The impact of rail access on condominium prices in Hamburg

Sebastian Brandt · Wolfgang Maennig

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

Keywords Accessibility · Real estate economics · Public transport · Location choice · Hamburg

Introduction

Public transit companies in Germany achieve an average cost recovery ratio of about 70% (BMVBW 1999) and are therefore dependent on the support of the public sector.[1] One of the justifications usually given for such subsidies are the positive externalities of public

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

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transit. Accordingly, the CO_2 emissions of rail transport per passenger-km are well below the CO_2 emissions of motor vehicles (IFEU 2008; Kennedy 2002). Also, especially railway transport helps to relieve the road network, thus reducing congestion and increasing accessibility, for example, of workplaces, shopping and leisure destinations (Baum-Snow and Kahn 2000). High quality public transport reduces travel times at constant distances or increases the mobility range at constant travel times (Gibbons and Machin 2005), which could be reflected in higher property prices in the vicinity of railway stations (Bowes and Ihlanfeldt 2001). Put literally, these arguments do not prove positive externalities for public transport. Instead, it could be argued that public transport generates some negative externalities (e.g., noise, pollution) that are, however, much smaller than the negative externalities for road transport in cars and trucks. The failure of governments to charge appropriately for (larger) negative externalities for individual transport modes and distributional principles (the rich might be relatively less inclined to use public transport than the poor) may be relevant arguments for public transport subsidies.[2]

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

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

This study complements the previous literature in a number of respects. This study examines the influence of rail infrastructure on residential property prices, not only of individual lines, but for the entire rail network of a metropolitan region. Contrary to previous studies that have investigated mainly the effects of specific or few commuter rail lines on the structure of suburban residential property prices, we include in our analysis the entire Hamburg railway network, consisting of commuter rail as well as city trains ("S-Bahn") and underground rail ("U-Bahn") spread out across a total of 17 lines. The study uses a sensitivity analysis to examine the impact that the nature and scope of the control variables used have on the relation between access to railway stations and real estate prices.[3]

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

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[2] We owe this to an anonymous referee.

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

contributes to an understanding of the hitherto little explored influence of income level on the connection between access to railway infrastructure and residential real estate prices.

"Literature review" section provides an overview of the current literature on the subject. Then "Data" section describes the data that formed the basis of the study. "Empirical methodology" section illustrates the empirical models used. In "Results" section the results are presented and an approach is introduced to quantify the fiscal benefits of public transit for the city of Hamburg. The conclusions are presented in last section.

Literature review

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

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

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

Second, the size and type of a mass transit system can be significant for its effect on house prices. It is likely that the effect is particularly pronounced in cities with a well-developed rail network. It is likely also that rapid commuter rail systems have a greater impact on property prices than slower light rail systems. As well, individual stations can generate different effects when they differ in terms of service frequency, connection to the transport network, above-ground or underground location as well as park-and-ride

facilities. Third, the influence of railway stations may also depend on socio-demographic factors such as the income level of a region or a neighbourhood. The direction of effect does not seem to be unambiguous here. While Gatzlaff and Smith (1993) observe a positive relationship between income and the effects of railway stations on house prices, Nelson (1992) finds a negative relationship. Possible time savings due to good access to transport may be valued higher in high-income neighbourhoods, but this is in contrast to a higher proportion of public transport users in lower-income areas (Kim 2003).

The present study uses a cross-sectional hedonic approach to investigate the influence of the existing rail infrastructure on Hamburg condo prices. Gibbons and Machin (2005) criticise this method in that the results of the regression analysis are biased if variables that are correlated with access to railway stations are not included in the regression equation. However, the results of studies examining the transport infrastructure on the basis of longitudinal analyses may also be biased, as it seems unclear how long it takes a real estate market to reflect in its prices a change in the quality of the rail infrastructure (Henneberry 1998). McMillen and McDonald (2004) have observed that house prices react to new transport infrastructure as early as 6 years before and as many as 6 years after the opening of a new railway line. If one chooses too short a period of investigation, it is possible to underestimate the effect of a new transport system on the surrounding property prices. We take the criticism of Gibbons and Machin (2005) into account, by testing a number of positive and negative externalities of railway stations as well as potentially correlated variables. For a detailed review of the literature on the effects of railway stations on property prices, we refer to Wrigley and Wyatt (2001) and NEORail II (2001), and for a review on methodological problems to Löchl and Axhausen (2010).

Data

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

Williams (1995) analyses the prices of single-family homes in Queensland, Australia. By using linear functional forms two separate regressions are estimated, once on the basis of offer prices and, once on the basis of sales prices. In both equations the same coefficients are statistically significant, and all significant coefficients in both equations have the same sign. However, the coefficients of two variables differ from each other significantly.[5] As for the remaining 16 significant variables, the coefficient pairs do not deviate from each other by more than 12%. Merlo and Ortalo-Magné (2004) as well as Knight (2002) show that the difference between offer and transaction prices is greater the longer a property is on the market. If we observed a correlation between time on market and distance to the

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

[5] 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%.

closest train station with respect to our dataset, an unsystematic variance of the difference between listing and sales prices in relation to the distance to the closest station would, thus, be doubtful. In our case, the Pearson correlation coefficient for time on market and distance to next rail station, however, is small (0.006) and insignificant at conventional levels.[6] For the condominium market in Hamburg, where the average differential between listing and transaction prices is approximately 8%, no systematic variance of this difference for properties of different age, size or price category has been observed.[7] Since we use semi-logarithmic forms, which reflect relative—and not absolute—changes in property prices for an additional unit of a characteristic, it may be assumed that the offer prices should yield unbiased coefficients.[8]

The study area comprises the entire city of Hamburg, which has an area of 755.2 km^2 and at the end of the study period a population of 1.767 million (March 31, 2008). The primary source of data for this study is a dataset supplied by F+B GmbH that contains 4,832 listing prices for condominiums in Hamburg that were put up for sale on Internet portals between April 1, 2002, and March 31, 2008.[9] All datasets contain information on the year of construction, size of the condominium, listing price and date, time on market as well as the complete address of the property. In addition, information on the characteristics of the condominiums was extracted from the portals. We further considered the location of the properties by calculating a variety of variables related to neighbourhood and accessibility.[10] Using a directory supplied by the Hamburg Office for Urban Development and the Environment (BSU), each address was allocated to one of the 938 statistical districts of Hamburg. A statistical district is the smallest statistical unit for which the Statistics Office of Hamburg collects demographic and socioeconomic population data.[11] In addition, we used GIS to calculate distances between properties and train stations, public infrastructure (such as schools, kindergartens and shopping), water and green spaces as well as jobs. BSU has supplied us with further small-scale datasets on the noise pollution caused by road, air and rail traffic for the area of Hamburg, so that we were able to determine property-specific noise pollution levels in dB(A).

In 1965 the transit companies of the metropolitan region of Hamburg formed the Hamburg Transit Association (HVV)—one of the oldest transport associations in the world (HVV 2009). Nine of today's total of 33 transit companies provide their transportation services by rail. In 2008 they carried 554 million passengers, that is, 58.5% of all passengers within the transit network. Assuming for each passenger one round trip per day, there are on average approx. 750,000 people in the metropolitan region of Hamburg who

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

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

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

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

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

[11] All population data refer to the year in which the property was offered for sale most recently. The information regarding average income, however, was available only for 1995.
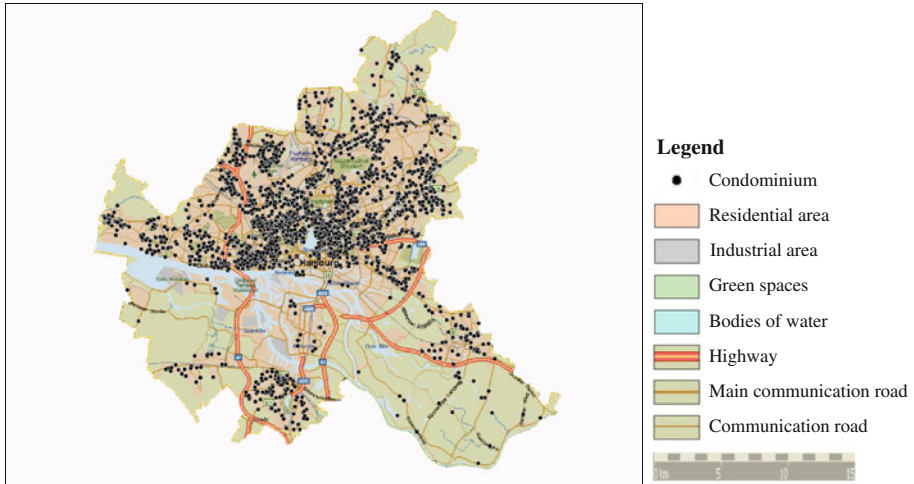
Fig. 1 Spatial distribution of condominiums

use rail transport. About half of the approximately 3.37 million inhabitants in the HVV area live in Hamburg. Taking into account that the inhabitants of the city of Hamburg take public transport at least twice as often as the population of the surrounding countryside (Infas 2004), the daily average of the people in Hamburg who travel by train comes to more than 500,000, or more than 28%.[12] This demonstrates the substantial importance of rail transport in the city of Hamburg (Infas and DIW 2004). The 803 km railway tracks in the network area are operated by 27 lines (HVV 2009). There is a total of 278 stations along the network, 134 of which are located in Hamburg.[13] By using the data made available by HVV, we were able to determine for each station the number of serving train and bus routes as well as the service frequency. We also collected information on whether a station is a transfer station, the stop is located above or underground, and whether it has a parking lot.

Empirical methodology

Hedonic approach and choice of functional form

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

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

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

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

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

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

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

Empirical models

Basic model (model 1)

In our basic model we use a hedonic cross-sectional approach that takes into account property and neighbourhood characteristics, accessibility and noise indicators as well as access to rail stations. For the semi-logarithmic form, the basic model (1) can be written as:

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

where α is a constant and β, γ, δ, η, θ, λ and μ are representing the vectors of coefficients to be estimated and ε is an error term. PROP is a vector capturing the property characteristics, including information regarding age and size—that we have considered in both linear form and with an additional quadratic term (e.g., Voith 1993)—as well as dummy variables for the property's physical attributes.[15] In selecting the variables, we rely on Sirmans et al. (2005) and Wilhelmsson (2000), who evaluated the control variables most commonly used in hedonic studies.[16] NEIGH is a vector of neighbourhood characteristics, consisting of the proportion of those aged 65 and older (ELDERLYPOP: e.g., Ahlfeldt and Maennig 2010), the average income (INCOME: e.g., Andersson et al. 2010), the proportion of population with non-German passport (FOREIGNPOP: e.g., Theebe 2004) as well as the number of social housing units per 1,000 inhabitants (SOCHOUSE: e.g., Gibbons and Machin 2005).[17]

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

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

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

Table 1 Variable names, definitions and summary statistics

Variable	Definition	Mean	Std. dev.
Dependent variable			
PRICE	Last asking price of property	193,897	177,747
Property			
SIZE	Living area in square metres	81.78	47.10
AGE	Age of property in years	39.41	35.25
ROOMS	Number of rooms	2.79	1.71
GARAGE	1 if property has a garage, 0 otherwise	0.52	0.50
BALCONY	1 if property has a balcony, 0 otherwise	0.82	0.39
TERRACE	1 if property has a terrace, 0 otherwise	0.77	0.42
KITCHEN	1 if property has a built-in kitchen, 0 otherwise	0.65	0.48
POOL	1 if property has a pool, 0 otherwise	0.03	0.17
FIREPLACE	1 if property has a fireplace, 0 otherwise	0.04	0.20
GOODCOND	1 if property is in good condition, 0 otherwise	0.13	0.34
BADCOND	1 if property is in bad condition, 0 otherwise	0.06	0.24
Neighbourhood			
ELDERLYPOP	Proportion of population in census tract that is 65 years and older	18.93	6.73
INCOME	Mean income of population in census tract (in 1,000 €)	34.80	15.18
FOREIGNPOP	Proportion of population with non-German passport	13.06	6.64
SOCHOUSE	Number of social housing units per 1,000 inhabitants in census tract	40.65	62.27
Access			
DISTCENT	Distance to next central place according to zoning plan (in kilometres)	1.16	0.82
EMPGRAV	District proximity (air distance) to employment (measured by a gravity variable)	146,016	44,153
DISTWATER	Distance to closest of the bodies of water Elbe and Binnen-/Aussenalster (in kilometres)	4.68	3.67
DISTPARK	Distance to next park, forest or nature protection area (in kilometres)	0.69	0.51
BUS_NUMBER	Number of bus lines that stop at the next rail station in the peak	3.82	4.38
Noise exposure/visual disamenities			
WIDEROAD	1 if property is located on a wide road (with at least one lane per driving direction), 0 otherwise	0.08	0.27
ROADNOISE	Road noise in dB(A) as measured by a L_{den}-Index	56.67	11.69
AIRNOISE	Air noise in dB(A) as measured by a L_{den}-Index if property is located within noise protection zone two ($\geq$67 dB(A)) or three ($\geq$62 dB(A)) around Hamburg Airport, 0 otherwise	2.19	10.95
RAILNOISE	Rail noise in dB(A) as measured by a L_{den}-Index if property is located in the vicinity of rail tracks, 0 otherwise	9.36	20.93
DISTIND	Distance to next industrial site (in kilometres)	0.55	0.46

Table 1 continued

Variable	Definition	Mean	Std. dev.
Station accessibility			
DISTSTAT_250	1 if distance to next rail station ≤250 m, 0 otherwise	0.09	0.29
DISTSTAT_250_750	1 if distance to next rail station >250 and ≤750 m, 0 otherwise	0.50	0.50
DISTSTAT_750_1250	1 if distance to next rail station >750 and ≤1,250 m, 0 otherwise	0.25	0.43
DISTSTAT_1250_1750	1 if distance to next rail station >1,250 and ≤1,750 m, 0 otherwise	0.11	0.31
UNDERGR	1 if next rail station is located underground, 0 otherwise	0.26	0.44

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

$$\text{EMPGRAV}_i = \sum_j \frac{\text{Emp}_j}{d_{ij}}, \quad d_{ii} = \frac{1}{3}\sqrt{\frac{\text{area}_i}{\prod}}, \tag{3}$$

where Emp represents all jobs subject to social insurance in an urban district or in one of the surrounding communities. j stands for all urban districts and communities other than i, and d_{ij} is the distance between the centroids of i and j. Since some of the urban districts cover relatively large areas, we also take into account a district-internal distance measure d_{ii} (cf. e.g., Crafts 2005).[18] Proximity to shopping and recreation has been captured by the distance to central locations (DISTCENT) according to the zoning plan of Hamburg (BSU 2003). These 35 locations are characterised by a differentiated supply of everyday goods as well as bars, restaurants, cinemas, etc., despite a scarcity of space. The zoning plan differentiates the central locations with decreasing diversification of supply and retail space into A Centre (city), B Centre (district centre) and C Centre (neighbourhood centre). Thus, depending on the type of the nearest central place one must expect different levels of price premiums for location proximity. We therefore introduce three dummy variables, each of which assumes the value 1 if the nearest central place is an A (CBD) or B (B_CENT) or C centre (C_CENT); otherwise, the value is 0. Then we multiply the variables by the distance between the property and the nearest central location (DISTCENT). Consequently, the location of properties from shopping and leisure facilities can be considered separately for the different types of central places. Indicating the access to recreation we considered the distance from the closest green space (DISTPARK: e.g., Agostini and Palmucci 2008) as well as from the nearest bodies of water (Inner and Outer Alster Lake and Elbe River: DISTWATER). It is mostly North-American publications that tend to use the distance from highway on-ramps as an indicator of accessibility (e.g., McMillen 2004). This may be meaningful for metropolitan regions with an extensive network of city highways as in

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

many U.S. American metropolises). The often-congested highways in Hamburg, due to transit and commuter traffic, however, are only rarely used by the inhabitants of Hamburg for their daily trips to work or to go shopping, which is why the distance from highway on-ramps as a measure of accessibility has been excluded from our models. BUS_NUMBER, that captures the number of bus lines that stop at the next rail station in the peak, is included to make sure that we do not positively bias the effect of the train station accessibility. ACCESS is thus a vector to map the previously discussed accessibility indicators.[19]

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

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

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

The vector DISTSTAT, according to Bowes and Ihlanfeldt (2001), represents in the following a set of dummy variables that map the distance contours to the nearest train station. We have examined the price-distance trend first with kernel regressions using the residuals of Eq. 2, but without the term μ DISTSTAT. Figure 2 shows that the price gradient is exclusively negative from a distance of about 1,750 m, which is why we select

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

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

[21] Can and Megbolugbe (1997) consider properties within a radius of 3 km. However, their study area covers a large-area suburban county in the metropolitan region of Miami. As concerns the small-scale housing market in Hamburg, it is reasonable to assume that the offer price of a condominium is affected only by prices of properties that are located in the immediate vicinity. However, we computed AUTOREG using various critical distances (0.5, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 7.5 and 10.0 km) and found the best fit of the model when we considered properties within a radius of 2 km. In contrast to Can and Megbolugbe (1997), who take into account surrounding properties if they were sold in the previous 6 months, we believe, given the relatively low volatility of the condominium market in Hamburg, that it is reasonable to include properties in the neighbourhood that were offered for sale within the previous 12 months.
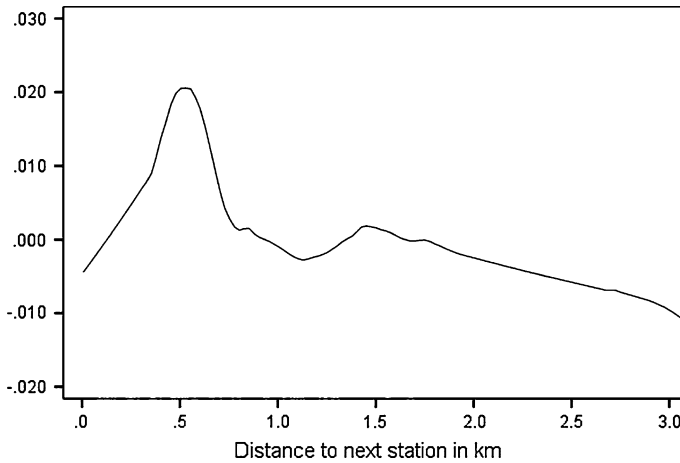
Fig. 2 Property price gradient, with distance to next railway station. *Remark*: Figure shows kernel regression of residuals from Eq. 2 omitting the term λ DISTSTAT. Kernel uses the Epanechnikov function

properties with distances greater than 1,750 m to the next station as the reference group. This also seems to be a possible maximum walking distance to the nearest station. In light of the price-distance trend determined by kernel regressions, we have defined four dummy variables that each take on the value of 1 if a property is up to 250 m, more than 250 m and up to 750 m, more than 750 m and up to 1,250 m or more than 1,250 m and up to 1,750 m from the next train stop; otherwise the value is 0. While we expect to find decreasing premiums for condos for distances of 250 to 1,750 m with increasing distance to a station, we think that relatively lower property prices are possible for distances up to 250 m due to the negative externalities of stations.

Model with interactives (model 2)

As already mentioned above, the influence of train stations on the surrounding housing prices may also depend on station characteristics and the income level of a neighbourhood. To investigate these factors, we have interacted DISTSTAT with the dummy variable UNDERGR, which takes on the value of 1 if the nearest railway station is located underground.[22] Furthermore, DISTSTAT is interacted with the dummy variable HIGHINC that takes on the value of 1 if a property is located in a statistical area with incomes above the median income.[23] The model with interactives is thus:

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

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

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

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

Results

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

Control variables

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

   The effects of the proportion of the population with non-German passport as well as the proportion of those aged 65 and older on property prices are significantly negative. The relationship between medium income in the statistical district (INCOME) and condominium prices is positive and statistically highly significant. While we do not observe any significant price premiums when the nearest central location is downtown (DISTCENT × CBD), the price-distance gradient is the steepest for C centres (DISTCENT × C_CENT). This is plausible insofar as there are few shopping opportunities for daily goods in the inner city, unlike in the B and C centres, but instead mostly clothing and electronics stores. Since the average resident rarely seeks out such goods, he or she tends to be less willing to pay a premium for a short route. The different results for B and C centres could be due to the fact that the B centres are located primarily in densely populated neighbourhoods where numerous retail shops with goods for daily needs are to be found even outside the central locations. Outside the predominantly peripheral C centres, however, there is likely to be

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

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

Table 2 Results

	Basic model	Model with interactives
CONSTANT	8.3023***	8.3804***
YEAR_2002	−0.0336	−0.0316
YEAR_2003	0.0061	0.0048
YEAR_2004	−0.0256*	−0.0266*
YEAR_2005	−0.0624***	−0.0625***
YEAR_2006	−0.0384***	−0.0385***
YEAR_2007	−0.0229*	−0.0210*
Property		
SIZE	0.0131***	0.0131***
SIZESQ	−0.000009***	−0.000009***
AGE	−0.0129***	−0.0128***
AGESQ	0.000097***	0.000097***
ROOMS	0.0271***	0.0275***
GARAGE	0.0340***	0.0329***
BALCONY	0.0559***	0.0564***
TERRACE	0.0448***	0.0427***
KITCHEN	0.0446***	0.0415***
POOL	0.0345	0.0329
FIREPLACE	0.0119	0.0129
GOODCOND	0.0514***	0.0520***
BADCOND	−0.1040***	−0.1056***
Neighbourhood		
ELDERLYPOP	−0.0032***	−0.0033***
INCOME	0.0033***	0.0028***
FOREIGNPOP	−0.0055***	−0.0049***
SOCHOUSE	−0.0001**	−0.0001**
Access		
DISTCENT × CBD	−0.0545	−0.0543
DISTCENT × B_CENT	−0.0161**	−0.0158**
DISTCENT × C_CENT	−0.0361***	−0.0394***
EMPGRAV	0.000002***	0.000002***
DISTWATER	−0.0091***	−0.0095***
DISTPARK	−0.0342***	−0.0367***
BUS_NUMBER	0.0013	0.0014
Noise exposure/visual disamenities		
WIDEROAD	−0.0489***	−0.0498***
ROADNOISESQ	−0.000019***	−0.000020***
AIRNOISE	−0.0012***	−0.0014***
RAILNOISE	−0.0011***	−0.0011***
DISTIND	0.0156	0.0144
Station accessibility		
DISTSTAT_250	0.0178	−0.0355
DISTSTAT_250_750	0.0455**	0.0155

Table 2 continued

	Basic model	Model with interactives
DISTSTAT_750_1250	0.0236	0.0092
DISTSTAT_1250_1750	0.0138	0.0042
DISTSTAT_250 × UNDERGR		0.0445*
DISTSTAT_250_750 × UNDERGR		0.0020
DISTSTAT_750_1250 × UNDERGR		−0.0051
DISTSTAT_1250_1750 × UNDERGR		0.0534
DISTSTAT_250 × HIGHINC		0.0655***
DISTSTAT_250_750 × HIGHINC		0.0526***
DISTSTAT_750_1250 × HIGHINC		0.0261
DISTSTAT_1250_1750 × HIGHINC		0.0114
Spatial lag term	Yes	Yes
Number of observations	4,832	4,832
White's correction	Yes	Yes
R^2	0.87286	0.87357
Adjusted R^2	0.87180	0.87230

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

* Significance at the 10% level; ** significance at the 5% level; *** significance at the 1% level

significantly less retail space, which makes proximity to these centres an attractive aspect. While proximity to jobs, represented by EMPGRAV, is seen as positive, all variables that measure distance from local amenities have the expected negative signs. All the variables that capture noise or visual disturbances exhibit significant coefficients. If a flat, for example, is exposed to road noise of 75 dB(A)—as is the case in close proximity to heavy traffic road sections—its price will be discounted by approx. 4.5% compared to a flat with an average noise level of 57 dB(A). The variable BUS_NUMBER is not significantly different from zero.

Impact of railway stations[26]

Basic model results (model 1) and sensitivity analysis

Our results show that it is attractive for residents to live near, but not in immediate proximity to, railway stations. Compared to properties that are located at a distance of more than 1,750 m to the next station, condo prices rise with decreasing distance between 1,750 and 750 m insignificantly at first, but then rise significantly coupled with maximum premiums of 4.6% in a radius of 250–750 m to the nearest station. In immediate proximity to a station (≤250 m), the premiums are not significantly different from zero. As Fig. 3 illustrates, a linear price-distance trend with a *t*-value of −3.190 would be significant, but would underestimate the premiums for properties in a radius of 250–750 m and overestimate the premiums in the immediate vicinity of a station. The rail access premiums

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[26] Since for both models the results are independent of whether the lag term is included or not, we do not adjust our estimates for spatial correlation (Andersson et al. 2009).
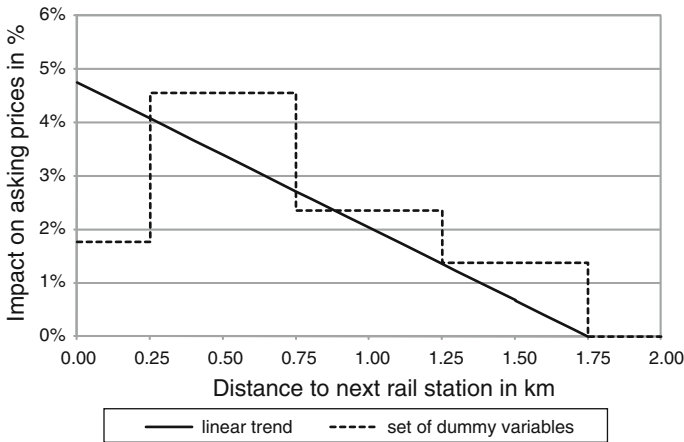
Fig. 3 Linear price-distance trend versus set of dummy variables. *Remark*: Reference group of dummy variables are station distances >1,750 m

calculated by us are lower than those determined by most of the previous studies that have examined the effect of access to railway stations on residential property prices. Debrezion et al. (2006), for example, have identified premiums of up to 32.3% for residential properties near train stations in the Netherlands. In suburban locations of Chicago McMillen and McDonald (2004) have observed discounts of up to 19.4% for each mile that a property is located further away from a station. Grass (1992) has shown premiums in Washington, DC, of up to 38% for locations near train stations. In principle, (our) lower coefficients could be due to the generally high level of accessibility in the Hamburg area compared to the areas in other studies.[27] It should also be mentioned that the other studies pointed out control only for a few location and accessibility indicators.[28] As a result, the coefficients mapping access to train stations each represent all the location and accessibility criteria which are not controlled for.

To be more specific, Fig. 4 indicates that higher coefficients in other studies may be biased if determinants are neglected that are correlated with access to train stations. In Fig. 4, the dotted line represents the coefficients calculated for the base model for access to train stations, of which, as mentioned above, only the coefficient for distances of 250–750 m to the next station is significant. The black solid line shows estimates that would result for model 1 if the vectors ACCESS and NOISE_VIS_DIS from Eq. 2 were excluded. All coefficients are significant and, depending on the distance to the nearest train station, are 5.4 to 12.3% higher than the coefficients calculated on the basis of Eq. 2. This can be explained by the fact that the vector DISTSTAT now represents all the location-specific factors. Since positive accessibility effects appear to weigh more strongly than negative externalities, higher price premiums are observed than for the basic model. If the vector NOISE_VIS_DIS is again added to Eq. 2, we obtain the coefficients shown by the dashed line (see Fig. 4). All regressors are significant and take on even higher values, as

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

[28] Debrezion et al. (2006) only consider the distance to railway tracks and the nearest motorway junction, McMillen and McDonald (2004) control for the distance to railway tracks and to CBD, and Grass (1992) only considers the distance to the CBD.
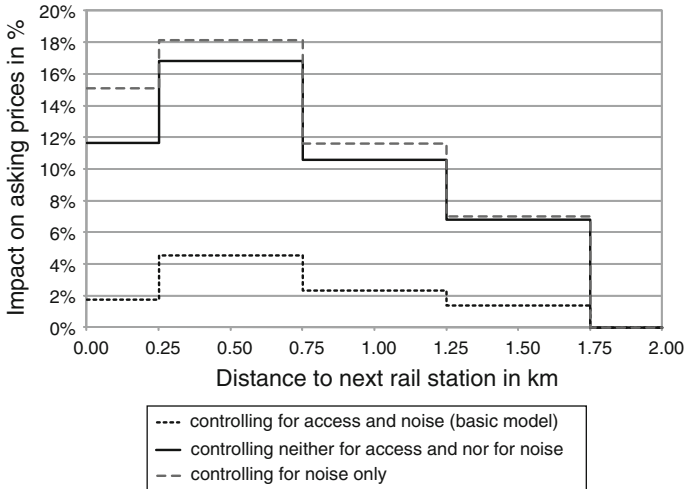
Fig. 4 Results with and without controlling for location-related variables. *Remark*: Reference group of dummy variables are station distances >1,750 m. Basic model coefficients for distances ≤250 and >750 m are insignificant. All other coefficients are statistically significant

they now represent exclusively positive effects, namely, accessibility (ACCESS) and access to train stations (DISTSTAT). While the distance between the *x*-axis and dotted line can be interpreted as a price premium for access to train stations, the distance between the dotted and dashed line must be seen as a premium for other accessibility factors. The gap between the black and dashed line, however, can be interpreted as a price discount for noise exposure, which is highest in immediate proximity to train stations. Keeping in mind that stations are often located near busy roads or intersections, this result is plausible. That the influence of train stations, calculated from Eq. 2 and illustrated by the dotted line, is ultimately also a net effect, namely accessibility less negative externalities in the form of vibration, noise and visual nuisance, is borne out by the fact that the price premiums in the immediate vicinity of train stations, where the negative effects are strongest, are lower than for distances between 250 and 750 m to the next station.

Results for model with interactives (model 2)

The coefficients established for model 2 indicate that prices for condominiums in the immediate vicinity (≤250 m) of underground stations (DISTSTAT_250 × UNDERGR) are higher by 4.5% than for properties within a radius of 250 m around above-ground stations. For longer distances, there are no significant price differences between above-ground and underground stations. This result is plausible insofar as the negative effects of stations decrease with increasing distance. Furthermore, the coefficients of the vector DISTSTAT × HIGHINC for distances of up to 750 m are significantly positive and exhibit premiums that are up to 6.6% higher for access to stations in upper-income neighbourhoods (as compared to lower-income areas). Two opposing effects determine the impact of income on the price-distance gradient in the vicinity of stations. On the one hand, German households adjust their modal split, due to the well-developed public transport system, to their income situation more closely than, say, American households, which are

often forced by the spatial structure of many metropolitan regions to rely on the car as a means of transport (Kim 2003). In Germany, lower-income households use mass transit more often than households with above-average incomes. This would suggest that access to railway infrastructure in residential areas with below-average income is valued higher. Our results, similar to those obtained by Bowes and Ihlanfeldt (2001), suggest that among the households that use public transit as a means of transport, potential time savings from good access to train stations are valued higher by high-income households. This is also evidenced by the fact that price premiums in upper-income neighbourhoods are significantly higher only for locations with good accessibility of train stations (at distances of up to 750 m) compared to neighbourhoods with lower incomes.

Aggregated price effects of access to railway stations

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

$$\Delta TAX = TAXRATE \times PROPSOLD \times \left(\sum_i \sum_c \mu_c \times V_{ic} \right) \tag{6}$$

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

The value of the residential properties per urban district and distance contour was then estimated by multiplying for each urban district i the average sales prices per type of use P_{iu} with the number of residential units per type of use N_{iu} and then summing them up via the types of use u. We obtain V_{ic} by multiplying this term by the share of addresses per distance contour $PROP_{ic}$.[29] Then we calculated for each urban district the price increases of properties due to access to train stations by multiplying V_{ic} with the significant coefficient μ_c from model 1. For all 103 urban districts i the aggregate price increases resulting from access to stations amount to a total of EUR 2.33 billion.[30] If one considers that the purchase of a property in Hamburg is subject to a land transfer tax (TAXRATE) in the amount of 4.5% of the assessed value, which generally corresponds to the sales price, and if one further considers that every year about 4% of the residential properties are sold (PROPSOLD), proximity to train stations increases the annual revenue from land transfer

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

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

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

Conclusions

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

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

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

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