owner occupancy. Although we cannot observe the rate of owner occupancy directly, comparison of submarkets a) and b) still allow for an evaluation of the impact of aircraft noise on a) an owner-occupied and b) a rental market. The price of multi-family properties with rented units reflects the expected cash flow of discounted rent streams. Given the lower mobility cost for renters, we expect renters to be less risk averse with regards to the potential (dis)utility effect of aircraft noise, which they will usually be uncertain about before moving in. This could result in a lower marginal price effect of aircraft noise within the residential market (b) compared to the owner-occupied market a).

Besides distinguishing into three separate submarkets, we first separately focus on the impact areas of the three airports in order to increase homogeneity within the reduced study areas, which encompass very different submarkets and potentially exhibit heterogeneity in implicit prices of various housing and location characteristics. In the second step we pool the data across the entire city area to estimate an average treatment effect for the noise exposure as well as airport accessibility effects. Last, we investigate how individual sources of noise are perceived in interaction, i.e. if the disamenity effect of aircraft noise increases or decreases in the presence of street noise.

Empirical specification

We employ a standard hedonic specification controlling for structural (*S*) as well as locational (*L*) and neighborhood (*N*) characteristics in order to estimate the conditional impact of access to airports and aircraft noise on the log of price per square meter of land (*P*). Given that the airport proximity effect potentially is a net-effect of accessibility and noise, failure of controlling for either of the two effects may lead to biased coefficients.

(1) $$\log(P_{it}) = \sum_k \alpha_k S_{ik} + \sum_l \beta_l L_{il} + \sum_m \gamma_m N_{im} + \sum_t \delta_t EAST_{it} \times \varphi_t + f\left(AA_{ij}\right) + g(AN_{ij}) + \varphi_t + \varepsilon_{it}$$

, where φ_t is a full set of year fixed effects and ε_{it} is an error term. All other Greek letters are parameters. *EAST* is a dummy denoting all transactions within the eastern part of the formerly separated city. This specification is set up to detect localized externalities at an intra-city scale as this article contributes to the discussion of the optimal location of airports within a city or region. All factors that impact on the study area as whole are captured by time effects φ_t.In order to capture the gradual reduction in the price differential between both city parts (Ahlfeldt, 2010b) the *EAST* dummy is interacted with a set of year dummies. Hedonic controls include a conventional set of structural characteristics as well as broad and established sets of neighborhood attributes and environmental (dis)amenities (Ahlfeldt, 2010a) . Table A1 in the appendix provides a description of variables used in the hedonic models. *AA* is an indicator of airport accessibility to airport *j*. As a default we use road distance measures to terminals (*DA*) of all airports.

(2) $$f(AA_{ij}) = \sum_j \theta_j DA_{ij}$$

At city-wide scale we also use an alternative airport accessibility indicator. Instead of estimating the marginal price effects for all three airports individually, we estimate the marginal price effect for the average distance to airport terminals (*ADA*), weighted by airports' proportions at overall air traffic (n_j/N). While being slightly more restrictive, this functional specification still accounts for the size of the airports in the study areas and correspondingly heterogeneous effects while at the same time reducing the sensitivity to correlations of airport distances with unobserved neighborhood or location characteristics.

(3) $$f(AA_{ij}) = ADA_i = \theta \sum_j \frac{n_j}{N} DA_{ij}$$

Given the non-linear log scale of the decibel scale and the unknown subjective perception of noise, we estimate the unknown non-linear relation between aircraft noise level and the (log) of land price per square meter *g*(*AN*) rather than assuming a log-linear functional form ex-ante. We make use of dummy variables denoting 5 db grid cells (e.g. 50-55) and employ difference based semi-parametric estimation techniques (Lokshin, 2006). Informed by non-parametric estimates, the true functional relationship can then be approximated by an appropriate parametric specification.

Note that the vector ΣL_l in specification (1) includes street noise as the most important alternative source of noise, so that specification (1) yields and estimate of aircraft noise effects, conditional on the effect of street noise. Specification (1), however, treats both sources of noise as independent, which not necessarily has to be true. Let´s assume that household utility (*U*) is a function of both air noise (*A*) and street noise (*R*) and other factors (*Z*) that are independent from both: $U = h(A, R, Z)$. Clearly, we expect that ${\partial U}/{\partial A} < 0$ and ${\partial U}/{\partial R} < 0$. If *A* and *R* are not independent, it follows that ${\partial U'}/{\partial A} \lesseqgtr 0$ and ${\partial U'}/{\partial R} \lesseqgtr 0$. In principle, second-order derivatives may be negative, if both sources of noise are perceived to amplify each other, or positive, if the marginal utility effect of one source of noise becomes smaller in the presence of another. This rationale applies analogically to marginal productivity effect. As a result, the marginal effect on property prices for each of the noise sources may depend on the presence of the alternative noise source. The hypothesis of a dependency among the two sources of noise can be tested empirically by introducing an interactive term of air noise (*AN*) and street noise (*SN*) into specification (1).

(4) $$\log(P_{it}) = \sum_k \alpha_k S_{ik} + \sum_l \beta_l L_{il} + \sum_m \gamma_m N_{im} + \sum_t \delta_t EAST_{it} \times \varphi_t + f(AA_{ij}) + g\big(AN_{ij}\big) + \psi\, AN_i \times SN_i + \varphi_t + \varepsilon_{it}$$

Parameter ψ then gives the change in marginal utility (productivity) effect as the level of alternative noise increases by 1 db. If one of the two noise sources is perceived as dominating, so that the presence of an alternative source of noise adds less to the perceived disutility (disproductivity) of residents (workers), ψ will be positive.

In line with the common strategy in applied urban economics research we control for various location attributes by a distance to the nearest feature measures (e.g. distance to the nearest green space, rail station, etc.). The implicit assumption underlying the inclusion of these variables is that the value of these features, discounted by distance, is traded against the land price. Similarly, building on the traditional framework of rent theory, hedonic studies typically control for the distance to the central business district (CBD). As Berlin exhibits a highly polycentric structure, with two dominating business areas, we include the minimum distance to the western (Breitscheidplatz) or the eastern CBD (metro station “Stadtmitte”) in our specifications.[1] Moreover, we calculate an employment potentiality as a detailed labour market accessibility indicator following Ahlfeldt (2010a). Transaction *i* receives the employment potentiality of the precincts *v* it falls within (EP_{iv}) , which is the aggregate of employment within all 1201 precincts in Berlin and 206 sur-

[1] This specification implicitly treats both centres as perfect substitutes, which is in line with the definition of the Senate Department (Senatsverwaltung für Wirtschaft Arbeit und Frauen, 2004). This specification also avoids collinearity problems compared to the alternative of introducing distances to both CBD individually.

rounding municipalities within a 50 km buffer zone from the city´s outboundaries, weighted by (car) travel time (tt_{vw}).[2]

(5) $$EP_{iv} = \sum_w E_w \exp\left(-\tau tt_{vw}\right)$$

Analogically we calculate a green and water potentiality as the distance weighted sum of surrounding water or green areas to better capture the endowment with natural amenities. This is particularly important in this analysis since Tegel Airport lies within a major recreational area and our objective is to estimate the impact of the adverse environmental quality due to noise emissions net of the utility derived from these amenities. Green (*GP*) and water (*WP*) potentialities are calculated as the distance-weighted sum of the surface area for green and water spaces, respectively, at the level of 15,937 statistical blocks, which are connected by a straight-line distance matrix (in km). To reflect car (employment) and walking (green and water) speed we employ spatial discount parameters of 0.1 (car) and 2 (green and water) following Ahlfeldt(2010a)and Ahlfeldt (2009) and Ahlfeldt & Maennig(2010) respectively.[3] All potentialities enter the empirical specifications in logarithms so that coefficients can be interpreted as elasticities. Besides the potentiality variables another variable is worth mentioning, which is less common in the applied urban and real estate economics literature: the number of designated landmarks within 600 m, a threshold based on Ahlfeldt & Maennig (2010). This variable accounts for the historic quality of the neighbourhood, which is receiving increasing attention in the literature.[4]

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2 The internal distance for precinct *i* $\frac{1}{2}\sqrt{\frac{area_i}{\pi}}$ is calculated on the basis of its surface area ($area_i$) (seeKeeble, Owens, & Thompson, 1982).See Ahlfeldt(2010a).

3 The car discount parameter (0.1) is based on a gravity type urban labour market accessibility model for the metropolitain area for Berlin. The walking (2) discount parameter was set to yield and exponential cost functionthat converges towards zero at a maximum walking distance of 2 km.

4 See Coulson & Lahr (2005) and Ahlfeldt & Maennig (2010) for recentexamples for the U.S. and Europe.

Note that with relatively few exceptions, we find a systematic spatial structure in the error term, which is typical for micro level spatial analyses. We use spatial autoregressive (SAR) models to obtain unbiased and efficient estimates in the presence of spatial dependency. LM tests in most of these cases reject a spatial-lag model in favor of an error-corrections model.

(6) $\varepsilon = \lambda W \varepsilon + \mu$

where W is a binary row standardized weights matrix indicating transactions that are neighbours, λ is a parameter and μ is a random error term.[5] In few cases, however, a weak autoregressive structure seems to be resent in the price generating process so that a spatial-lag model is employed as a robustness check.

(7) $y = \rho W y + Z a + \mu$

where y is our endogenous variable, Z is a vector of variables included in specification (1), a is the respective coefficient vector and ρ the lag parameter. Note that in spatial lag-models, coefficients need to be adjusted before the usual interpretation applies. It can be shown that using a row standardized spatial weights matrix, the appropriate "spatial" multiplier for the estimated coefficients is $1/(1-\rho)$ (see e.g. Won Kim, Phipps, & Anselin, 2003). Spatial error-correction models as well as spatial lag-models are estimated using maximum likelihood techniques.

Data

In the present analysis we make use of an exhaustive record of 32,763 transactions of developed properties that took place between January 1, 2000 and December 31, 2007 within the boundaries

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[5] Wedefine transactions as neighbors if they occur within a 500 m radius. In very few cases where not transaction occured within the threshold, we define the nearest transaction as neighbor. The specification generally produces-similar resuls to an alternative weights matrix with inverse distance weights. We prefer the binary weights matrix since inverse distance weights in some of our models with a limited geographic scope and few observations tend to produce a strong spatial smooth.

of the Federal State of Berlin, Germany.[6] This study period stops almost 17 month before April 27, 2008, when the referendum confirmed that Tempelhof would be closed. Our data set is a complete record, covering transactions for commercial (1,474) and residential properties (31,289), which following rent theory facilitate the evaluation of the impact of accessibility and environmental quality on the productivity of land (commercial land) as well as on household utility and location desirability (residential land). Throughout our empirical analyses, we distinguish residential transactions into transactions of properties of a) on/two-family houses, townhouses and villas (15,199 observations) and b) multi-family houses (14,998 observations).

The transaction data provided by the Committee of Valuation Experts in Berlin (2008) includes the usual parameters such as age, floor space, plot area, storeys as well as information on land use, physical conditionand building type. Employing a GIS-environment, property transactions were geo-referenced based on geographic coordinates and merged with the framework of the Urban and Environmental Information System of the Senate Department of Berlin (Senatsverwaltung für Stadtentwicklung Berlin, 2006). Within this GIS-environment, additional environmental control variables capturing the impact of natural and environmental amenities, transport and public infrastructure and built heritage, as well as noise emissions and airport accessibility variables could be generated. All distances are precise at least at a 6 digit level and accurate to the level of addresses when referring to transactions. When referring to precincts or blocks, distances strictly refer to their geographic centroids. Within the GIS-environment, neighborhood data are merged that were available for 15,937 statistical blocks (population by age and origin, all referring to 2005, and employment at workplace, referring to 2003), 338 traffic cells (rate of unemployment,

6 Onlyrelatively few observations had to beexcludedfrom the full record due to missing values in crucial characteristicss. No signs for a sample selection bias were found.

referring to 2005) or 191 zip codes (purchasing power, referring to 2008).[7] With the exception of purchasing power, which was bought from the market research organization GfK, these data were provided by the State Statistical Institute Berlin-Brandenburg.

The primary variables of interest used to assess the external effects are indicators of access to the flight connections offered by the three (city) airports as well as the exposure to aircraft noise within the affected neighborhoods. Access to the airports is measured by the effective road distance from every individual transaction to the terminal buildings of the three airports. A distance matrix is created on the basis of the full Berlin road map built-in in MS Mappoint 2009. From an official report (Laermkartierung nach Umgebungsrichtline, 09.07.2007),data on exposure to street noise and aircraft noise for Tegel Airport were available at a very detailed level of 10x10m grid cells. The noise map for Tegel Airport covers approximately the northern half of the city, including the air corridors. Within this area, noise levels are recorded for all developed properties and expressed in an equivalent long-term sound pressure index (L_{den}) in the standard log decibel-scale (dB). These official records refer to the effective sound pressure at facades and take into account all physical obstacles that potentially affect noise patterns.

Officially, local authorities are required to determine noise protection zones where land use activities are restricted for all airports. For Tempelhof, however, the noise protection zone defined on the basis of an equivalent long-term sound pressure level of more than 67 dB(A) zone hardly exceeds the territory of the airport and is therefore of little use in the present analysis. The best available data that could be obtained were from the Berlin airports operating company (Flughafengesellschaft) in form of an electronic map for which sound pressure levels ranging from 50-55, 55-60, 60-65, 65-67 and more than 67 dB(A) are defined. Based on these discrete

7 Data on employment at workplace include all employees contributing to social insurances.

information, we employ a simple regression based interpolation approach in order to generated a detailed continuous noise surface that is compatible with the official information for Tegel airport. Therefore, in the first step we define an auxiliary 100 m×100m grid and a new coordinate system with an origin in the airfield centroid and the x-axis running parallel to the air corridor. Moreover, we define a 350m buffer around the outmost zone where we assume a noise pressure of 45–50dB. In the next step, a naive average of noise pressure (e.g. 52.5 for the 50-55 zone) as well x- and y-coordinates within the auxiliary coordinate system are assigned to the newly generated grid points(g). A regression of average noise pressure (NL) on third order polynomial vectors of x- ($X = x+x^2+x^3$) and y- ($Y=+y+y^2+y^3$) coordinates (suppressing negative signs), interactions of both ($X \times Y=xy+(xy)^2+(yx)^3$) and a full set of interactive terms with dummies denoting the northern (N) and the western (W) quadrants of the coordinate system yields predicted values of noise exposure for about 10,000 gird points (g) in the area.

$$NL_g = \begin{bmatrix} |X_g|a_1 + |Y_g|a_2 + |X_g \times Y_g|a_3 \\ +|N_g \times X_g|b_1 + |N_g \times Y_g|b_2 + |N_g \times X_g \times Y_g|b_3 \\ +|W_g \times X_g|c_1 + |W_g \times Y_g|c_2 + |W_g \times X_g \times Y_g|c_3 \end{bmatrix} + \omega_g \quad (8)$$

, where lower case letters form the set of parameters and ω is an error term. Based on the estimated parameter vectors ($\widehat{a_1} - \widehat{c_3}$)the level of noise exposure can be predicted for the about 10,000 grid points (g) in the area.

Naturally, this approach is better suited for producing reliable interpolations rather than extrapolations, so that we only keep grid points with a predicted value larger than 45dB. Overall, the procedure yields a reasonable fit as suggested by a R^2 of 81.5 and a close fit of obtained and imputed noise level along the zone boundaries (see Figure2). One limitation of this approach is that physical obstacles within a pre-defined noise-zone are not taken into account by the interpolated values. We note, however, that there are no evident obstacles, e.g. high-rise buildings, elevated roads or railways, evident for the noise impact area.

[Figure 2 about here]

For Schoenefeld airport, noise information is even more restricted. As the airport lies outside the boundaries of Berlin, with only a relatively small part of the air corridor crossing Berlin territory, no detailed noise maps were included into the noise report. The only available information therefore is a map of the area of restricted development, which, however, already takes into account that noise levels will increase considerably when the new international airport BBI will be inaugurated. Based on this zone of restricted development we further define a 3 km buffer zone. Figure3shows the study area and the areas exposed to considerable aircraft noise. Evidently, the noise emissions follow the extensions of runways, which run parallel in east-west direction in each case. Note that for Tegel airport the available noise data covers a much larger area, but we restrict the visualization to the area where noise exposure exceeds a threshold of 45 dB so that the scale is compatible with Tempelhof. We make use of the GIS-environment to assign transactions to noise levels and zones displayed in Figure 3.

[Figure 3 about here]

4.0 EMPIRICAL RESULTS

Airport impact areas: Residential

As discussed, Tegel Airport during the study period was the most important airport within the region and by far the most important of the two city airports. We start our empirical analyses for the residential submarkets a) and b) within the TXL impact area where aircraft noise exceeds a 40 dB level. Below this threshold, aircraft noise should hardly play an important role within an urban environment where the usual alternative noise sources are present. Table 1 presents a series of estimations following equation (1) that permit inference on the disutility effects of aircraft noise.

Column (1) shows results for a set of mutually exclusive 5-dB grid cell dummies for submarket a), starting at a 45-50 dB noise level. Coefficients on the grid cell dummies give the average price differential within the respective zones relative to the base zone with a noise level of 40-45 dB. Results indicate non-significant price effects up to a level of 50-55 dB and negative and significant price discounts at higher noise levels. While properties within the 55-60 dB zone sell at moderate discounts of about 7% compared to otherwise comparable properties, properties that are exposed to an equivalent sound pressure of more than 70 dB sell at discounts of more than 40%.[8] For an average property in our sample this implies an absolute reduction in sales price of close to €88,000.[9] These results are in line with a large negative impact on household utility and indicate a non-linear impact with a discontinuity around 55 dB. Price differentials remain virtually unchanged if estimated conditional on airport accessibility, measured as the road distance to the TXL terminal (column 2).

These results stand in sharp contrast to the corresponding findings for submarket b shown in column (3). While, as discussed, a smaller discount might be expected for submarket b) and renter occupied multi-family houses, the entire absence of significant effects is certainly surprising. For none of the noise zones, however, are there significant price differentials observable. Not even are there negative coefficients that systematically increase in magnitude at higher noise levels. Again,

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[8] The percentage impact (*PI*) is approximated from the coefficient *b* according to the standard interpretation for dummy variables in semi-log models : $PI = (\exp(b)-1)\times 100$ (Halvorsen&Palmquist, 1980).

[9] From the percentage impact (*PI*) the average absolute impact (*AI*) is derived according to following formula : $AI = PI/(1-PI)\times P\times S$, where *P* and *S* are the mean sales price and lot size of properties.

results hardly change if noise effects are estimated conditional on access to the airport (column 4). Note that correcting for a spatial structure in the error terms detected in models (3) and (4) hardly affects the results for either market (columns 5 and 6). Figure 4 shows the results of a semi-parametric regression of the noise treatment (conditional on structure, location, neighbourhood and airport access). We plot the conditional mean in transaction prices at different noise level relative to the area average of the 40–45-dB base zone (in log differences). The results pretty much confirms Table 1 findings. While for submarket b) price differentials hardly deviate form zero for all noise levels, for submarket a) prices continuously decline with in noise levels beyond 50 dB and become negative beyond 55dB. At the same time, the marginal impact increases with noise level, supporting the notion of a non-linear effect of aircraft noise on household utility.

Table2 presents the results for a similar set of estimates for the impact area of Tempelhof airport. Since our generated noise data does not cover noise levels below 45 dB, we define a 500-m buffer distance to the 45 dB area as base zone. Due to the much smaller size of the airport, the noise level, even for properties within the air corridor and very close to the airport, hardly exceeds a level of 60 dB. Overall, the pattern of results resembles the findings for the Tegel Airport impact area, although even for the dummy variables denoting the areas with the highest noise level, there are no coefficients that are negative and significant. The large and negative, albeit not significant, price differential for the 60+ dB zone, however, is nonetheless remarkable. It implies a negative price differential of about 27% compared to the control zone and even more compared to areas with lower noise levels. In terms of magnitude this price differential even exceeds the one for similar noise levels within the Tegel Airport neighbourhood. For an average property within the 60+ zone the relative discount implies an absolute discount of about €84000, which, despite the lower noise level, is close to the maximum noise effect in proximity to Tegel Airport. In contrast, similar to the case of TXL, there is hardly evidence for a negative noise effect on submarket b). Again, conditioning on airport access (columns 2 and 4) as well as accounting for spatial dependency (columns 5 and 6) hardy affects the pattern of results, which also becomes evident in the semi-parametric estimates in Figure 5. Prices for multi-family houses (b) even tend to increase when moving into areas with higher noise level. While properties in submarket a) similarly exhibit conditional mean prices that increase in noise at lower levels, there is a sharp discontinuity at approximately55dB, after which the relationship is reversed.

As discussed, for Schönefeld Airport, detailed noise records are not available. The best information we have is the zone of restricted development. In order to assess whether properties within this zone sell at a significant discount due to noise emissions, we run a set of Table 1 and 2 type regressions using a dummy for the zone of restricted development and a study area within a 3 km buffer surrounding this zone. Results in Table 3, again, reveal a relatively clear pattern of results. There is a significant price discount for submarket a) properties of about 27%, pointing to considerable disutility effect. For an average property within the zone this implies a considerable discount of about €70,000. Although generally within the same range, this is a slightly lower magnitude compared to the maximum noise effects found for Tegel and Tempelhof airport. At the same time no significant discounts are found for submarket b). These findings are robust to controlling for airport accessibility and spatial dependency, which following the LM-test scores is addressed by spatial-lag models (5). Note that no spatial dependency is evident in the column (4) estimates and that the column (6) results are provided as a robustness check only.

Airport impact areas: Commercial

As discussed in Section 2, we expect aircraft noise not only to have an adverse effect on household utility, but also on productivity of workers and employees and, consequently, the value of commercial land. Our record of property transactions covers commercial properties within the noise impact area of Tegel and Tempelhof airport. Analogically to Tables 1–3 for the residential submarkets, Table 4 presents estimated average price differentials within different zones of noise exposure for the commercial property market for the Tegel (columns 1-3) and Tempelhof (columns 4-6) impact areas. Again, taking the 40-45 dB noise zone as a basis, coefficients in column (1), similarly to the results for the owner-occupied residential submarket a), indicate negative price differentials for the 55–60dB zone. At higher noise levels, however, no significant effects are found. Once airport accessibility is accounted for (column 2), however, all coefficients become negative and considerably increase in magnitude. At the same time, the negative and significant coefficient on road distance to the airport in column (2) points to significant proximity benefits. Moreover, noise effects for the65-70 dB zone is large and negative (price discounts up to 85%), conditional on airport accessibility. Apparently, the negative productivity effects related to noise are compensated by productivity gains from quick access to the wide array of flight connections offered by the city's most important business airport. These results indicate that estimated aircraft noise effects can be biased if accessibility effects are not controlled for. More generally, they highlight the importance of disentangling positive and negative externalities emanated by transport infrastructure as shown by Ahlfeldt (2010a) for main roads and urban rail stations. Although negative and large, the coefficient for the 60–65-dB is not significant and of smaller magnitude than for the 55–60-dB zone, which seems somewhat anomalous. Closer inspection of the data reveals that this effect is most likely attributable to relatively high prices for commercial properties within a medium-size retail center at Residenzstrasse. Correction for spatial dependency (3) leaves the results largely unchanged. At first glance, the coefficient seems to be much lower for the 65–70dB zone. The decrease, however, is partially attributable to application of a lag-model, for which coefficients need to be corrected, as described in Section 2 (coefficient Rho takes a value of 0.36). In any case, the coefficient for the 60–65-dB noise zone is not significant in the lag-model.

Estimated noise effects on commercial properties are similar within the Tempelhof Airport impact area. There is a large, negative and highly statistically significant discount of about 75% within the 55–60-dB zone in addition to a smaller effect for the 50–55-dB zone (columns 1–3). Estimated noise effects are hardly affected by controlling for airport accessibility (2) and spatial dependency (3). The notable difference is that negative noise effects seem to be compensated by positive accessibility effects in the case of Tegel, but not Tempelholf, which is plausible in light of the relatively small number of flight connections offered by Tempehlhof airport.

Overall, these results strongly indicate the presence of localized positive and, in particular, negative productivity effects of (city) airports. Although positive effects seem to be limited to airports offering a large array of flight connections), these effects can be large enough to partially compensate for the negative effect of noise. Our results further suggest a discontinuity in the productivity effect of aircraft noise around 50–55dB, which is even more apparent than in the disutility effects for households. A (conditional) discount of about 75% within the area exposed to heavy aircraft noise indicates a considerable reduction in worker efficiency, making respective properties much less desirable for commercial purposes.

City-wide effects

The results presented so far consistently point to adverse productivity and utility effects related to exposure to aircraft noise within all airport impact areas, as well as a potential discontinuity in the noise perception at a threshold of about 55 dB. Only for submarket b, comprising renter-occupied multi-family houses, could a negative effect not been found. In the remainder of the article, we pool our data separately for each submarket across the whole city area in order to estimate the average treatment effects for aircraft noise and airport accessibility. While calibrating the hedonic models based to the full data-base allows us to exploit all available price variation and to achieve potentially higher parameter stability, the pooled models may be slightly less efficient in predicting hedonic prices within the airport impact areas as marginal prices for selected attributes may slightly vary across space.

We start with submarket a), the 1- and two-family houses, and repeat column (1) estimates form Tables 1 and 2 for the whole city area. Results presented in Table 5, column (1) are in line with the finding for the TXL and THF impact areas. There is a negative and statistically significant discount beyond 55 dB. The maximum percentage discount of about 47% is within the same range as in Table 1, even slightly larger. In column (2), we extend the specification by individual road distance to airport measures for all airports (see Equation 2) to account for airport accessibility. While there is a negative and significant impact for distance to TXL and THL, which is in line with a positive utility effect from access to flight connections, the opposite is true for SXF. Estimated noise effects remain virtually unaffected as they are in column (3) where neighbourhood effects corresponding to the airport impact areas used in the previous section are included to control for unobserved neighbourhood particularities. In column (4), finally, we replace individual accessibility variables by the (weighted) average distance to airport (*AVA*) measure defined in equation (3). This is our preferred accessibility treatment due to presumably lower correlations with unobserved characteristics of the airport neighbourhoods. We find a positive effect for proximity to flight connections, with property prices decreasing by about 2.2% per 1 km increase in average distance to airports.

Table 6 repeats column 5 estimates for submarket b), the renter occupied multi-family houses. In line with the previous findings for the individual airport impact areas, there are no significant noise discounts (columns 1-4). Individual airport accessibility effects are inconsistent (2-3) and the average distance to airport treatment effect insignificant (4). Similarly, no compelling accessibility effects are revealed for commercial properties in Table 7. Results for the productivity effects of aircraft noise are more ambiguous. For the zone of highest noise exposure (65-70 dB) there is a large and significant discount of about 50% in our preferred column (4) model, which is in line with previous findings. Contrary to Table 4 results for the TXL and THF impact areas, there is no adverse effect for the 55-60 dB zone in all models. Moreover, the problem with the medium size retail center at “Residenzstrasse” within the 60-65 dB noise zone of TXL airport, is considerably aggravated. The large and positive coefficient indicates that the pooled model is less capable to explain the relatively high prices for commercial properties in the center. The SAR model, for which results are presented in column (5), to some degree “cures” these inconsistencies. After correcting for the spatial structure in the error term, we find a large and significant discount of about 47% within the 55-60 dB zone, which, however, is still considerably less than suggested by Table 4 results. In line with the SAR model in Table 4, column (3), we find negative and relatively large, but not significant coefficients for the higher noise zones (60-65 and 65-70 dB).

Note that we don´t estimate SAR models for submarkets a) and b) at city-wide scale due to the large sample sizes. Spatial LM test scores presented in Table 5 and 6 notes strongly indicate the appropriateness of spatial error correction models. In contrast to lag-models, error-correction models leave OLS coefficients unbiased if the underlying models are appropriately specified. Given the consistency of OLS and SAR coefficient estimates for both submarkets in Tables 1 and 2, there is reason to believe that potential problems of spatial dependency are limited to inefficient standard errors at the city-wide level, too. Since for both submarkets noise effects are generally estimated at very high levels of statistical significance, we believe that qualitative and quantitative interpretations of OLS coefficients are justified.

Marginal price effects and treatment heterogeneity

In the last step of our empirical analyses we turn our attention to the marginal price effect of aircraft noise. Average treatment estimates at the city-level basically confirm previous findings from the narrower samples indicating negative and significant effects for submarkets a) and c). Noise effects become crucial beyond a threshold level of about 55 dB. This non-linearity needs to be taken into account when defining a parametric specification with the objective of revealing marginal noise effects. As a somewhat pathological result, we consistently find no effects for submarket b). Although at a city wide level airport accessibility does not seem to be a very critical determinant for household utility or firm productivity, the neighbourhood analysis of Tegel Airport shows that estimated aircraft noise effects may be considerably biased if airport accessibility is not accounted for. In addition, there is another important source of bias that has not been addressed in the previous steps and has often been overlooked in the literature: The interaction with alternative noise sources, in our case, street noise. As discussed in section 3, the marginal (dis)utility and (dis)productivity effects of aircraft noise may be expected to be larger if no alternative noise is present. Under this assumption, estimated aircraft noise effects will be biased if the spatial distribution of aircraft noise is correlated with street noise. In order to address this potential interaction effect we estimate specification (4), which includes an interactive term of aircraft noise and street noise.[10]

Results are presented in Table 8, starting with submarket a) and omitting the interaction effect in column (1). Throughout Table 8 only the variables of interest are displayed to save space. Full estimation results including hedonic characteristics are presented in Table A2 in the appendix for selected models (3, 6, 9) that stand exemplarily for the three submarkets. If the interaction of street noise and air noise is not accounted for, we find a negative and significant (log-)linear impact of both noise sources where, notably, street noise seems to have much greater (dis)utility effects than aircraft noise. While for an average 10 dB increase in street noise there is a price dis-

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[10] Our measure of street noise does not include sources of noise, especially not aircraft noise.

count of about 5%, a respective increase in air noise yields only a relatively moderate 1% effect (column2). This relationship changes considerably once the interaction between the two noise sources is accounted for (column 2). There is a positive and significant coefficient on the noise interactive term, revealing that the marginal price effect for one type of noise diminishes in the presence of another. Equivalently interesting, estimated individual noise effects increase considerably, in particular for air craft noise, whose impact is now within the same range as street noise. An average 10 dB increase in air or street noise now yield price discounts of 5% and 7%. As discussed, our previous findings indicate a discontinuity in the utility and productivity effect around 55 dB. We therefore extend the model by a dummy variable indicating areas with 55 or more dB noise level in order to test for a significant level shift, conditional on the log-linear average effect in column (3). Indeed, a significant discount of approximately 10% is evident for properties within that zone, while the marginal price effect of an average 10 dB increase is considerably reduced to 2% and no longer statistically significant. The coefficient on the interactive term is slightly reduced and sharply fails the 10% significance criterion (p-value: 0.14).

In column (4-6) we apply the same models as in (1-3) to subsample b). If the interaction between noise sources is not accounted for we, similar to the previous results, find the “pathological” positive noise effects for air noise and also for street noise (column 4). Once the interaction is considered, however, these effects are reversed (5). Individual noise effects are now negative, significant and within a similar range to the other residential submarket a). An average 10 dB increase in noise level yields a 6% (3%) reduction in property prices in the case of air (street) noise. As in the case of submarket a) the coefficient on the interactive term is positive and statistically significant, again pointing to considerable treatment heterogeneity. Interestingly, there results even remain unchanged if a level-shift at the 55 dB level is allowed for, indicating that there is no discontinuity at this threshold for this submarket. These findings are most notable as they highlight the potential of severe bias in estimated noise effects if interaction effects are not accounted for appropriately.

The pattern of results for the commercial property market (submarket c) in columns (7-10) exhibits some similarities. Without interactive term, estimated noise effects are small and insignificant for street noise and positive and significant for air noise (column 7). With the interactive term (column 8), both coefficients on individual noise sources are negative and of roughly the same magnitude as for the other submarkets, although not statistically significant at conventional levels. Similarly, the interactive term exhibits a positive, but not significant coefficient. Previous results had shown the strongest discontinuity for the commercial property prices, which is confirmed when we extend the present specification by the dummy for 55 or more dB (column 9). While the three coefficients of interest considerably increase in magnitude and the coefficients on street noise and the interactive term even become statistically significant, there is still a negative (conditional) price shift of about 40% once the 55 dB threshold is crossed. Submarket c) seems to be the only submarket where spatial misspecifications give some cause for concern. We therefore repeat column (9) estimates employing an SAR (error) model. Results do not change qualitatively. There is a negative and highly statistically significant discount for property exposed to 55 dB or more of now about 44%, while individual noise effects are not estimated precisely taking as a basis conventional criteria. These findings, nevertheless, confirm the presence of very strong adverse effects on the productivity of office workers. We note that the slight instability of noise estimates for the commercial property market might be partially caused by a relatively low number of observations of traded commercial properties within areas exposed to high air noise levels, which, however, is in line with firms' aversion to aircraft noise.

5.0 CONCLUSION

This paper contributes to the assessment of external effects of (city) airports by providing an in-depth investigation of three airports in Berlin, Germany. While we find strong evidence of negative productivity and utility effects reflected in significant property price discounts within areas that are exposed to high levels of aircraft noise, evidence of positive accessibility effects is less compelling. For residential properties, an average treatment effect of approximately 5–6% is evident for every 10-dB increase in aircraft noise, which is within the range for results available in the literature (Nelson, 2004). Moreover, for the submarket of one- and two-family houses, there is evidence of a significant discontinuity in the noise perception when a threshold of 55dB is crossed. Within the zones of highest noise exposure, properties sell at discounts of more than 40%, corresponding to €85,000 for an average property. For commercial properties, the discontinuity is even more pronounced. Conditional mean property prices decrease relatively abruptly by approximately 40% once the threshold is crossed, indicating a strong adverse effect on office worker productivity. Positive accessibility effects could only be found at the city level for one-and two family houses, where a 1-km increase in the weighted average distance to flight connections reduces prices by 2.2%, and for commercial properties within the narrower impact area of Tegel airport.

Our results support the notion that airport externalities are composite effects of positive and negative effects, so that failure to control for either of the effects can result in biased coefficients for the other. Even more crucial, a significant interaction effect with alternative sources of noise is evident, which can lead to severe bias if not appropriately accounted for. Although there are non-significant or even positive noise effects for the submarket of multi-family houses, significant negative effects within the usual range are evident once the interaction with street noise is accounted for. Consistently for all submarkets, the positive interaction effect indicates that the marginal price effect of either street or aircraft noise decreases in the presence of an alternative noise source.

Based on our findings, it is possible to inform planners and authorities about productivity and utility effects of city airports, which are quite controversial in general and especially in the case of Berlin.Overall, our results provide little justification for location of airports within densely developed downtown areas. Although at the city level there is hardly any evidence of positive accessibility effects, such effects within the narrower impact area seem, if present at all, to be more than compensated by adverse noise effects. As a result, the net effect is clearly dominated by adverse productivity and utility effects, making a more remote airport location desirable from a welfare economics point of view. More generally, our results confirm recent findings on limited productivity effects of intra-city access to inter-city transport hubs (Ahlfeldt, 2010b), which is somewhat surprising in light of the strong emphasis in economic geography on the benefits arising from good access to regional and international markets.

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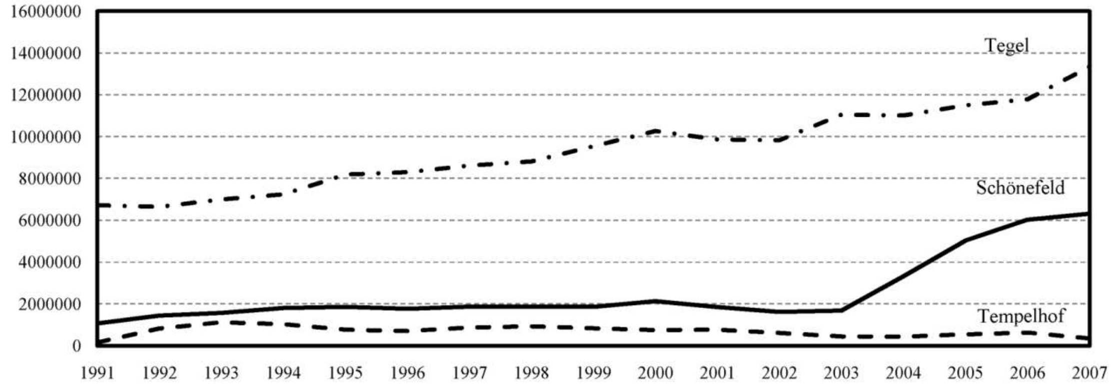
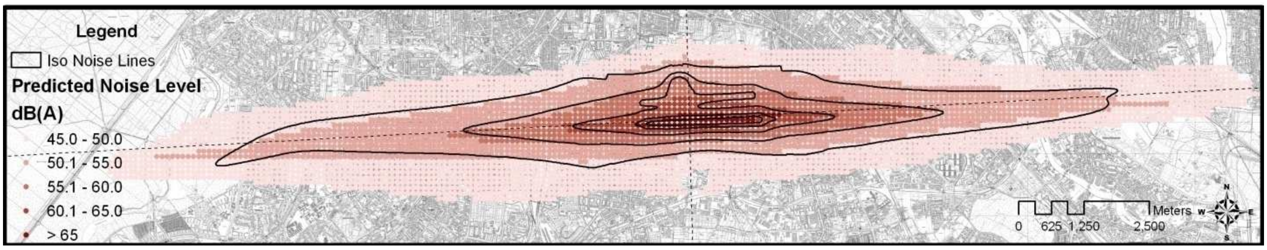
Fig. 1 - Passenger traffic at Berlin airports



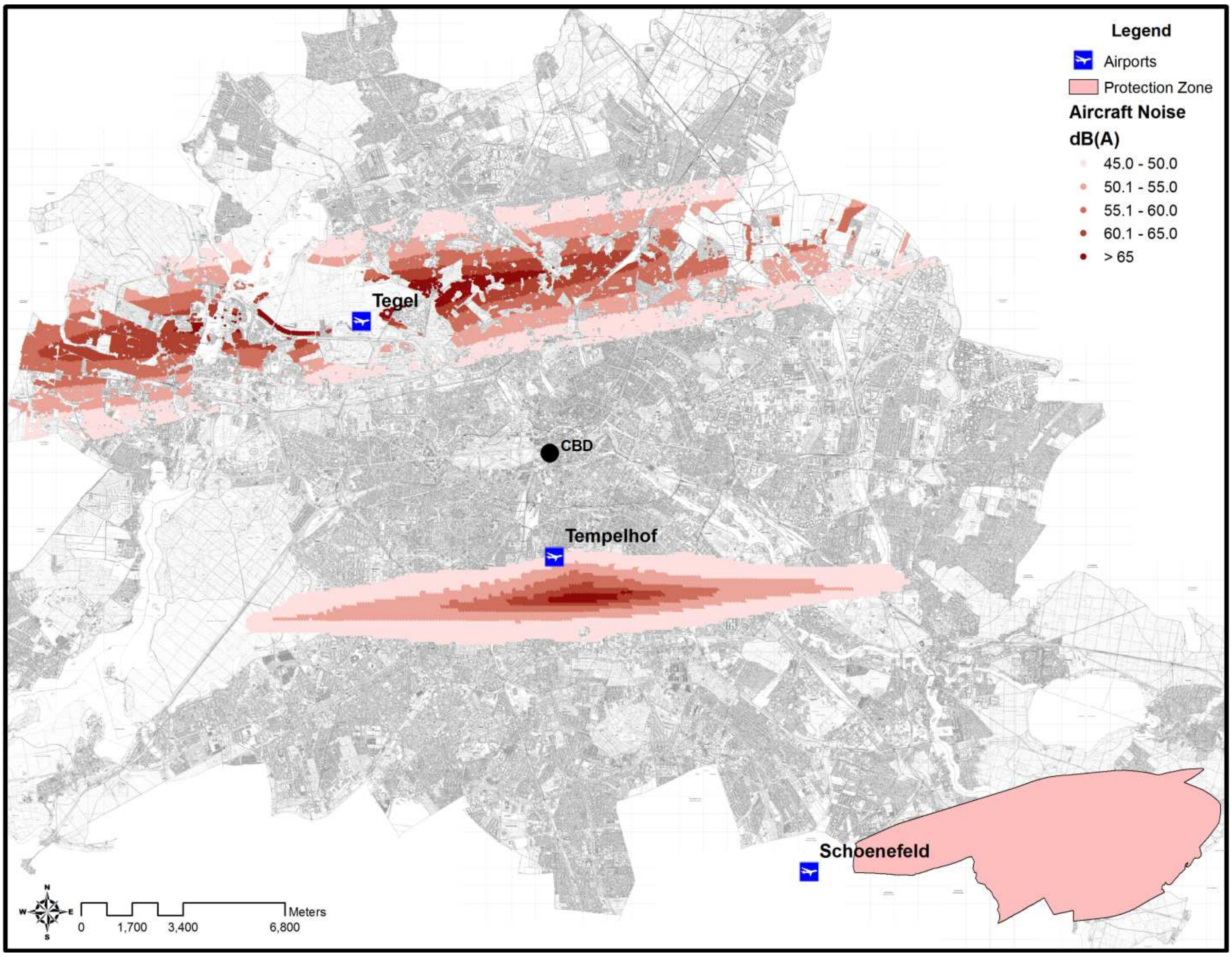
Source: German Airports Association. URL: http://www.adv-net.org/eng/gfx/index.php.

Fig. 2 – Noise protection zones and estimated aircraft noise: THF



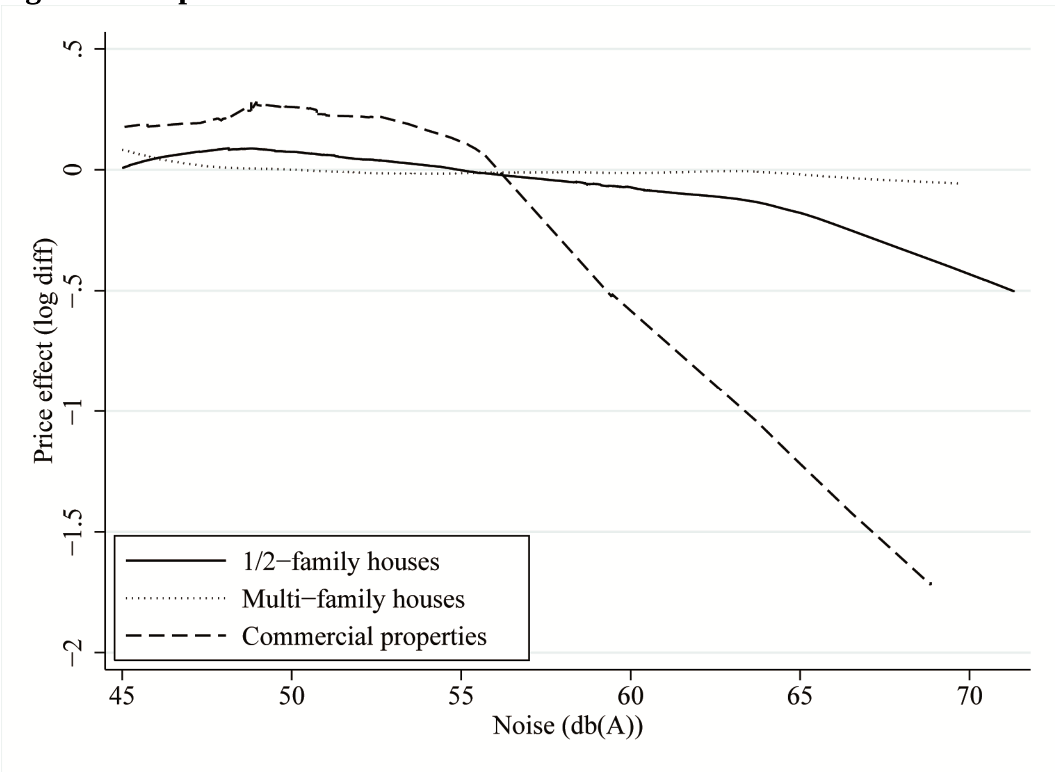
Notes: Figure created based on the Urban and Environmental Information System (Senatsverwaltung für Stadtentwicklung Berlin, 2006).

Fig. 3 – Aircraft noise in Berlin



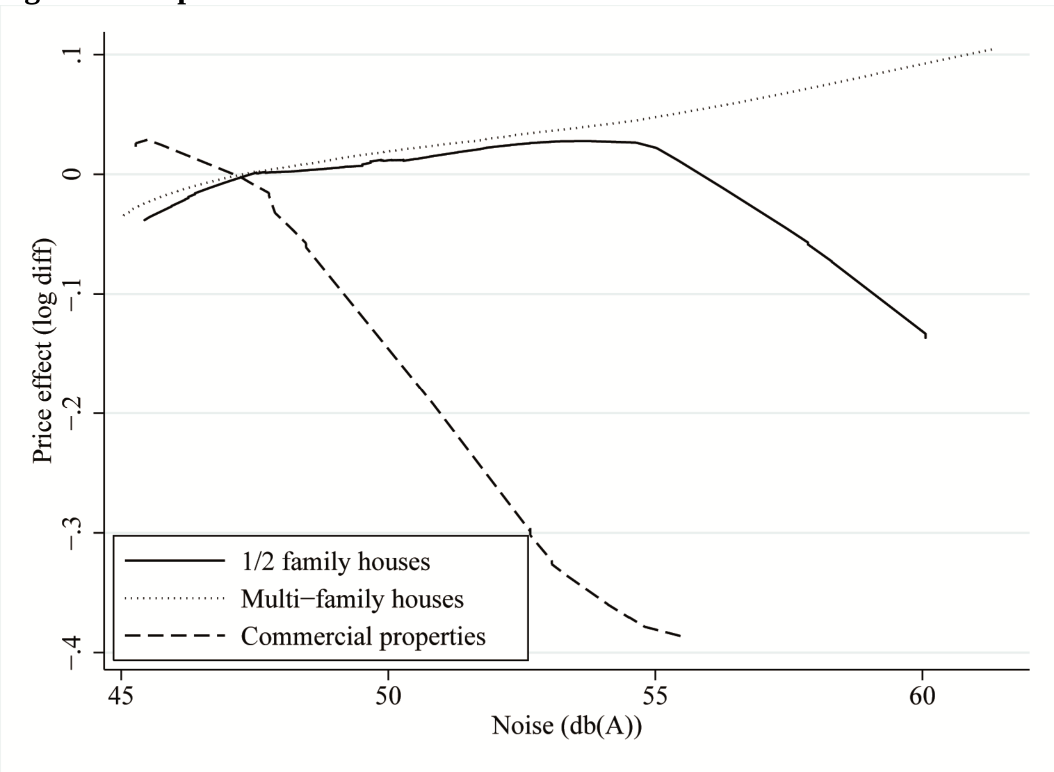
Notes: Figure created based on the Urban and Environmental Information System (Senatsverwaltung für Stadtentwicklung Berlin, 2006). Tempolhof noise is estimated based on own calculations

Fig. 4 - Semi-parametric noise effects: TXL



Notes: Difference-based semi-parametric estimates (Lokshin, 2006) are conditional on the control variables used in Table 1 and 4.

Fig. 5 - Semi-parametric noise effects: THF



Notes: Difference-based semi-parametric estimates (Lokshin, 2006) are conditional on the control variables used in Table 2 and 4.

Tab 1 - Residential submarkets – TXL impact area

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) SAR (error)	(6) SAR (error)
dB 45-50	-0.009	-0.011	0.033	0.004	-0.007	0.027
(Dummy)	(0.019)	(0.019)	(0.035)	(0.028)	(0.021)	(0.04)
dB 50-55	-0.012	-0.013	0.046	0.008	-0.018	0.061
(Dummy)	(0.021)	(0.021)	(0.031)	(0.03)	(0.024)	(0.048)
dB 55-60	-0.068**	-0.069**	0.041	-0.021	-0.060*	0.051
(Dummy)	(0.023)	(0.023)	(0.032)	(0.037)	(0.027)	(0.05)
dB 60-65	-0.073*	-0.078*	0.056	-0.012	-0.106**	0.05
(Dummy)	(0.033)	(0.033)	(0.037)	(0.038)	(0.039)	(0.056)
dB 65-70	-0.229**	-0.232**	0.115+	0.053	-0.252**	0.033
(Dummy)	(0.061)	(0.061)	(0.065)	(0.064)	(0.062)	(0.078)
dB>70	-0.519**	-0.528**			-0.528**	
(Dummy)	(0.085)	(0.085)			(0.091)	
Distanceto		-0.002		-0.038*	-0.007	0.027
TXL Airport (km)		(0.004)		(0.017)	(0.021)	(0.04)
Submarket	A	A	B	B	A	B
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year x East Effect	Yes	Yes	Yes	Yes	Yes	Yes
Structural Controls	Yes	Yes	Yes	Yes	Yes	Yes
Location Controls	Yes	Yes	Yes	Yes	Yes	Yes
Neighb. Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2998	2998	3502	3502	2998	3502
R-squared	0.81	0.81	0.61	0.61		

Notes: Endogenous variable is log of price per square meter land in all models. Baseline specification is equation (1). Controls are defined in Table A1 in the appendix. Submarket A covers one/two family houses, town-houses and villas, submarket B covers multi-family houses. Robust standard errors are in parenthesis. **/*/+ denote significance at the 1/5/10% level. Spatial LM statistics for model 2 [4] are: LM_{error}: 112.86 robust LM_{error}: 83.23, LM_{lag}: 46.89, robust LM_{lag}: 17.05 [LM_{error}: 230.04 robust LM_{error}: 136.22, LM_{lag}: 95.31, robust LM_{lag}: 1.46]

Tab. 2 - Residential submarkets – THF impact area

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) SAR (error)	(6) SAR (error)
dB 45-50	0.031	0.036	0.028	0.025	0.04	0.017
(Dummy))	(0.029)	(0.03)	(0.022)	(0.022)	(0.039)	(0.029)
dB 50-55	0.077+	0.088*	-0.003	-0.007	0.106*	-0.034
(Dummy)	(0.04)	(0.041)	(0.031)	(0.031)	(0.051)	(0.041)
dB 55-60	0.031	0.045	0.028	0.025	0.014	-0.019
(Dummy)	(0.067)	(0.066)	(0.032)	(0.032)	(0.079)	(0.044)
dB>60	-0.326	-0.309	-0.023	-0.03	-0.319	-0.041
(Dummy)	(0.234)	(0.234)	(0.061)	(0.061)	(0.244)	(0.071)
Distance to		0.015		-0.011	0.019	-0.011
THF Airport (km)		(0.012)		(0.01)	(0.018)	(0.015)
Submarket	A	A	B	B	A	B
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year x East Effect	Yes	Yes	Yes	Yes	Yes	Yes
Structural Controls	Yes	Yes	Yes	Yes	Yes	Yes
Location Controls	Yes	Yes	Yes	Yes	Yes	Yes
Neighb. Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1591	1591	4695	4695	1591	4695
R-squared	0.74	0.74	0.61	0.61		

Notes: Endogenous variable is log of price per square meter land in all models. Baseline specification is equation (1). Controls are defined in Table A1 in the appendix. Submarket A covers one/two family houses, town-houses and villas, submarket B covers multi-family houses. Robust standard errors are in parenthesis. **/*/+ denote significance at the 1/5/10% level. Spatial LM statistics for model 2 [4] are: LM_{error}: 49.64, robust LM_{error}: 16.38, LM_{lag}: 42.82, robust LM_{lag}: 8.56 [LM_{error}: 220.08 , robust LM_{error}:183.78, LM_{lag}: 43.89, robust LM_{lag}: 7.60].

Tab 3 - Residential submarkets – SXF impact area

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) SAR (error)	(6) SAR (error)
SXF Zone of rest.	-0.231**	-0.305**	0.086	0.091	-0.276**	0.034
Develop. (dummy)	(0.048)	(0.053)	(0.149)	(0.185)	(0.065)	(0.213)
Distance to		-0.033**		0.002	-0.024	-0.021
SXF Airport (km)		(0.013)		(0.036)	(0.017)	(0.045)
Submarket	A	A	B	B	A	B
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year x East Effect	Yes	Yes	Yes	Yes	Yes	Yes
Structural Controls	Yes	Yes	Yes	Yes	Yes	Yes
Location Controls	Yes	Yes	Yes	Yes	Yes	Yes
Neighb. Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1176	1176	158	158	1176	158
R-squared	0.83	0.83	0.91	0.91		

Notes: Endogenous variable is log of price per square meter land in all models. Baseline specification is equation (1). Controls are defined in Table A1 in the appendix. Submarket A covers one/two family houses, town-houses and villas, submarket B covers multi-family houses. Robust standard errors are in parenthesis. **/*/+ denote significance at the 1/5/10% level. Spatial LM statistics for model 2 [4] are: LM_{error}: 14.49, robust LM_{error}: 10.36, LM_{lag}: 5.35.13, robust LM_{lag}: 1.23 [LM_{error}: 1.02 , robust LM_{error}: 1.36, LM_{lag}: 0, robust LM_{lag}: 0.34]

Table 4 - Commercial properties – TXL and THF impact area

	(1) OLS	(2) OLS	(3) SAR (lag)	(4) OLS	(5) OLS	(6) SAR (error)
dB 45-50	-0.13	-0.306	-0.453+	0.082	0.072	0.106
(Dummy)	(0.284)	(0.308)	(0.26)	(0.122)	(0.12)	(0.097)
dB 50-55	0.035	-0.226	-0.306	-0.568**	-0.577**	-0.646**
(Dummy)	(0.332)	(0.351)	(0.289)	(0.2)	(0.207)	(0.155)
dB 55-60	-0.958+	-1.399*	-1.490**	-1.471**	-1.544**	-1.653**
(Dummy)	(0.488)	(0.557)	(0.469)	(0.277)	(0.296)	-0.239
dB 60-65	0.155	-0.883	-0.85			
(Dummy)	(0.415)	(0.693)	(0.554)			
dB 65-70	-0.431	-1.609+	-1.12			
(Dummy)	(0.6)	(0.835)	(0.701)			
Distanceto		-0.372+	-0.323*		0.118	0.227
Airport (km)		(0.203)	(0.157)		(0.179)	(0.14)
Airport	TXL	TXL	TXL	THF	THF	THF
Submarket	C	C	C	C	C	C
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year x East Effect	Yes	Yes	Yes	Yes	Yes	Yes
Structural Controls	Yes	Yes	Yes	Yes	Yes	Yes
Location Controls	Yes	Yes	Yes	Yes	Yes	Yes
Neighb. Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	159	159	159	105	105	105
R-squared	0.8	0.81		0.94	0.94	

Notes: Endogenous variable is log of price per square meter land in all models. Baseline specification is equation (1). Controls are defined in Table A1 in the appendix. Submarket C covers commercial properties. Robust standard errors are in parenthesis. **/*/+ denote significance at the 1/5/10% level. Spatial LM statistics for model 2 [5] are: LM_{error}: 2.13 , robust LM_{error}: 2.91, LM_{lag}: 10.92, robust LM_{lag}: 11.07 [LM_{error}: 5.20 , robust LM_{error}:6.41, LM_{lag}: 0.21, robust LM_{lag}: 1.41] The spatial lag parameter Rho takes a value of 0.36 in model (3).

Tab. 5 - 1/2 family houses (a) – city-wide effects

	(1)	(2)	(3)	(4)
SXF Zone of Rest.	-0.129**	-0.075**	-0.089**	-0.153**
Develp. (dummy)	(0.026)	(0.029)	(0.029)	(0.027)
dB 45-50	0.041**	0.031*	0.029+	0.029*
(Dummy)	(0.013)	(0.013)	(0.015)	(0.013)
dB 50-55	0.069**	0.056**	0.056**	0.059**
(Dummy)	(0.015)	(0.015)	(0.016)	(0.015)
dB 55-60	-0.031+	-0.062**	-0.058**	-0.046**
(Dummy)	(0.017)	(0.017)	(0.019)	(0.017)
dB 60-65	-0.059*	-0.103**	-0.096**	-0.092**
(Dummy)	(0.029)	(0.029)	(0.03)	(0.029)
dB 65-70	-0.260**	-0.242**	-0.235**	-0.295**
(Dummy)	(0.057)	(0.059)	(0.059)	(0.061)
dB>70	-0.631**	-0.618**	-0.609**	-0.685**
(Dummy)	(0.083)	(0.084)	(0.083)	(0.084)
Distanceto		-0.005+	-0.004	
Airport (TXL) (km)		(0.003)	(0.003)	
Distanceto		-0.015**	-0.015**	
Airport (THF)) (km)		(0.003)	(0.003)	
Distanceto		0.012**	0.013**	
Airport (SXF)) (km)		(0.001)	(0.001)	
AverageDistance				-0.022**
to Airport (ADA)				(0.004)
Submarket	A	A	A	A
Year Effects	Yes	Yes	Yes	Yes
Year x East Effect	Yes	Yes	Yes	Yes
Neighb. Effects	-	-	Yes	-
Structural Controls	Yes	Yes	Yes	Yes
Location Controls	Yes	Yes	Yes	Yes
Neighb. Controls	Yes	Yes	Yes	Yes
Observations	15199	15199	15199	15199
R-squared	0.73	0.74	0.74	0.73

Notes: Endogenous variable is log of price per square meter land in all models. Baseline specification is equation (1). Controls are defined in Table A1 in the appendix. Submarket A covers one/two family houses, town-houses and villas. Robust standard errors are in parenthesis. **/*/+ denote significance at the 1/5/10% level. Spatial LM statistics for model 4 are: LM_{error}: 2941.09 , robust LM_{error}:1058.76, LM_{lag}: 1918.77, robust LM_{lag}: 36.43.

Tab. 6 – Multi-family houses (b) – city-wide effects

	(1) OLS	(2) OLS	(3) OLS	(4) OLS
SXF Zone of Rest.	0.201+	0.152	0.183	0.197
Develp. (dummy)	(0.12)	(0.127)	(0.132)	(0.12)
dB 45-50	0.079**	0.090**	0.052**	0.078**
(Dummy)	(0.012)	(0.013)	(0.016)	(0.013)
dB 50-55	0.048**	0.061**	0.021	0.047**
(Dummy)	(0.017)	(0.018)	(0.019)	(0.018)
dB 55-60	0.070**	0.085**	0.050**	0.068**
(Dummy)	(0.016)	(0.017)	(0.018)	(0.017)
dB 60-65	0.078**	0.089**	0.041	0.076**
(Dummy)	(0.025)	(0.026)	(0.027)	(0.026)
dB 65-70	0.044	0.042	-0.008	0.042
(Dummy)	(0.057)	(0.057)	(0.058)	(0.057)
Distanceto		-0.004	-0.004	
Airport (TXL) (km)		(0.005)	(0.005)	
Distanceto		0.028**	0.027**	
Airport (THF)) (km)		(0.005)	(0.005)	
Distanceto		-0.011**	-0.014**	
Airport (SXF)) (km)		(0.002)	(0.002)	
AverageDistance				-0.002
to Airport (ADA)				(0.006)
Submarket	B	B	B	B
Year Effects	Yes	Yes	Yes	Yes
Year x East Effect	Yes	Yes	Yes	Yes
Neighb. Effects	-	-	Yes	-
Structural Controls	Yes	Yes	Yes	Yes
Location Controls	Yes	Yes	Yes	Yes
Neighb. Controls	Yes	Yes	Yes	Yes
Observations	14998	14998	14998	14998
R-squared	0.65	0.65	0.65	0.65

Notes: Endogenous variable is log of price per square meter land in all models. Baseline specification is equation (1). Controls are defined in Table A1 in the appendix. Submarket B covers multi-family houses. Robust standard errors are in parenthesis. **/*/+ denote significance at the 1/5/10% level. Spatial LM statistics for model 4 are: LM_{error}: 2220.73, robust LM_{error}: 4351.75, LM_{lag}: 2131.02, robust LM_{lag}: 3.25.

Tab. 7 - Commercial properties (c) – city-wide effects

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) SAR (error)
dB 45-50	0.334**	0.327**	0.199*	0.342**	0.109
(Dummy)	(0.089)	(0.09)	(0.096)	(0.089)	(0.107)
dB 50-55	0.228**	0.282**	0.141	0.253**	-0.052
(Dummy)	(0.077)	(0.089)	(0.099)	(0.088)	(0.139)
dB 55-60	-0.152	-0.124	-0.232	-0.123	-0.630**
(Dummy)	(0.172)	(0.169)	(0.174)	(0.176)	(0.244)
dB 60-65	0.926**	0.989**	0.898**	0.974**	-0.299
(Dummy)	(0.307)	(0.323)	(0.323)	(0.312)	(0.589)
dB 65-70	-0.768*	-0.859*	-0.909*	-0.723*	-0.471
(Dummy)	(0.341)	(0.398)	(0.391)	(0.348)	(0.562)
Distanceto		-0.011	0.007		
Airport (TXL) (km)		(0.031)	(0.032)		
Distanceto		0.01	0.039		
Airport (THF)) (km)		(0.026)	(0.032)		
Distanceto		-0.033*	-0.036*		
Airport (SXF)) (km)		(0.016)	(0.016)		
AverageDistance				0.024	-0.028
to Airport (ADA)				(0.038)	(0.054)
Submarket	C	C	C	C	C
Year Effects	Yes	Yes	Yes	Yes	Yes
Year x East Effect	Yes	Yes	Yes	Yes	Yes
Neighb. Effects	-	-	Yes	-	-
Structural Controls	Yes	Yes	Yes	Yes	Yes
Location Controls	Yes	Yes	Yes	Yes	Yes
Neighb. Controls	Yes	Yes	Yes	Yes	Yes
Observations	1474	1474	1474	1474	1474
R-squared	0.77	0.77	0.77	0.77	

Notes: Endogenous variable is log of price per square meter land in all models. Baseline specification is equation (1). Controls are defined in Table A1 in the appendix. Submarket C covers commercial properties. Robust standard errors are in parenthesis. **/*/+ denote significance at the 1/5/10% level. Spatial LM statistics for model 4 are: LM_{error}: 421.76 , robust LM_{error}:247.05, LM_{lag}: 184.76, robust LM_{lag}: 10.05.

Tab. 8 - Marginal price effects and treatment heterogeneity

	(1) (OLS)	(2) (OLS)	(3) (OLS)	(4) (OLS)	(5) (OLS)	(6) (OLS)	(7) (OLS)	(8) (OLS)	(9) (OLS)	(10) (SAR)
AverageDistance	-0.020**	-0.020**	-0.021**	-0.002	-0.004	-0.004	0.036	0.033	0.012	-0.031
to Airport (ADA) (km)	(0.004)	(0.004)	(0.004)	(0.007)	(0.007)	(0.007)	(0.036)	(0.036)	(0.036)	(0.054)
Street Noise (dB)	-0.005**	-0.007**	-0.007**	0.002**	-0.003**	-0.003**	-0.001	-0.007	-0.010+	-0.006
6.0	(0)	(0.001)	(0.001)	(0)	(0.001)	(0.001)	(0.002)	(0.005)	(0.006)	(0.006)
Air Noise (dB)	-0.001*	-0.005*	-0.002	0.003**	-0.006**	-0.005**	0.007*	-0.008	-0.013	-0.018
7.0	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.002)	(0.003)	(0.013)	(0.013)	(0.017)
Street Noise		0.00007+	0.00006		0.00015**	0.00015**		0.00023	0.00033+	0.0002
x Air Noise		(0.00004)	(0.00004)		(0.00002)	(0.00002)		(0.00018)	(0.00019)	(0.0002)
dB>55			-0.103**			-0.004			-0.500**	-0.576**
(Dummy))			(0.018)			(0.015)			(0.158)	(0.187)
Submarket	A	A	A	B	B	B	C	C	C	C
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year x East Effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Structural Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Location Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Neighb. Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SXF Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	15199	15199	15199	14998	14998	14998	1474	1474	1474	1474
R-squared	0.73	0.73	0.73	0.65	0.65	0.65	0.76	0.76	0.76	

Notes: Endogenous variable is log of price per square meter land in all models. Baseline specification is equation (1). Controls are defined in Table A1 in the appendix. Submarket A covers one/two family houses, townhouses and villas, submarket B covers multi-family houses, submarket C covers commercial properties. Full estimation results for models (3), (6) and (6) are presented in Table A2 in the appendix. Robust standard errors are in parenthesis. **/*/+ denote significance at the 1/5/10% level. Spatial LM statistics for model 9 are: LM_{error}: 484.30 , robust LM_{error}: 280.33, LM_{lag}: 215.603, robust LM_{lag}: 11.64.

Tab. A1 – Hedonic controls

Structural Controls	
Floor Space Index (FSI)	Ratio of total floor space and plot area size
Plot Area (m^2)	Surface are of the plot of land
Storey	Number of storeys of the building
Age (Years)	Age of the building in years
Age (Years) squared	Squared age of the building in years
Condition: Good	Building is in good physical condition
Condition: Bad	Building is in bad physical condtion
Locationl Controls	
Dist. to Centre (km)	Minimum distance (great circle) to "Breitscheidplatz" (CBD-West) or metro station "Stadtmitte" (CBD-East) in km
Emp. Potentiality (log)	Log of employment potentiality as defined in equation €
Dist. to Station (km)	Distance (great circle) to nearest metro or suburban railway station in km
Dist. to Main St. (km)	Distance (great circle) to the nearest main road in km
Dist. To School (km)	Distance (great circle) to the nearest school in km
Landmarks within 600m	Number of designated historical landmarks within 600m
Dist. toWater (km)	Distance (great circle) to the nearest water body in km
WaterPotentiality (log)	Log of water potentiality as defined in equation €
Dist. to Green (km)	Distance to the nearest green area in km
Green Potentiality (log)	Log of green potentiality as defined in equation €
Dist. toIndustry (km)	Distance (great circle) to the nearest industrial zone in km
Neighborhood Controls	
Proportion (%) Foreign	Proportion of non-German population at total population in statistical block
Proportion (%) Young	Proportion of 18 years-old and younger at total population in statistical block
Proportion (%) Old	Proportion of 65 years-old and older at total population in statistical block
Proportion (%) Unemp.	Proportion of unemployed population at total population in traffic cell
P. Power (1000€/cap)	Average purchasing power in 1000€ per capita in post code
Noise related variables	
Year Effects	Mean shifter for year all years 2000-2007
Year x East Effects	Set of dummy variables denoting transactions in former East-Berlin for all years 2000-2007
SFX Effect / Zone	Dummy for SXF zone of restricted development
Neighborhood Effects	Dummy variables denoting a) the area exposed to 40 dB or more TXL air noise, b) the 350m buffer area around the area exposed to 45 dB or more THF air noise, c) the 3 km buffer area around the SXF zone of restricted development
dB*h - j*	Dummy for area exposed to air noise from *h* to *j*dB
AVA	Average distance (road network) to airports as defined in equation € in km
Distance to Airport	Distance (road network) to airport as defined in km
Air Noise	Air noise in long term equivalent sound pressure in dB
Street Noise	Street noise in long term equivalent sound pressure in dB

Tab. A2 – Hedonic estimates

	(1)		(2)		(3)	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Floor Space Index (FSI)	1.445**	0.043	0.450**	0.007	0.348**	0.032
Plot Area (m²)	-0.0001**	0	-0.000*	0	0.000**	0
Storey	0.017+	0.009	-0.002	0.005	-0.018	0.011
Age (Years)	-0.009**	0.001	-0.006**	0.001	-0.003+	0.002
Age (Years) squared	0.000**	0	0.000**	0	0	0
Condition: Good	0.209**	0.011	0.437**	0.014	0.743**	0.047
Condition: Bad	-0.314**	0.012	-0.411**	0.014	-0.465**	0.064
Dist. to Centre (km)	-0.055**	0.003	-0.061**	0.005	-0.131**	0.024
Emp. Potentiality (log)	0.040*	0.018	0.007	0.035	-0.287	0.185
Dist. to Station (km)	-0.075**	0.008	-0.074**	0.010	-0.343**	0.105
Dist. to Main St. (km)	-0.024	0.0160	0.114**	0.040	-0.619*	0.247
Dist. To School (km)	0.052**	0.003	0.027**	0.002	0.000**	0
Landmarks within 600m	0.003**	0	0.001**	0	0.090**	0.028
Dist. toWater (km)	0.009	0.010	0.022	0.016	0.054	0.097
WaterPotentiality (log)	0.011*	0.005	0.009	0.008	0.094+	0.051
Dist. to Green (km)	-0.009	0.011	-0.106**	0.020	-0.217*	0.109
Green Potentiality (log)	0.022**	0.006	-0.046**	0.011	-0.098+	0.058
Dist. toIndustry (km)	0.041**	0.003	0.032**	0.012	0.218**	0.50
Proportion (%) Foreign	0.002*	0.001	-0.004**	0.001	0.002*	0.001
Proportion (%) Young	0.001	0	0.007**	0.001	-0.003	0.002
Proportion (%) Old	0.001**	0	0.002**	0.001	0	0.002
Proportion (%) Unemp.	-0.010**	0.001	-0.014**	0.002	0.006	0.008
P. Power (1000€/cap)	0.015**	0.002	0.034**	0.004	0.085**	0.026
Av. Dist. to Air. (AVA)	-0.021**	0.004	-0.004	0.007	0.012	0.036
SXF Zone	-0.151**	0.027	0.186	0.12	8.0	9.0
Street Noise	-0.007**	0.001	-0.003**	0.001	-0.010+	0.006
Air Noise	-0.002	0.002	-0.005**	0.002	-0.013	0.013
Street Noise x Air Noise	0	0	0.000**	0	0.000+	0
dB> 55	-0.103**	0.018	-0.004	0.015	-0.500**	0.158
Submarket	A		B		C	
Year Effects	Yes		Yes		Yes	
Year x East Eff.	Yes		Yes		Yes	
Observations	15199		14998		1474	
R-squared	0.73		0.65		0.76	

Notes: Endogenous variable is log of price per square meter land in all models. Baseline specification is equation (1). Variables are defined in Table A1. Submarket A covers one/two family houses, town-houses and villas, submarket B covers multi-family houses, submarket C covers commercial properties. Robust standard errors are in parenthesis. **/*/+ denote significance at the 1/5/10% level.