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The Impact of Rail Transport on Real Estate Prices: An Empirical Analysis of the Dutch Housing Market

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Abstract

A hedonic pricing model is estimated based on sales data from three metropolitan areas in the Netherlands (Amsterdam, Rotterdam and Enschede) to analyse the effect of railway accessibility on house prices. Railway accessibility is measured by both the distance to a railway station and an index of quality of railway services provided at the station. Two railway station considerations were taken: the nearest railway station and the most frequently chosen railway station. Correcting for a wide range of other determinants, the model based on the most frequently chosen station outperforms the model based on the nearest railway station in estimating the effect of railway accessibility. The dissimilarity between the results of the two models increases with the increase in the urbanisation level of the metropolitan area.

1. Introduction

The hedonic pricing method treats real estate as a composite good with several value-determining features. The sum of the value of the individual features comprises the value of the property as a whole. Studies on real estate prices generally divide the value-determining features of properties into three categories: namely, physical, accessibility and environmental (Fujita, 1989; Bowes and Ihlanfeldt, 2001). The focus of this paper is generally on accessibility, and particularly on railway accessibility. Accessibility as provided by rail in particular has received some attention in the literature. Railway accessibility is generally explained in relation to railway stations. In order to single out the effect of railway stations on property values, it is suggested that stations should be regarded as nodes in a transport network and places in an area (Bertolini and Spit, 1998). Using this

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framework, recent empirical studies treat the node feature and the place feature of a station separately: the former characteristic accounts for the accessibility effect, which is generally positive; and the latter feature accounts for the externalities of the station and can have both positive and negative effects. In addition to the accessibility feature of a station, Bowes and Ihlanfeldt (2001) draw attention to the retail employment and crime that stations attract. On the other hand, high population movement in the immediate location gives rise to the development of retail activities that are eventually capitalised in commercial property values, but may (at the same time) attract crimes. Bowes and Ihlanfeldt observe a significant relation between stations and crime rates. However, no proximity variable shows a significant effect on retail employment. Their model shows that the immediate neighbourhood is affected by the negative impact of the station. The nearest properties (within a quarter of a mile of the station) were found to have an 18.7 per cent lower value compared with those situated farther away between one and three miles from the station.

With reference to the three categories of property features mentioned, this paper examines the effect of railway stations on Dutch house prices. There are three types of rail service in the Netherlands: light rail (trams), heavy rail (metro lines) and commuter rail, whereby the services of the first two are confined to the main cities and the third type serves the whole country. This paper assesses the effect of accessibility provided by commuter railway stations on residential house prices. However, road accessibility creates major competition for railway accessibility. Hence, the road network is used to calculate the average (weighted) distance needed to reach 100 000 jobs from the location of the residential property.

The accessibility and nuisance effects of a railway station are functions of the distance between the station and the house under consideration. As the distance increases, the impact of both these features on the house price declines. The level of accessibility at a railway station is measured by the quality of the railway network. This relates to the number of destinations that can be reached from the station; the frequency of train services at the station; and other departure-station-related facilities. Railway stations with higher network quality (i.e. a larger number of destinations and a higher frequency of trains) have a higher accessibility level. This is expected to have a relatively high positive effect on the house prices. At the same time, railway stations impose localised negative environmental effects on house prices due to noise nuisance. An important difference between the two effects is that the accessibility effects are concentrated around nodes (railway stations), whereas the negative noise effects take place everywhere along the railway line.

In our analysis, we determine the impact of the three railway features on residential property prices: namely, railway station proximity; rail service levels; and proximity to a railway line. The data for our analysis include the selling prices of residential properties in the Netherlands. Because of the transport cost and time savings made possible in commuting, households are expected to be willing to pay higher prices in order to live near to a station, compared with other locations. Furthermore, leisure activities that involve rail transport then become more accessible. This paper takes into account only sales of residential properties; we intend to cover the effects of the railway station on commercial property values in a follow-up paper.

Three different metropolitan areas are selected in order to compare the implication of regional differences for the impact of the variables of interest on real estate prices. These areas are Amsterdam, Rotterdam and Enschede. They differ in urbanisation level and the choices of departure railway station they offer, with the most choice in the

Amsterdam metropolitan area and the least in the Enschede metropolitan area.

2. Literature Review

Most of the land value theories are rooted in the work of von Thünen (von Thünen, 1830), who explored variations in farmland values. According to von Thünen, accessibility to the marketplace is responsible for the difference in value between areas of farmland with similar fertility but different location. In subsequent studies, Alonso and Muth refined this line of reasoning in a bid–rent analysis (Alonso, 1964; Muth, 1969), in which the premise is that all agents are prepared to pay a certain amount of money, depending on the location of the land. This leads to a rent gradient that declines with distance from the central business district (CBD) for sites that have equal utility. In the analyses conducted thus far, the dominant factor that explains the difference between land (property) values was accessibility, as measured by the distance to the CBD and associated transport costs. The physical characteristics of the land were assumed as given.

The basic theory on real estate prices can therefore be outlined as follows: as a location becomes more attractive due to certain characteristics, demand increases and thus the bidding process pushes prices up. In most cases, CBDs are the centres of myriad activities and, therefore, proximity to the CBD is considered as an attractive quality that increases property prices. However, investments in transport infrastructure reduce this demand friction around the CBD to some degree (Fejarang, 1994) by attracting households to settle instead around the stations. Properties close to the investment area (railway stations) enjoy benefits from transport time and cost saving because of the investment. We expect that a price curve will have a negative slope: as we move away from the station, prices decrease.

The hedonic pricing methodology introduced by Rosen (1974) led to an easier way of attributing value to the features of properties. In subsequent studies, we observe the integration of physical, accessibility and environmental characteristics of the property in models which address the differences in property values. Accessibility, however, remains a key feature for urban property values. Yet, earlier attempts to account for it by using transport cost have been limited. Attempts have been made, however, to introduce a broader concept of accessibility by including all features that contribute to the potential for economic and social interaction in a particular location (Hansen, 1959; Martellato *et al.*, 1998). Although a comprehensive definition of the concept is available, the lack of data and appropriate measuring techniques usually implies that simple measures are used most often. Thus, in the literature we observe that emphasis is given only to a limited number of factors, especially a CBD-oriented interaction related to employment and shopping. In most property value studies, other trip purposes are missing from the model.

Our focus in this paper is an analysis of the impact of railway accessibility on residential house prices. However, as Voith (1993) pointed out, highway accessibility is an important competitor for rail accessibility. The benefits of these facilities and services are also capitalised in urban property values (Damm *et al.*, 1980). In order to single out the effect of railway accessibility, competing modes of accessibility also need to be included.

The motivations for studies on the impact of railway accessibility are diverse. The larger part of the literature on railways presents them as a feasible solution to the rising congestion posed by automobile traffic and urban sprawl. Railway investment is expected to support a more compact urban structure (Goldberg, 1981). Apart from illustrating that railway investments do result in compact urbanisation, most of these studies were conducted to provide evidence for the implementation of value capture schemes for financing rail investments (Cervero and Susantono, 1999). This was based on the assertion that the value of proximity to accessibility points is capitalised in the value of properties around these stations.

In general, the empirical studies conducted in this area are diverse in methodology and focus. Although the functional forms can differ from study to study, the most common methodology encountered in the literature is hedonic pricing. However, to date, no consistent relationship between proximity to railway stations and property values has been reported. Moreover, the magnitudes of these effects can be either minor or major. Dewees (1976) analysed the relationship between rail travel costs and residential property values, and found that a subway station increases the site rent adjacent to the facility within a radius of one-third of a mile from the railway station. Similar findings confirm that the distance of a lot from the nearest station has a statistically significant effect on the property value of the land (Damm *et al.*, 1980). Consistent with these conclusions, Grass (1992) finds a direct relationship between the distance of a newly opened metro and residential property values. Some of the extensively studied metro stations in the US, although having a range of small to modest impacts, show that properties close to the station have a higher value than properties farther away (Giuliano, 1986; Bajic, 1983; Voith, 1991). Other studies, however, have found insignificant effects (Lee, 1973; Gatzlaff and Smith, 1993). Moreover, contrary to the general assumption, Dornbusch (1975) and Landis *et al.* (1995) trace a negative effect of station proximity. Evidence from other studies indicates little impact in the absence of favourable factors (Gordon and Richardson, 1989; Giuliano, 1986). For a detailed documentation of the findings, we refer to Vessali (1996), Smith and Huang (1995), NEORail II (2001) and RICS (2002). In general, some studies indicate that the impact of railway stations on property values has declined, which is attributable to improvements in accessibility, advances in telecommunications, computer networks and other areas of technology said to make companies 'footloose' in their location choices (Gatzlaff and Smith, 1993).

The impact of railway stations on property values varies and for three main reasons. First, railway stations differ in terms of the level of rail service they provide. This can be explained in terms of frequency of service, network connectivity, service coverage and so on. The meta-analysis in Debrezion *et al.* (2007) shows that different types of railway station have different levels of impact on property values. Commuter railway stations have a relatively higher impact on property values than light and heavy railway stations (Debrezion *et al.*, 2007; Cervero and Duncan, 2001; NEORail II, 2001; Cervero, 1984). Railway stations also differ in the level and quality of their facilities. Stations with a higher level and quality of facilities are expected to have a greater impact on the value of surrounding properties. The presence and number of parking lots are station facilities that, among many others, have received attention in the literature. Bowes and Ihlanfeldt (2001) found that stations with parking facilities have a higher positive impact on property values. In addition, the impact of a railway station depends on its proximity to the CBD. Stations that are located close to the CBD have a greater positive impact on property values (Bowes and Ihlanfeldt, 2001). In another study, Gatzlaff and Smith (1993) claim that the variation in the findings of the empirical work can be attributed to local factors in each city.

Secondly, railway stations affect residential and commercial properties differently. Most studies have treated the effect of railway stations on the different property types separately. The extent of the impact area of railway stations is larger for residential properties, whereas the impact of a railway station on commercial properties is limited to immediately adjacent areas. Generally, it has been shown that the impact of railway stations on commercial properties is greater than it is on residential properties within short distances of the stations (Debrezion *et al.*, 2007; Cervero and Duncan, 2001; Weinstein and Clower, 1999). This finding is in line with the assertion that railway stations—as focal gathering points—attract commercial activities, which subsequently have the effect of increasing commercial property values. However, contrary to this assertion, Landis *et al.* (1995) determine that railway stations have a negative effect on commercial property values.

Thirdly, the impact of railway stations on property values is subject to the demographic segmentation of neighbourhoods. Income and social (racial) divisions are common. Proximity to a railway station is of higher value to low-income residential neighbourhoods than to high-income residential neighbourhoods (Nelson, 1998; Bowes and Ihlanfeldt, 2001). The reason is that low-income residents tend to rely on public transport and thus attach higher value to living close to the station. Because this group depends mostly on slow modes (walking and bicycle) to access railway stations, it would be expected that locations adjacent to a railway station would be occupied by poor segments of the community.

3. Data

The data used in this analysis cover sales transactions of the Dutch residential housing market for a period of 6 years from 1996 to 2001. These transactions are recorded by the Dutch Association for Real Estate Brokers (Nederlandse Vereniging van Makelaars, NVM). NVM is one of the biggest brokers operating in the Dutch housing market. Thus, the data acquired represent a sample of housing transactions. The fact that the broker operates country-wide gives the data enough randomness to make an analysis without having to worry about selection bias. The data incorporate information related to the price of the dwellings, the characteristics of the dwellings and a number of environmental features. To enrich the dataset, each of the houses sold was geo-coded separately to enable us to compute distance to railway stations and highway entry/exit points. Some houses are geo-coded at the precise house address level and the remainder are geo-coded at the 6-digit postcode level (for example, 1234 XX), an area comprising up to about 20 houses (households). The Netherlands has 433 470 6-digit areas. A 4-digit postcode area is another important postcode unit. The country has 4009 such units, each of which on average contains about 1800 houses. However, postcode areas differ greatly in terms of area size and number of houses. In the urban context, the 4-digit postcode area is smaller but is densely populated. Conversely, in rural areas the postcode area represents a larger area but with low population density.

House characteristics, accessibility and neighbourhood features are used in our model. The land use data were acquired from the Central Office of Statistics for the Netherlands (Centraal Bureau voor de Statistiek, CBS). These data are available at the 4-digit postcode level. Moreover, population-related data are available at this level of aggregation. Income levels of the population in the postcode area, the density and population composition and, in particular, the percentage of foreigners in the area, are included in our analysis. The descriptive statistics of the three categories of features affecting property values are given in Table 1. The descriptions are presented for the three separate metropolitan areas in the Netherlands: namely, Amsterdam, Rotterdam and Enschede.

3.1 Physical Characteristics

For the physical features of the houses, we use a large number of relevant items. Examples

Table 1. Descriptive statistics of characteristics

	Minimum	*Maximum*	*Mean*	*S.D.*
Amsterdam metropolitan area				
Dependent variable				
Transaction price in euros	14 067	5 558 808	176 603	128 584
Independent variables				
House features				
Surface area in square metres	11	65000	194	1019
Building age in years	0	967	46	52
Total number of rooms	1	24	4	1
Number of bathrooms	0	4	1	1
Monument[a]			0.026	
Gas heater[a]			0.108	
Open fireplace[a]			0.090	
Garage[a]			0.141	
Garden[a]			0.574	
Accessibility features				
Distance to nearest railway station (km)	0.048	11.203	2.589	1.995
Distance to most frequently chosen railway station (km)	0.051	25.448	3.826	4.085
RSQI (nearest railway station)	0.235	1.832	0.962	0.323
RSQI (most frequently chosen railway station)	0.338	1.832	1.137	0.321
Distance to nearest school (km)	0.00	9.04	0.99	0.95
Distance to nearest hospital (km)	0.00	12.01	2.81	2.42
Distance to 100 000 jobs (km)	0.01	21.94	7.32	3.83
Environmental				
Income in euros (4-digit postcode level)	7 600	20 908	2 579	2 175
Population composition (percentage of foreigners)	0.000	0.746	0.141	0.127
Rotterdam metropolitan area				
Dependent variable				
Transaction price in euros	15 882	2 042 011	137 729	100 004
Independent variables				
House features				
Surface area in square metres	11	99998	191	1210
Building age in years	0	970	39	31
Total number of rooms	1	22	4	1
Number of bathrooms	0	4	1	1
Monument[a]		0.005		
Gas heater[a]		0.109		
Open fireplace[a]		0.113		
Garage[a]		0.143		
Garden[a]		0.543		
Accessibility features				
Distance to nearest railway station (km)	0.034	9.079	2.261	1.959
Distance to most frequently chosen railway station (km)	0.063	27.407	3.736	4.244

Table 1. *(Continued)*

	Minimum	*Maximum*	*Mean*	*S.D.*
RSQI (nearest railway station)	0.197	1.255	0.679	0.237
RSQI (most frequently chosen railway station)	0.208	1.255	1.029	0.275
Distance to nearest school (km)	0.000	5.837	0.948	0.851
Distance to nearest hospital (km)	0.072	13.732	2.304	1.817
Distance to 100 000 jobs (km)	0.003	21.319	9.553	2.934
Environmental				
Income in euros (4-digit postcode level)	6 761	16 338	11 803	1 721
Population composition (percentage of foreigners)	0.000	0.705	0.137	0.125
Enschede metropolitan area				
Dependent variable				
Transaction price in euros	22 689	2 042 011	143 085	83 624
Independent variables				
House features				
Surface area in square metres	11	77500	609	2266
Building age in years	0	917	32	29
Total number of rooms	1	21	5	1
Number of bathrooms	0	4	1	1
Monument[a]		0.001		
Gas heater[a]		0.098		
Open fireplace[a]		0.191		
Garage[a]		0.539		
Garden[a]		0.886		
Accessibility features				
Distance to nearest railway station (km)	0.056	15.373	2.432	2.040
Distance to most frequently chosen railway station (km)	0.055	18.234	2.220	2.529
RSQI (nearest railway station)	0.055	0.631	0.324	0.166
RSQI (most frequently chosen railway station)	0.058	0.631	0.365	0.194
Distance to nearest school (km)	0.000	8.073	1.533	1.327
Distance to nearest hospital (km)	0.123	18.861	6.041	4.415
Distance to 100 000 jobs (km)	0.230	25.549	13.738	3.702
Environmental				
Income in euros (4-digit postcode level)	7 993	11 952	10 089	830
Population composition (percentage of foreigners)	0.000	0.275	0.046	0.053

[a] Dummy variable

are the surface area of the house (including the built-up and the non-built-up part of the property), the age of the house, the number of rooms and the number of bathrooms; all these variables are continuous. The rest of the physical characteristics, such as the monument status of the dwelling, availability of a gas heater, presence of an open fireplace and presence of a garden and garage, are indicated by dummy variables. The monument status of a property is its official recognition as a building of architectural and/or historical interest by regional authorities; such recognition grants certain privileges but also imposes restrictions with regard to the degree of allowable renovation work. The mean values for some of these features are given in Table 1.

3.2 Accessibility Features

Railway accessibility. In the Netherlands, railways are an important mode transport. Of all the travel demand, 8 per cent relates to railways. Railway accessibility has two components. First, is a local accessibility component which measures how close a property is located in relation to a railway station. This is measured by the Euclidean distance between a property and a railway station. Secondly, there is a regional accessibility component that measures the potential level of train services provided at the railway station. A derived railway service quality index (RSQI) is used to measure this component of railway accessibility. In the context of rail services, the service provided at a station can be assumed to relate to four aspects, each of which has implications for the total travel time. First, it is related to how quickly travellers can get service. In other words, this means the average time that travellers have to wait before catching a train. This feature is determined by the frequency of trains leaving the station during a period of time. A shorter waiting time implies a higher level of service. Secondly, service is related to how well the station concerned is connected to other stations in the network. This indicates the level of service coverage or network connectivity provided by the railway station. The number of direct connections from the station is a good indicator of the network connectivity of a station. However, some stations can only be accessed via a transfer station. Thus, the number of transfers needed is a good indicator of how well the station is connected to other stations in the network. Thirdly, the rail service provided at a station relates to the relative position of the station in the network. This feature is directly related to the distance between stations and the speeds at which the trains operate. The in-vehicle travel time is an important determinant of this feature. Furthermore, being close to important destination stations in the network increases the attractiveness of a station as a departure point. Fourthly, service relates to the monetary costs (fares) incurred in travelling to a certain destination. All these points represent elements of the generalised cost (GC) of travel. Thus, the RSQI requires a comprehensive approach that integrates all these features. An outline of the estimation and computation methods used to derive this measure is given in the Appendix.

A sizeable proportion of the railway travellers use a railway station as their departure station that is not the nearest one. This indicates that the assumption that real estate prices are influenced by railway accessibility in relation to the nearest railway station may not be entirely valid. To explore this issue, we analysed the effect of railway accessibility on property values for two railway station considerations: the *nearest* and the *most frequently chosen* railway station. The nearest station is easily determined using GIS methods. The identification of the most frequently chosen station was based on a revealed choice survey study conducted by the Dutch National Railway Company (Nederlandse Spoorwegen, NS). Even though the survey was conducted at an individual-traveller level, aggregation was used to identify the most frequently chosen station at the 4-digit postcode area level.

The entire Dutch railway network has about 360 stations. The distance to the most frequently chosen station is on average about 1 km longer than the average distance to the nearest railway station. The average RSQI of the *most frequently chosen* railway station is 25 per cent higher than the RSQI of the *nearest* railway station. This gives an indication of the trade-off that travellers make between the proximity of stations and the level of service offered.

Road accessibility—accessibility to jobs. One would expect proximity to employment areas to be an important factor in determining house prices. In this connection, the road network was used to compute accessibility to employment areas. However, determining the proximity to an employment area is a rather difficult task. In the monocentric city case, all jobs are assumed to concentrate in a central core, which is mostly referred to as the central business district (CBD). Thus, most studies which try to determine the effect of proximity to an employment area do so by focusing on the proximity to the CBD. However, because of the increasing decentralisation of jobs out of the historical CBDs, the usefulness of this approach is limited. In this study, we account for the proximity to employment areas by considering the distance to a fixed number of jobs. We take this fixed number of jobs to be 100 000. Thus, proximity to jobs is measured by the (weighted) average distance to the 100 000 jobs from the location of the dwelling. The data are available at the 100 x 100 metres grid level.

Accessibility to schools and hospitals. One would expect proximity to schools and hospitals to contribute positively to the property values. In the Netherlands, differences in the quality of schools are not an issue compared with the situation in many other countries and thus we decided to use a standard proximity effect. Accessibility to schools and hospitals is measured as the Euclidean distance between the dwelling concerned and the nearest school and hospital respectively. The schools in our case provide secondary education (equivalent to the junior and secondary school level in the US educational system).

3.3 Environmental Characteristics

The environmental characteristics used in this analysis include land use features at the local level (4-digit postcode area). About 14 land use types are identified. In addition, the socioeconomic composition of the population is accounted for by the average household income and percentage of foreigners in the postcode area.

4. Methodology

The hedonic pricing methodology is effective in singling out the effect of one characteristic from a number of characteristics of a property (Rosen, 1974). We used this approach to determine the effect of the three categories of house features in general, and of railway accessibility in particular. A semi-logarithmic specification is adopted. Thus, the dependent variable in our analysis is the natural logarithm of the transaction price of residential houses. A wide range of independent variables that are expected to explain the house prices are included, such as the physical characteristics of the houses, environmental amenities and the accessibility variables corresponding to the houses under scrutiny. Because the dataset covers a relatively long period and house prices have increased continuously during the past decade, temporal effects are also expected to play a role in illustrating the variation in the selling price of houses. We therefore include sales year dummies to capture the temporal effects. These account for the inflation, real value changes and other temporal effects across the time-period. To account for the spatial effect, regional dummies are included at the municipality level. The focus of the analysis here is the effect of railway station proximity and the rail service quality of the stations; we also include a road accessibility measure to account for competition from the car.

4.1 Model Specification

We organised our data in a cross-sectional pattern. The semi-logarithmic hedonic specification is widely used in the property value literature. Its use is justified because it gives robust estimates and enables convenient coefficient interpretation. The general structure of our model is

$$Ln(P_i) = B_0 + B_1'X_{i1} + B_2'X_{i2} + \ldots + B_n'X_{in} + \varepsilon_i \quad (1)$$

where, P_i is the price of house i; and $X_{i1} \ldots X_{in}$ are vectors of explanatory variables for the price of house i. The dependent variable is given in the natural logarithmic form; thus, the values of the coefficients represent percentage change. The specifications used in the estimations are given by equation (2). Both the distance to the railway station and the railway service quality index (RSQI) are entered in the model in the natural logarithmic form. The models attain the following form

$$\begin{aligned} \ln(tranPrice_i) = \alpha &+ \beta'_{HC} \times HouseChr_i + \beta \times \ln raildist_i + \beta_{RSQI} \times \ln RSQI_i \\ &+ \beta_{railline} \times Drailline_i + \beta_{hwline} \times Dhwline_i + \beta_{hw} \times \ln Djobs_i \\ &+ \beta_{school} \times \ln Dschool_i + \beta_{hw} \times \ln Dhospital_i + \beta'_{Neigh} \times Neighb_i \\ &+ \beta'_{Region} \times Dregional_i + \beta'_{time} \times Dtime_i + \varepsilon_i, \end{aligned} \quad (2)$$

where, $tranPrice_i$ represents the transaction price of house i; $HouseChr_i$ is a vector of house characteristics for house i, which includes variables for type of house, surface area, total number of rooms, number of bathrooms, presence of garage and garden for the house, presence of gas heater and fireplace, monument status of the house and age of the building. Some of these variables are continuous, while others are represented by dummies. A logarithmic transformation of the continuous variables can be used in the estimation. Among the continuous variables, surface area and total number of rooms have entered the estimation as logs. There are a substantial number of observations with zero values for the age of the building and number of bathrooms. Therefore, these variables are measured in absolute numbers and not in logs. $raildist_i$ is the Euclidean distance between house i and the railway station concerned. $RSQI_i$ is the RSQI for the railway station concerned. In our analysis, we considered two station references: the nearest vs the most frequently chosen station in the postcode area. $Drailline_i$ and $Dhwline_i$ are dummy values which indicate whether house i is located within 100 metres of the railway line and highway respectively and are also expected to capture the noise-related effects. $Neighb_i$ is a vector of neighbourhood characteristics which includes income level, percentage of foreigners and share of land use types. It is given at the 4-digit postcode level. These variables were included to take into account neighbourhood externalities, since house prices may react to social aspects of the community. The income level of households in a certain neighbourhood is a reflection of the economic status of the neighbourhood. On the other hand, a large share of foreign residents may lead to the neighbourhood having bad reputation. $Dregional_i$ is a vector of dummy variables representing the municipality to which the house belongs. $Dtime_i$ is a vector of time dummy variables representing the year when the transaction took place. ε_i is the error term ($iid(0, \sigma^2)$).

The accessibility-related variables included are the distance to the railway stations, the RSQI, distance to schools, distance to hospitals and distance to job areas. The structural features considered are the types of houses, the surface area of the houses, the total number of rooms, the number of bathrooms, the presence of a garage, garden, gas heater and fireplace, the monument status of the houses and the age of the houses. Variables included under the environmental features are average household income, percentage of foreigners and share of different land use types at the postcode level. Regional variables are accounted by municipality dummy variables. Dummy variables representing distances within 100 metres from the railway line and the highway are included to capture the nuisance effect from the railway and the highway respectively. Year dummies are also used to account for the temporal effect. The total number of explanatory variables in the hedonic pricing models is 82. Of these, 33 relate to house characteristics, 16 to neighbourhood features, 5 to time series dummies and there are a maximum of 21 municipality dummies. The remaining 7 variables relate to different accessibility features: they relate to railway, highway and public facilities such as schools, hospitals and job concentration. The municipality dummies represent the many municipality-specific factors that may affect house values. Thus, the effects we find for railway station proximity have been corrected for municipality-specific impacts.

Generally, one would expect house prices to rise the nearer houses are located to the railway station and/or job concentration area. At the same time, one would expect the influence of a station on house prices to increase with a rise in the service level provided by the station, as given by the RSQI computed in this paper. We find the RSQI to be a comprehensive measure of train service quality because it addresses all the components of the generalised journey time.

The high-quality nature of the data on house sales and other variables has allowed us to control for a wide range of features that could affect house prices. This will in turn help to isolate the effect of our variable of interest—railway accessibility—with a higher level of precision. On the other hand, it may be argued that the inclusion of a huge number of variables increases the risk of multicollinearity. At the same time, a missing variable bias would be present if the control variables were to be excluded from the estimation. However, we do not find any systematic relationship between the railway accessibility variables and the other control variables. Thus, since the problem of multicollinearity does not interfere with the variable of interest, the discussions of the effect of railway accessibility remain valid.

5. Estimation Results and Discussion

Table 2 gives the estimation results for the three metropolitan areas based on the nearest railway station. Table 3 gives the estimation results based on the most frequently chosen station. To save space, the coefficients of the municipality dummies are not reported. The complete estimation results are available on request from the authors. The fact that the dependent variable is given in a logarithmic form facilitates the interpretation of the coefficients. For variables entered as natural logarithms, the coefficients represent the elasticities. For variables entered without any transformation, the coefficients represent percentage changes.

5.1 Effects of Railway Accessibility

The variables of concern in this paper relate to the accessibility features and particularly the accessibility provided by railway stations. Thus, the discussion in this section will concentrate on the accessibility variables. From Table 2, in the Amsterdam metropolitan area the elasticity of distance to the nearest railway station is –0.01. This means that, if the distance between the location of the real estate and the nearest railway station doubles, the real estate price declines by 1 per cent. On the other hand, the elasticity of the railway service quality index (RSQI) for this metropolitan area is –0.036. The sign of the coefficient is counter to the expectation. For the Rotterdam metropolitan area, both variables are found to be insignificant. A significant

Table 2. Estimation results based on the nearest railway station

	Amsterdam (N = 40 326)		*Rotterdam (N = 17 772)*		*Enschede (N = 5 997)*	
Variables	*Coefficient*	*T-test*	*Coefficient*	*T-test*	*Coefficient*	*T-test*
(Constant)	10.239***	282.773	9.465***	146.443	9.990***	13.370
Physical house characteristics						
Log (surface area)	0.320***	110.695	0.290***	60.710	0.240***	49.732
Building age ('100 years)	–0.032***	–6.712	–0.233***	–23.464	–0.317***	–20.015
Building age squared ('100 years)	0.005***	6.967	0.031***	15.685	0.034***	13.550
Log (number of rooms)	0.312***	75.087	0.307***	43.187	0.220***	18.424
Number of bathrooms	0.063***	33.652	0.049***	15.217	0.045***	8.425
Gas heater	–0.125***	–30.800	–0.210***	–33.146	–0.079***	–8.447
Open fireplace	0.030***	7.004	0.045***	7.404	0.053***	8.012
Monument status	0.176***	20.953	0.308***	11.460	0.190**	2.008
Presence of garage	0.080***	19.990	0.113***	17.796	0.112***	19.848
Presence of garden	0.072***	18.131	0.038***	5.276	–0.045***	–4.261
Accessibility variables						
Log (distance to railway station)	–0.009***	–3.542	0.001	0.356	–0.020***	–3.194
Log rail service quality index (RSQI)	–0.036***	–4.960	–0.007	–1.146	0.040***	2.794
Railway line within 100 metres	0.009	1.286	0.010	1.035	–0.059***	–3.722
Highway line within 100 metres	–0.050***	–4.889	0.005	0.284	0.098***	3.232
log (distance to 100 000 jobs)	–0.052***	–20.188	–0.037***	–11.544	–0.030	–1.217
log (distance to school)	–0.005**	–2.471	0.008***	2.618	0.005	1.149
log (distance to hospital)	–0.037***	–16.485	–0.055***	–12.669	–0.030***	–3.242
Socioeconomic variables						
Log (average income p.p.) ('000)	0.047***	47.539	0.081***	36.036	0.053***	5.717
Ratio of foreigners	–0.447***	–23.798	0.632***	22.428	–0.462***	-2.950
Type of house						
Middle-class house	0.094***	13.001	0.087***	6.656	0.161***	13.195
Upper-class house	0.292***	36.232	0.282***	19.981	0.363***	26.883
Villa	0.447***	37.737	0.428***	22.457	0.634***	23.617
Country house	0.312***	13.668	0.454***	12.917	0.562***	21.935
Estate	–0.066	–0.844	–0.025	–0.202	0.485**	2.471
Detached house	0.263***	15.527	0.341***	11.100	0.274***	12.575
Detached house with patio	0.282***	11.795	0.167***	5.424	0.363***	8.589
Semi-detached house	0.248***	15.339	0.279***	8.351	0.443***	27.365
Split-level house	0.313***	9.861	0.224***	5.715	0.347***	4.097
Meander house	–0.016	–0.262				
Ground-floor flat	0.172***	18.849	–0.021	–1.447	0.286***	2.995
Upstairs flat	0.147***	16.845	–0.100***	–6.533	0.180***	3.732
Ground- and first-floor flat	0.265***	11.836	–0.012	–0.481		
House with porch	0.106***	6.967	–0.174***	–9.406	–0.049	–0.856
Canal house	0.661***	36.562	0.510***	8.630		
Maisonette	0.129***	12.535	–0.056***	–3.380	0.154	1.614
Care flat	–0.679***	–25.552	–0.273***	–5.477		
Flat with lift	0.066***	7.638	0.017	1.104	–0.007	–0.264
Flat without lift	0.070***	8.041	–0.138***	–9.268	0.030	1.167
Practice house	0.427***	20.478	0.337***	11.045	0.368***	8.410
Drive-in house	0.209***	14.094	0.149***	6.226	0.212***	2.719

Table 2. *(Continued)*

Variables	*Amsterdam (N = 40 326)* *Coefficient*	*T-test*	*Rotterdam (N = 17 772)* *Coefficient*	*T-test*	*Enschede (N = 5 997)* *Coefficient*	*T-test*
Farmhouse	0.177***	7.344	0.179***	3.226	0.365***	17.309
Apartment	0.231***	26.702	0.042***	2.732	0.404***	15.569
Temporal variables						
Year96	–0.616***	–98.851	–0.518***	–60.252	–0.534***	–39.347
Year97	–0.492***	–79.583	–0.416***	–47.750	–0.436***	–32.732
Year98	–0.363***	–59.252	–0.363***	–25.798	–0.343***	–26.063
Year99	–0.198***	–32.504	–0.176***	–21.673	–0.181***	–13.645
Year00	–0.080***	–13.033	–0.017**	–2.078	–0.053***	–3.982
Land use variables						
Residential area, high/medium density density}	–0.059***	–8.786	0.013	0.595	0.158	0.210
Residential area, medium density	–0.033***	–2.692	–0.063**	–2.389	0.115	0.159
Residential area, medium/low density	–0.080***	–5.041	0.607***	8.924	0.749	1.123
Residential area, low density	–0.323**	–2.516	–0.794	–1.245	–0.228	–0.314
Commercial sites	–0.191***	–5.014	–0.402***	–8.440	–3.165	–1.325
Firm sites	–0.095***	–4.776	0.268***	6.479	–0.177	–0.242
Socio-cultural sites	0.286***	5.319	0.121**	2.013	0.394	0.702
Seaport	0.286***	10.577	–0.256***	–4.358		
Recreational sites	–0.384***	–24.043	0.119***	3.940	–0.191	–0.258
Agricultural sites	–0.015	–1.666	0.275***	9.270	0.245	0.333
Natural areas	0.229***	10.112	0.394***	5.127	0.314	0.423
Infrastructure	–0.139***	–3.411	–0.817***	–18.055	–0.628	–0.815
Surface water	0.180***	8.473	0.738***	18.674	–0.002	–0.002
Remaining land use	0.231***	8.844	–0.014	–0.223	1.338	1.778
R^2	0.817		0.823		0.831	

Notes: ** significant at the 5 per cent level; *** significant at the 1 per cent level.

effect with the expected sign is observed for the Enschede metropolitan area. The elasticity of distance to the nearest railway station and of the RSQI of the nearest station are –0.02 and 0.04 respectively.

In Table 3, almost all the variables related to the railway accessibility have a significant effect with the expected signs. In the Amsterdam metropolitan area, the elasticities of distance to the most frequently chosen station in the postcode area and of its RSQI are –0.012 and 0.118 respectively. In the Rotterdam metropolitan area, distance has no significant effect. However, the RSQI of the most frequently chosen station has a significant effect on real estate price with 0.108 elasticity. Moreover, the elasticities of distance to the most frequently chosen station and its RSQI for the Enschede metropolitan area are –0.025 and 0.030 respectively.

If we compare the results of the two railway station considerations, we see that regional differences present particular implications for the effect of railway accessibility on real estate. In the less urbanised metropolitan area, represented by Enschede, the effect of the nearest railway station and most frequently chosen station are more or less comparable. This means that, in most cases, the nearest railway station and the most frequently chosen station are the same. This is particularly true in less urbanised areas, where the choice of departure

Table 3. Estimation results based on the most frequently chosen station

	Amsterdam (N = 40 326)		*Rotterdam (N = 17 772)*		*Enschede (N = 5 997)*	
Variables	*Coefficient*	*T-test*	*Coefficient*	*T-test*	*Coefficient*	*T-test*
(Constant)	10.230***	294.614	9.522***	142.006	9.991***	13.308
Physical house characteristics						
Log (surface area)	0.321***	111.137	0.291***	61.235	0.240***	49.661
Building age ('100 years)	−0.031***	−6.433	−0.240***	−24.169	−0.319***	−20.142
Building age squared ('100 years)	0.005***	6.732	0.032***	16.177	0.034***	13.651
Log (number of rooms)	0.313***	75.590	0.307***	43.441	0.220***	18.410
Number of bathrooms	0.063***	33.869	0.048***	15.166	0.045***	8.475
Gas heater	−0.125***	−30.926	−0.213***	−33.722	−0.079***	−8.449
Open fireplace	0.031***	7.229	0.045***	7.463	0.054***	8.117
Monument status	0.167***	20.051	0.302***	11.261	0.196**	2.075
Presence of garage	0.081***	20.298	0.112***	17.612	0.112***	19.858
Presence of garden	0.072***	18.043	0.037***	5.080	−0.045***	−4.277
Accessibility variables						
Log (distance to railway station)	−0.012***	−4.781	0.000	0.031	−0.025***	−4.034
Rail service quality index (RSQI)	0.118***	15.826	0.104***	8.724	0.030	1.876
Railway line within 100 metres	0.016**	2.287	0.013	1.289	−0.060***	−3.815
Highway line within 100 metres	−0.043***	−4.226	−0.009	−0.586	0.117***	3.455
Log (average income p.p.) ('000)	0.045***	45.974	0.074***	31.846	0.056***	6.305
log (distance to school)	−0.011***	−5.927	0.012***	4.075	0.005	1.170
Log (distance to hospital)	−0.030***	−13.528	−0.053***	−12.332	−0.028***	−3.122
Socioeconomic variables						
Ratio of foreigners	−0.502***	−26.409	0.587***	21.004	−0.427***	−2.765
log (distance to 100 000 jobs)	−0.042***	−16.679	−0.036***	−11.337	−0.026	−1.066
Type of house						
Middle-class house	0.095***	13.259	0.086***	6.591	0.161***	13.169
Upper-class house	0.296***	36.792	0.277***	19.688	0.362***	26.806
Villa	0.451***	38.219	0.423***	22.281	0.634***	23.613
Country house	0.322***	14.177	0.448***	12.792	0.562***	21.945
Estate	−0.094	−1.212	−0.022	−0.184	0.476**	2.428
Detached house	0.272***	16.117	0.338***	11.062	0.272***	12.506
Detached house with patio	0.302***	12.676	0.163***	5.332	0.363***	8.578
Semi-detached house	0.250***	15.505	0.274***	8.226	0.442***	27.323
Split-level house	0.310***	9.817	0.222***	5.668	0.347***	4.093
Meander house	−0.028	−0.454				
Ground-floor flat	0.181***	19.910	−0.025	−1.698	0.281***	2.943
Upstairs flat	0.156***	17.911	−0.106***	−7.003	0.179***	3.698
Ground- and first-floor flat	0.272***	12.171	−0.014	−0.569		
House with porch	0.112***	7.402	−0.175***	−9.471	−0.053	−0.926
Canal house	0.663***	36.828	0.513***	8.705		
Maisonette	0.138***	13.503	−0.054***	−3.280	0.153	1.602
Care flat	-0.662***	−25.025	−0.267***	−5.372		
Flat with lift	0.078***	9.052	0.015	0.961	−0.008	−0.298
Flat without lift	0.079***	9.101	−0.139***	−9.380	0.027***	1.067
Practice house	0.431***	20.746	0.335***	10.992	0.368***	8.414
Drive-in house	0.218***	14.732	0.147***	6.192	0.213***	2.731

Table 3. *(Continued)*

	Amsterdam (N = 40 326)		*Rotterdam (N = 17 772)*		*Enschede (N = 5 997)*	
Variables	*Coefficient*	*T-test*	*Coefficient*	*T-test*	*Coefficient*	*T-test*
Farmhouse	0.175***	7.274	0.178***	3.220	0.364***	17.260
Apartment	0.239***	27.673	0.036**	2.381	0.401***	15.451
Temporal variables						
Year96	–0.615***	–99.022	–0.516***	–60.224	–0.534***	–39.357
Year97	–0.492***	–79.716	–0.414***	–47.647	–0.435***	–32.703
Year98	–0.361***	–59.221	–0.360***	–25.644	–0.343***	–26.053
Year99	–0.196***	–32.304	–0.173***	–21.423	–0.181***	–13.606
Year00	–0.078***	–12.791	–0.015	–1.792	–0.053***	–3.984
Land use variables						
Residential area-high/medium density density}	–0.052***	–7.840	–0.014	–0.610	0.110	0.147
Residential area, medium density	0.029**	2.320	–0.071***	–2.690	0.078	0.108
Residential area, medium/low density	–0.105***	–6.624	0.732***	10.738	0.754	1.119
Residential area, low density	–0.229	–1.789	–0.883***	–1.388	–0.362	–0.495
Commercial sites	–0.197***	–5.158	–0.401***	–8.486	–3.728	–1.570
Firm sites	–0.116***	–5.819	0.249***	6.069	–0.219	–0.300
Socio-cultural sites	0.326***	6.083	0.056***	0.938	0.398	0.710
Seaport	0.202***	7.495	–0.280***	–4.785		
Recreational sites	–0.369***	–23.190	0.138***	4.591	–0.228	–0.308
Agricultural sites	–0.005	–0.602	0.303***	10.235	0.210	0.284
Natural areas	0.008	0.301	0.782***	9.303	0.283	0.378
Infrastructure	–0.128***	–3.146	–0.841***	–17.791	–0.732	–0.953
Surface water	0.159***	7.523	0.652***	16.217	–0.192	–0.209
Remaining land use	0.207***	7.927	–0.150**	–2.322	1.260	1.678
R^2	0.818		0.824		0.831	

Notes: ** significant at the 5 per cent level; *** significant at the 1 per cent level.

railway stations is limited. On the other hand, in the most urbanised metropolitan area covered by the analysis, represented by the Amsterdam metropolitan area, the most frequently chosen railway station has a highly pronounced effect on real estate prices. This means that, in many cases, the most frequently chosen station is not the nearest railway station. The general conclusion that we can draw from this comparison is that, when estimating the effect of railway accessibility on property values, the most frequently chosen station outperforms the nearest railway station.

For a discussion of the results of the remaining features, we refer to the estimation results based on the most frequently chosen railway stations. Our estimation captures the effect of noise from the railway line and highway up to 100 metres. However, no consistent effect of noise is found. The elasticities of distance to 100 000 jobs via the road network for the Amsterdam and the Rotterdam metropolitan area are –0.042 and –0.036 respectively. No significant effect is found for the Enschede area.

6. Summary and Conclusions

This paper has analysed the effect of railway station accessibility on house prices. A cross-sectional hedonic price model was estimated based on Dutch residential house transactions in the years from 1996 to 2001. The model accounted for physical, environmental, temporal and accessibility features of the residential houses. For each of these features, a wide range of variables was included. However, our focus in this paper was to analyse the effect of accessibility provided by railway transport on property values. Most studies in this area consider only the proximity of properties to railway stations, but this approach is limited because the accessibility of railway stations is more than mere proximity to railway stations. In other words, railway stations are not chosen as departure points for reasons of proximity alone, so it was necessary to formulate a better approach to address railway accessibility.

Railway accessibility is a function of distance and train service levels at the relevant departure railway stations. The choice for a departure railway station is also affected by the levels of rail service, network connectivity, service coverage and station facilities. Thus, it is possible for the residential property value to react more to an important railway station located farther away than to a less important one located nearby. In this respect, most previous studies have had shortcomings in that they have neglected the choice process for a departure station in their property value effect analysis by considering only the nearest railway station. This paper has added to the literature in this area in two respects. First, we made a distinction between the nearest railway station to the property and the most frequently chosen station in the postcode area to which the property under consideration belongs. Secondly, a broader approach for addressing accessibility was applied by taking into account a comprehensive railway service quality index (RSQI). The RSQI accounts for the generalised journey time between all pairs of stations in the network, the importance of the destination railway station and the centrality of the concerned station in the network. The effects of proximity and train service levels on property values were then analysed. We also paid attention to the distance to railway lines in order to reflect potential noise and other disturbance effects.

Correcting for a wide range of other determinants of house prices, we found that prices of real estate are influenced more by the most frequently chosen station than by the nearest railway station to the dwelling. Thus, the model based on the most frequently chosen station outperforms the one based on the nearest railway station in terms of capturing the effect related to railway accessibility. In addition, our analysis found that the differences in results of the estimation are bigger for more urbanised areas than for less urbanised areas. This is because the instances where the most frequently chosen station is different from the nearest railway station occur more in urbanised areas than in less urbanised areas.

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Appendix

The estimation of the rail service quality index (RSQI) of a station is based on the doubly constrained spatial interaction model given as follows

$$T_{ij} = A_i O_i B_j D_j f(GJT_{ij})\, g(GJT_{ij}/d_{ij}) \exp(\xi_{ij}) \quad \text{(A1)}$$

$$O_i = \sum_j T_{ij} \quad \text{(A2)}$$

$$D_j = \sum_i T_{ij} \quad \text{(A3)}$$

where, T_{ij} is the number of trips between stations i and j; O_i is the total number of trips originating in station i; D_j is the total number of trips attracted by station j. A_i and B_j are the balancing factors which ensure that the constraints on origins and destinations (given by equations (A2) and (A3)) are met; GJT_{ij} is the generalised journey time between origin station i and destination station j; d_{ij} is the Euclidian distance between origin station i and destination station j; and ξ_{ij} is the error component of the model which follows an independently and identically normal distribution. We specify the functions f and g as follows

$$\mathrm{f}(GJT_{ij}) = \exp\left(\sum_{c=1}^{C} \beta_c DGJT_c^{ij}\right) \quad \text{(A4)}$$

$$g(GJT_{ij}/d_{ij}) = (GJT_{ij}/d_{ij})^{\gamma} \quad \text{(A5)}$$

where, $DGJT_c^{ij}$ is a dummy variable, which is equal to 1 if GJT_{ij} falls in the generalised journey time category c and zero otherwise. Thus, the doubly constrained gravity model we estimated is given by

$$T_{ij} = A_i O_i B_j D_j \exp\left(\sum_{c=1}^{C} \beta_c DGJT_c^{ij}\right)\left(GJT_{ij}/d_{ij}\right)^{\gamma} \exp(\xi_{ij}) \quad \text{(A6)}$$

This equation can be linearised by taking the natural logarithm of both sides:

$$\ln\left(T_{ij}/O_i D_j\right) = \ln A_i + \ln B_j + \left(\sum_{c=1}^{C} \beta_c DGJT_c^{ij}\right) + \gamma \ln\left(GJT_{ij}/d_{ij}\right) + \xi_{ij} \quad \text{(A7)}$$

The coefficient of the generalised journey time categories, the ratio of generalised journey time and the balancing factors will be estimated from equation (A7). Thus, in the estimation, the logs of the balancing factors in the equation represent the coefficients to be estimated. This requires that the logs of the balancing factors are multiplied by the dummy variable for the corresponding station. Therefore, the equation for the estimation is given as

$$\ln\left(\frac{T_{ij}}{O_i D_j}\right) = \sum_{\bar{i}=1}^{N} \ln A_{\bar{i}} S_{\bar{i}} + \sum_{\bar{j}=1}^{N-1} \ln B_{\bar{j}} S_{\bar{j}} + \ln\left(\sum_{c=1}^{C} \beta_c DGJT_c^{ij}\right) + \gamma \ln\left(\frac{GJT_{ij}}{d_{ij}}\right) + \xi_{ij} \quad \text{(A8)}$$

where, N is the number of railway stations in the railway network; and $S_{\tilde{i}}$ and $S_{\tilde{j}}$ are dummy variables for departure station $\tilde{i}$ and destination station $\tilde{j}$. They assume the value 1 when $i = \tilde{i}$ and $j = \tilde{j}$ respectively, and 0 otherwise. Given the assumption on the error components, equation A8 can be estimated using ordinary least squares (OLS). The estimated coefficients are then used in determining the RSQIs for each station. The RSQI of any departure station i is determined as the aggregation sum of the quality measures over all the destination stations (js). Thus, the RSQI of a given departure station is given by

$$RSQI_i = \sum_j \hat{B}_j D_j \hat{f}(GJT_{ij}) \hat{f}(\frac{GJT_{ij}}{d_{ij}}) = \sum_j \hat{B}_j D_j \exp\left(\sum_{c=1}^{C} \hat{\beta}_c DGJT_c^{\,ij} \right) \left(\frac{GJT_{ij}}{d_{ij}} \right)^{\hat{\gamma}} \quad \text{(A9)}$$