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Geographical range of amenity benefits: hedonic price analysis for railway stations

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Abstract in English

People want to live nearby consumption amenities as this saves time on commuting. By developing land nearby existing or new amenities local governments can try to internalize these proximity benefits. This paper develops a residential location model in which the geographical range and the magnitude of amenity benefits as reflected in residential prices can *ex post* be assessed. First we extend a standard residential location model with a non-essential consumption amenity. We show that the geographical range of amenity benefits can be determined as the minimal distance to the amenity beyond which residential rents are independent of the distance to the amenity. We apply this insight in a hedonic analysis of the effect of proximity to a railway station on local housing prices in the wider metropolitan area of Amsterdam, the Netherlands. The geographical range of the railway stations is estimated to be 1.1 kilometer and the house price premium paid for station proximity is estimated to be 3 to 5 percent. We show furthermore that failing to account for the localized character of the amenity benefits can lead to a considerable under- or overestimation of the magnitude of the benefits.

Key words: Consumption amenities; house prices; hedonic models; geographical range of benefits
JEL code: H41, R4

Abstract in Dutch

Mensen willen graag in de buurt van lokale publieke voorzieningen wonen omdat dit reistijd naar deze voorzieningen bespaart. Door grond in de buurt van bestaande of nieuwe voorzieningen te ontwikkelen, kunnen lokale overheden deze nabijheidsbaten internaliseren. Dit paper ontwikkelt een consumenten-locatiekeuzemodel waarmee de reikwijdte en de omvang van de baten van voorzieningen, zoals weergegeven in woningprijzen, in beeld gebracht kunnen worden. Eerst breiden we een standaard consumenten-locatiekeuzemodel uit met een niet-essentiële consumptievoorziening. We laten zien dat de reikwijdte van de baten van de voorziening kan worden uitgerekend als de minimale afstand tot de voorziening waarbuiten de grondrente onafhankelijk is van deze afstand. Dit inzicht wordt vervolgens toegepast in een hedonische analyse van het nabijheidseffect van stations op huizenprijzen in de omgeving van Amsterdam. We schatten de reikwijdte van de stations op 1,1 kilometer en de prijspremie die voor de nabijheid van station wordt betaald, op 3 tot 5 percent. We laten zien dat als geen rekening wordt gehouden met het lokale karakter van de baten van voorzieningen, het nabijheidseffect van de voorzieningen sterk over- of onderschat kan worden.

Steekwoorden: Consumentenvoorzieningen; huizenprijzen, hedonische modellen; reikwijdte van baten.

Contents

Summary

People want to live nearby consumption amenities such as schools, swimming pools, railway stations, as this saves time on commuting. By developing land nearby existing or new amenities local governments can try to internalize these proximity benefits. In this paper we analyze the geographical range and the magnitude of the benefits from proximity as reflected in land prices. In contrast to what is usual in the literature in this study we explicitly allow for the possibility of a limited geographical range of these amenity benefits.

In a simple theoretical residential location model we show that the amenity benefits are capitalized in the residential rents and that the geographical range of these benefits can be determined as the minimal distance to the amenity beyond which residential rents are independent of the changes in this distance. We apply this insight in a hedonic analysis of residential property transaction data in the region of Amsterdam, the Netherlands, in order to estimate the effect of proximity to the railway stations on sales prices of apartments. We estimate the average geographical range of railway station benefits to equal 1.1 kilometer. Within this geographical range and outside the immediate proximity of the station, apartments are sold at a price premium of approximately 5%. Within the immediate proximity where people are likely to experience nuisance from the station, this price premium is lower and equals approximately 3%. Furthermore, we illustrate that failing to account for the geographical range of amenity benefits may lead to misestimating severely the magnitude of these benefits.

The insights from this paper may be applied in designing urban development policies. In the Netherlands these are mostly (local) governments that decide on land development for new housing construction. Recently relatively much attention has been given in different regions to residential construction in railway station areas. Results of this paper provide some support for this policy. We show that by internalizing station proximity benefits residential development of railway station areas can yield additional revenues in comparison with residential development elsewhere. At the same time however railway station area development is not seldom accompanied by considerable costs, with the costs of tunneling the rail to create new construction ground being an extreme example. A careful comparison of costs and benefits of residential construction in railway station areas is thus necessary in every specific case to make a well-considered decision about the area development.

Another implication of this research concerns the financing of railway stations. Railways are supra local amenities and these are usually financed by the central government. Railway stations have however apart from supra local benefits also purely local benefits, which can be internalized by local governments with the help of land development. Our research suggests a

way to determine the size of the local benefits of railway stations and to formulate a reasonable division of investment expenses between the local and the central government levels.

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1 Introduction

The location of a house forms a key factor that determines its price. People are ready to pay for location benefits, such as accessibility of consumption amenities that saves time on commuting. By developing land nearby existing or new amenities local governments can try to internalize these location benefits. In the Netherlands, for example, where (local) governments decide on locations for land development and housing construction, residential construction in railway station areas has been given much attention recently, not in the last place for the above mentioned reason.[1] Sometimes even an investment in tunneling of the railway is considered in order to extend the space available for urban development nearby the station (see e.g. Eijgenraam and Ossokina, 2008). To make appropriate decisions concerning land development and provision of consumption amenities, city and regional planners need to know within which geographical range potential users of the amenities live and how these people value amenity benefits. This paper develops a residential location model in which the geographical range and the magnitude of the benefits of local amenities can be assessed. This model is tested empirically for the case of railway stations.

We develop a simple monocentric city model of the type of Fujita (1989, ch.2) and extend it with a local public good providing consumption amenity. Consumption of this amenity involves transport costs that depend on the distance to it. In this model we show that: (i) the amenity benefits are capitalized in the residential rent; (ii) the size of these benefits decreases with the distance to the amenity; (iii) the geographical range of the amenity benefits can be determined as the minimal distance to it beyond which residential rents are independent of the changes in this distance. We use the results (i)-(iii) to assess empirically the geographical range and magnitude of the benefits of railway stations in the wider metropolitan area of Amsterdam, the Netherlands. For this purpose we extend a standard hedonic price model of residential properties with an independent variable measuring the distance to the railway station. We estimate the geographical range as the distance to the railway station beyond which no significant effect of the distance variable on the property price can be found.

The theoretical part of this paper is related to a small literature that analyzes the effects of local public goods in an urban residential location model and shows that benefits from public goods are capitalized in residential rents. Little attention has been paid in this literature however to the analysis of how the benefits from public goods change with distance and how far these benefits range. Most of the papers in question assume that these benefits can only be enjoyed in the

[1] Examples are: major real estate development in the South Axis area near railway station South in Amsterdam, re-development and urban construction in the Paleiskwartier near railway station Den Bosch, re-development and urban construction in the railway station area in Delft, etc. There are also examples of land development that exploit proximity to other amenities, such as e.g. the new urban district Nieuw Crooswijk close to the major park Kralingse Bos in Rotterdam.

direct vicinity of public goods (see for example Fujita, 1989, chapter 6; Rowendal en Van der Straaten, 2008), thus postulating the geographical range to be equal to the direct vicinity and leaving the effect of distance on the magnitude of the benefits outside the scope of the analysis. Wu (2001) incorporates in his model consumption amenities with benefits that fall with distance. He shows that these benefits are capitalized in residential rents that reach a local peak in the direct vicinity of the amenity and decrease with the distance to it. However, Wu does not explicitly model the reason why benefits of the public good decline with distance. As a result the geographical range of the amenity benefits does not follow from the model but is by assumption reached at the city boundary. In our paper declining with distance benefits of a public good result endogenously from the assumption of positive transport costs to the amenity. We show furthermore that in the optimum city residents living far from the public good may choose not to use it. The geographical range of the amenity benefits in our model is thus endogenously determined and can be achieved within the city borders.

The empirical part of our research is related to a rather large and growing hedonic price literature that measures the effect of distance to local public goods on housing prices. Studies in question generally find negative significant effects of an increase in the distance to the amenity.[2] Anderson and West (2006) show using American data that the magnitude of these effects varies with the size of the amenity in question (e.g., large or small park) as well as with the location of the residential property and its surroundings.[3] Cavailhes et al. (2009) argue using French data that for small distances the amenities in sight have a much larger effect on the housing prices than the amenities out of sight.[4] Few empirical studies however examine explicitly the geographical range of the proximity effects.[5] In this paper we estimate from data the geographical range within which a significant effect of proximity to an amenity can be observed. We show furthermore that a failure to account for the correct geographical range may lead to misestimating the magnitude of the amenity proximity effect severely.

Our study is furthermore related to the research that assesses economic benefits of railway station proximity, and especially Gibbons and Machin (2005) and Debrezion, Pels and Rietveld (2006). Gibbons and Machin examine the benefits of rail access by estimating the effects of a transport innovation (opening of two new line extensions in London underground) on housing prices in London area, England; they use a difference-in-difference approach to distinguish the benefits of rail access from other station proximity effects. In this paper we focus on proximity

[2] Brander and Koetse (2008) and Anderson and West (2006) provide overviews of studies on the effects of distance to open space. Gibbons and Machin (2005) provides an overview of studies on the effects of distance to public transport stations.
[3] De Vor and De Groot (2009) find for the Netherlands that the influence of proximity to a disamenity (industrial sites) on housing prices also varies with the disamenity's size.
[4] Dekkers and Koomen (2008) find similar results for the Netherlands.
[5] Gibbons and Machin (2005) is a notable exception, they find the geographical range of the effect of a new railway station to be equal to 2 kilometres.

effects of existing railway stations, which allows us to get a better insight in the profitability of land development in railway station areas. We use a cross-sectional approach to study the proximity effects as these are reflected in housing prices. Debrezion et al. (2006) uses a cross-sectional analysis to study the proximity effects of Dutch railway stations on housing values; their study however does not aim at analyzing explicitly the geographical range of these effects.

The remainder of the paper is organized as follows. In Section 2 we present the theoretical model. The discussion is structured so as to give foundation for the empirical estimation of the geographical range and the magnitude of the amenity proximity effect. Sections 3 to 5 present the empirical application. In Section 3 we describe the data and the econometric methodology used. In Sections 4 and 5 we present and discuss the results of the econometric estimation and perform various robustness checks. Section 6 concludes and discusses policy implications of our research.

2 Theoretical framework

The residential location model we introduce in this section conforms to some of the basic assumptions of standard spatial equilibrium models of the type of Solow (1973) or Fujita (1989). These include: a central business district (CBD), a population of households with similar incomes and preferences, a travel cost that depends on the distance traveled. In contrast to the standard residential location models and in line with Wu (2001) our model assumes that residential sites are differentiated not only by the distance to the CBD, but also by the distance to the amenity, and that consumption of the amenity positively influences utility. In contrast to Wu, however, we assume that consumption of the amenity involves transport costs that increase with the distance to the amenity, and that the optimal consumption level of the amenity at any location is endogenous.

2.1 Description of the model

Consider a monocentric city on a two-dimensional plane with a Central Business District (CBD) in $r=0$ and the city boundary at the distance $r=R_f$ from the CBD. Identical households work in the CBD and earn there a given income $\overline{Y}$. They live at a distance $r<R_f$ from the CBD and are free to choose this residential location r. Each household chooses its most preferred consumption bundle that consists of a combination of the composite good (z), residential space (s) and number of visits to the amenity (A), to maximize the utility $U[z, s, A]$ given their budget constraint. The composite good (z) and residential space (s) are essential goods, in the sense that the utility function is only defined for positive values of these goods. Visits to the amenity are non-essential: the utility function is defined for non-negative values of the number of visits (A).

The amenity (think for example of a park, a swimming pool, a railway station) is located at an exogenously given distance a from the CBD.[6] Consumption of the amenity (A) is measured in terms of the frequency with which consumers visit the amenity. Making use of the amenity involves a cost-price equal to k, in the remaining part of the model we set $k=0$ without loss of generality. Fixed costs of setting up the amenity are paid from the local taxes that are fixed at G for each household. The net income of the household can thus be written down as: $Y = \overline{Y} - G$.[7]

Households living at distance r from CBD make transport costs $T(r)$ to work and transport costs $D(r,a)A$ to the local amenity. The frequency of trips to work is normalized to 1, the frequency of visits to the amenity equals A. Total transport costs to the amenity are a product of the cost of a single visit, $D(r,a)$ (where a is the exogenously determined location of the amenity) and the number of visits A. Besides transport costs the households have to pay for the residential space s they use. At any location households take the residential rent denoted by

[6] In a monocentric city this implies that at distance $r=a$ from the CBD there is a belt with amenities located on it. A similar way of modelling a monocentric city with an amenity is used by Homans and Marshall (2008).

[7] We assume that it is optimal to have the amenity in the city.

R(r,a) as exogenous, but can choose the rent they face by choosing the residential location *r*. The competition for houses will bid up rental prices at desirable locations. In equilibrium, spatial variations in rental rates will make households indifferent to residential locations.

We normalize the price of the composite good to 1. Then the choice problem of the household takes the following form:

$$\begin{aligned} &\underset{z,s,A}{Max}\, U[z,s,A] \\ &s.t. \\ &z + R(r,a)s + T(r) + D(r,a)A \le Y \\ &where \quad r > 0,\, r \neq a,\, z > 0,\, s > 0,\, A \ge 0. \end{aligned} \tag{2.1}$$

Model (2.1) is a variant of the standard residential location model (for example, Fujita, 1989, ch. 2). Standard assumptions in this model are:

Assumption (i): The utility function is continuous and increases for all z>0, s>0, A≥0, all indifference curves are convex and smooth. [8]

Assumption (ii): Transport costs *T(r)* are continuous in *r*, *T(r)* increases for all *r*>0, $0 < T(r) < Y$ en $T(\infty) = \infty$.

To these two assumptions, we add assumption (iii) about the transport costs to the amenity. Assumption (iii) states that transport costs to the amenity increase with the distance to it (|*r*-*a*|).

Assumption (iii): Transport costs *D(r,a)* are continuous in *r*; *∂D(r,a)/∂*r >0 for *r*>*a* en *∂D(r,a)/∂*r <0 for *r*<*a*; $0 < D(r,a) < Y$ en $D(\infty, a) = \infty$.

2.2 Equilibrium residential rent

In this section, we derive for model (2.1) a formula for the residential rent gradient in equilibrium. First, we consider the case when the model has an internal solution with *A*>0, then the case with a corner solution *A*=0. By definition, the residential locations where the model has an internal solution (and where residents do use the amenity in equilibrium) lie within the geographical range of the amenity benefits, while the residential locations where the model has a corner solution (and where residents do not use the amenity in equilibrium) lie outside the geographical range.

[8] With respect to *A,* we relax the standard assumption that indifference curves do not cut the axes.

Case 1. Model (2.1) has an internal solution with A>0.

Writing down the first-order conditions for model (2.1) we obtain:

$$\frac{\partial U}{\partial z}=\lambda;\ \frac{\partial U}{\partial s}=\lambda R(r,a);\ \frac{\partial U}{\partial A}=\lambda D(r,a);\ \frac{\partial U}{\partial \lambda}=Y-z-R(r,a)s-D(r,a)A-T(r),$$

where λ is the shadow price of the budget constraint.

In equilibrium housing prices are bid up in desired locations such that household utilities are identical across the landscape and households have no desire to move. This implies that the total differential of the utility function equals zero[9]:

$$\frac{dU}{dr}=\frac{\partial U}{\partial z}z_r^{'}+\frac{\partial U}{\partial s}s_r^{'}+\frac{\partial U}{\partial A}A_r^{'}=\lambda[z_r^{'}+R(r,a)s_r^{'}+D(r,a)A_r^{'}]=0. \quad (2.2)$$

Besides, in equilibrium the budget constraint is binding:

$$z_r^{'}+sR_r^{'}+Rs_r^{'}+DA_r^{'}+AD_r^{'}+T_r^{'}=0. \quad (2.3)$$

Substituting (2.2) into (2.3) and rearranging, we obtain the equation for the residential rent gradient that describes the marginal change in the residential rent as a result of a marginal change in location r.

$$\frac{\partial R}{\partial r}=\frac{-T'(r)-D'(r,a)A}{s(r)}. \quad (2.4)$$

Equation (2.4) can be identified as a generalized Muth condition. It shows that the rent gradient, or the spatial distribution of residential rents in equilibrium, consists of two components: (a) the savings on the transport costs to the CBD, $T'(r)/s(r)$; (b) the savings on the transport costs to the amenity, which are a product of a change in the costs of a single visit to the amenity, $D'(r,a)$, and the optimal number of visits, A. Like in the standard version of the Muth condition, accessibility differences determine the differences in rent between locations. However, in our case not only accessibility of the CBD (a) plays a role, but also accessibility of the local amenity (b).

Case 2. Model (2.1) has a corner solution A=0.

For the values of r where model (2.1) has a corner solution with $A=0$, the consumption bundle in equilibrium (s, z) is obtained as a solution of the standard residential choice problem:

[9] Henceforth, we use a prime to denote the first derivative with respect to *r*.

$$
\begin{aligned}
&\underset{z,s}{Max}\, U[z(r), s(r)] \\
&s.t. \\
&z(r) + R(r)s(r) + T(r) \leq Y \\
&where \quad r > 0,\ z > 0,\ s > 0.
\end{aligned}
$$

The residential rent gradient (the Muth condition) for this problem has the following form (see, for example, Fujita, 1989, ch. 2):

$$\frac{\partial R}{\partial r} = \frac{-T'(r)}{s(r)} \tag{2.5}$$

The rent gradient here does not depend on the distance to the amenity.

2.3 Geographical range of the amenity benefits

From the model of the previous paragraph the following results can be derived.

Lemma 1

For $r|\ A(r)>0$, holds: $\partial A(r)/\partial r < 0$ if $r>a$ and $\partial A(r)/\partial r > 0$ if $r<a$. In other words, for the residential locations where the model has an internal solution consumption of amenity falls with the distance to it.

Proof: As visits to the amenity are a normal good and the costs connected with a single visit rise with the distance, consumption of the amenity falls with the distance to it.

From Lemma 1 it follows that if our model has a corner solution, this solution will occur for the residential locations situated either nearby the CBD or nearby the city boundary. This is summarized in Proposition 1.

Proposition 1

If $A(\hat{r}) = 0$ and $\hat{r} > a$, then for each $\tilde{r} > \hat{r}\ \ A(\tilde{r}) = 0$. If $A(\hat{r}) = 0$ and $\hat{r} < a$, then for each $\tilde{r} < \hat{r}\ \ A(\tilde{r}) = 0$.

Proof: follows from Lemma 1.

Proposition 1 states that the geographical range of the amenity benefits is a continuous area around the amenity. Proposition 2 elaborates on the behavior of the residential rent within and outside the geographical range.

Proposition 2

For $r|\ A(r)>0$ the residential rent gradient negatively depends on the changes in the distance to the amenity. For $r|\ A(r)=0$ distance to the amenity has no influence on the rent gradient.

The *Proof* follows from the equations (2.4) en (2.5).

Propositions 1 and 2 suggest that the geographical range of amenity benefits can be determined as the minimal distance to the amenity, beyond which changes in this distance do not have any effects on the residential rent. As the benefits of the amenity are capitalized in the residential rents, fall with the distance to the amenity and completely level out outside the geographical range, residential rents can be used to empirically determine the geographical range. This empirical exercise is described in the following sections.

3 Empirical framework

This section sets up and applies an empirical framework whose aim is to help us identify the geographical range of benefits for a specific consumption amenity. The empirical question is how to estimate econometrically the distance beyond which there exists no significant relationship between the residential rent and the distance to the amenity. Below we suggest to perform this estimation using a hedonic model of residential property prices.

For the purpose of the empirical application, let s in residential choice model (2.1) be the amount of housing services consumed and R be the price of one housing service. Furthermore, let in line with the standard hedonic theory (Rosen, 1974), the amount of housing services consumed be a function of some structural and neighborhood characteristics of housing $X=X_1, \dots X_n$: $s=H(X)$. The value of housing P equals then: $P=H(X_1,X_2,\dots,X_n)R$. Taking logarithms yields: $\ln P = \ln H(X_1, X_2, ..., X_n) + \ln R$.

The above obtained expression for lnP and the outcomes of the theoretical model of the previous section suggest that the geographical range of the amenity benefits can be estimated from the following equation:

$$\begin{cases} \ln P = \ln H(X) + \ln R(d_{CBD}, D) + \varepsilon, \\ D = d_{amenity} \ if \ d_{amenity} < \tau, D = \tau \ if \ d_{amenity} \geq \tau. \end{cases} \tag{3.1}$$

where d_{CBD} is the distance to the CBD, $d_{amenity}$ is the distance to the amenity, τ is the geographic range of the benefits of the amenity, and ϵ is the standard error. In (3.1) the observed variables are: P, X, d_{CBD} and $d_{amenity}$, and the parameters to be estimated are: the parameters of the functions H and R and the geographical range τ.

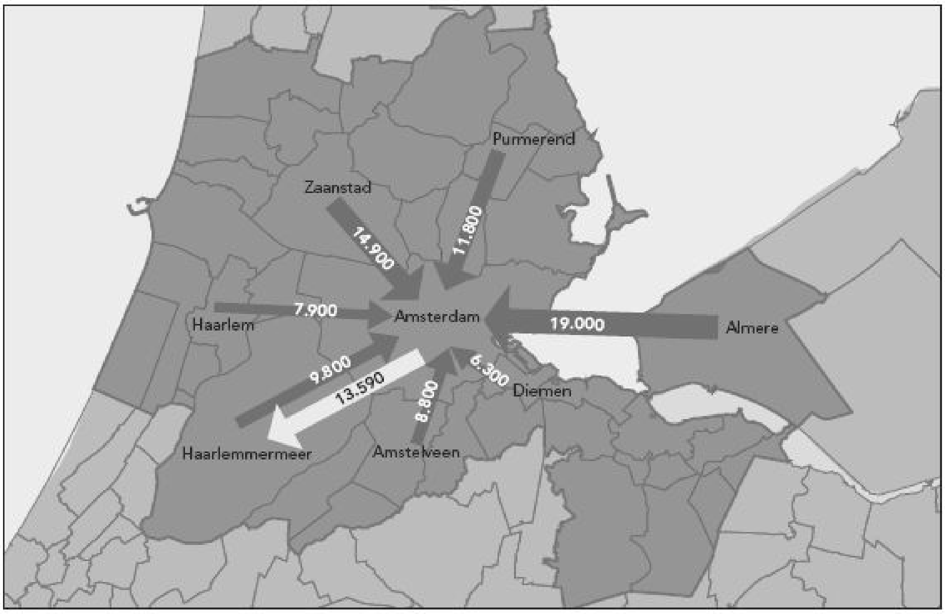
Knowing from Section 2 that R declines with $d_{amenity}$, we can interpret (3.1) as follows. Equation (3.1) states that the property price, controlled for other relevant variables, declines with the distance to the amenity as long as the distance to the amenity is smaller than the geographical range of the amenity benefits. When the distance to the amenity is larger than the geographical range, there is no dependence any more between the price and the distance. We are interested in econometrically assessing the geographical range τ.

Below, we estimate equation (3.1) for residential properties in the region of Amsterdam, the Netherlands, with d_{CBD} being the distance to the center of Amsterdam, $d_{amenity}$ being the distance to the nearest railway station and τ being the geographical range of the benefits of the railway stations. To control for differences between regional housing markets we use a fixed effects estimation.

3.1 Data description

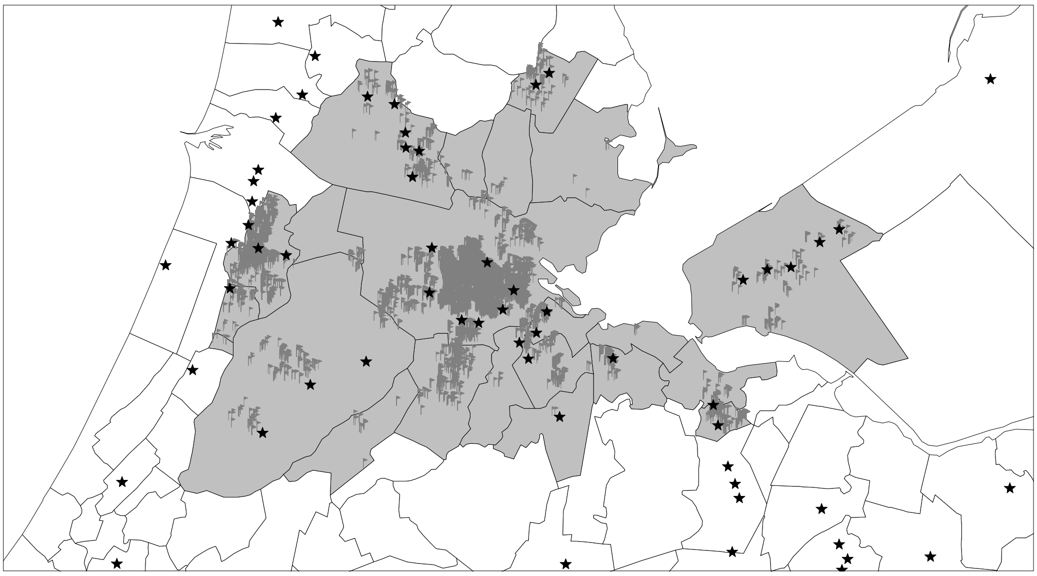
Our research uses data on dwellings sold between 2003 and 2005 in a wider metropolitan area of Amsterdam in the Netherlands. A Dutch study on residential housing preferences (Ossokina and Verkade, 2006) suggests that residents of apartments give a higher value to accessibility with public transport than residents of single-family dwellings. For this reason we focus our analysis on the market for apartments. In accordance with the assumptions of the theoretical model we define the research region as the area in which the bulk of people working in Amsterdam is likely to reside. Figure 3.1 below shows the main commuting flows between municipalities in the metropolitan area of Amsterdam. Using these data as a starting point we define our research region to contain: the municipality of Amsterdam itself, the seven municipalities originating the largest commuting flows to Amsterdam and the municipalities situated in between the seven largest suppliers of commuters and Amsterdam. This results in a geographical scope including 21 municipalities as shown in figure 3.2 below.

Figure 3.1 Largest commuting flows in the Metropolitan area of Amsterdam, 2005



bron: CBS/EBB/bewerking O+S

Figure 3.2 **The geographical extent of the sample (in grey) with locations of residential properties sold (in dark grey) and the locations of the railway stations (in stars). Solid lines denote borders of municipalities.**



Our dataset stems from three sources. First, the Dutch Association of Real Estate Brokers (NVM) provided micro data on properties sold within the geographical area of our interest.[10] This data includes the transaction price, the full postcode unit of the address, as well as extended information on housing attributes, such as age, construction descriptors (e.g. type of heating, presence of a built-in garage, ground rent[11], etc.) and various dimensional attributes (such as the size of the living area, the number of rooms, etc.). Information on the postcode unit allows us to assign geographical coordinates to the properties. After having deleted incomplete or incorrectly recorded listings, we have 24133 observations in the dataset. Second, we obtained from the Netherlands Environmental Assessment Agency (PBL) geo-coded data on the location of the railway stations. Using this data, we were able to calculate for each property sold the distance to the nearest railway station and the distance to the Central Business District (defined as the center of Amsterdam). Third, Statistics Netherlands (CBS) provided data on the detailed characteristics of the neighborhoods in which sold properties are located, including social-economic characteristics and characteristics of land use. The social-economic characteristics, such as the percentage of immigrants and population density, were made available for the lowest level statistical units (neighborhoods), of which there are more than 300 in our research area. The data on land use were made available on the level of aggregation that made it possible to calculate the percentage of land in the radius of 500 meter around each dwelling, which is

[10] Nationwide around 75% of all residential property sales is performed through a real estate broker who is member of NVM, in the region of Amsterdam this percentage is even higher.

[11] In some municipalities (for example the municipality of Amsterdam), land under the dwelling is municipal property; therefore, owners are obliged to pay annual ground rent to the municipality.

used for (i) transport infrastructure, (ii) industrial zones, (iii) open space, (iv) shops and restaurants. Table 3.1 below provides the descriptive statistics of the dataset. Figure 3.2 above gives an overview of the location of the properties sold and the railway stations in our data set.

Table 3.1 Descriptive statistics dataset residential sales

Number of observations: 24133

Variable	Minimum	Maximum	Mean	Stand. dev.
Sales price	€ 50.000	€ 998.000	€ 208.197	€ 101.659
Structural attributes				
Living area in m^2	26	245	83	28
Number of rooms	1	14	3.0	1.0
Dummy built-in garage	0	1	0.06	0.24
Dummy hot water heating	0	1	0.87	0.33
Dummy ground rent	0	1	0.27	0.44
Dummy pleasant view (water, open space)	0	1	0.42	0.49
Dummy year of construction <1905	0	1	0.13	0.33
Dummy year of construction 1906-1944	0	1	0.29	0.45
Dummy year of construction 1945-1970	0	1	0.22	0.42
Dummy year of construction 1971-1989	0	1	0.19	0.39
Dummy year of construction after 1990 (reference)	0	1	0.17	0.37
Social-economic characteristics of the neighborhood				
Percentage not-western immigrants	1%	80%	22%	16%
Population density (thousands per square kilometer)	0.02	27.36	10.78	6.90
Per capita income in € thousand	7.5	33.5	14.156	2.784
Land use in the radius of 500 meter around the property				
% Land under transport infrastructure	0%	29%	7%	4%
% Land under industrial zones	0%	77%	5%	8%
% Land under shops and restaurants	0%	25%	2%	4%
% Land under open space	0%	47%	7%	7%
Distance variables				
Distance to the center of Amsterdam in meters	84	28791	7517	6609
Distance to the nearest railway station in meters	25	9116	1704	1141
Nuisance dummy (distance to the railway station <400m)	0	1	0.04	0.19
Dummy for property located in the downtown of Amsterdam	0	1	0.03	0.16
Year dummies				
Sold in 2003 (reference)	0	1	0.29	0.46
Sold in 2004	0	1	0.33	0.47
Sold in 2005	0	1	0.37	0.48

3.2 Estimation

Economic theory provides little guidance on the form the hedonic price function *H(X)* in (3.1) should take. Following common practice, we use the following specification of *H*: $H = \prod_{i=1..n1} X_i^{\alpha_i} \prod_{j=1..n2} \exp(X_j^{\beta_j})$ with X_i being the dimensional attributes and X_j other attributes. This implies that the dependence between the sales price and the characteristics of the home and its neighborhood will be of a combined double-log and semi log form.

Different specifications have been used in the literature to model the price effect of the distance to the Central Business District, including: a double-log (e.g. Yinger, 1979), a semilog (e.g. Anderson and West, 2006) and a Box-Cox transformation (e.g. Cheshire and Sheppard, 2002). In this study we use the double-log specification as it provides the best fit for our dataset.

Finally, we need to specify in the hedonic equation (3.1) the functional dependence between the residential price and the distance to the amenity. The specification that imposes least restrictions on the data is a non-parametric one, in which dummy variables are included for different distance intervals (e.g., (0, 500], (500, 1000], etc.) and the last distance interval is taken as a reference. Debrezion et al. (2006) uses such a specification in a study of the proximity effect of Dutch railway stations. In theory, this specification should allow to determine the geographical range of the station as the distance beyond which the coefficients by the distance dummies are no more significant. For our sample, however, the distance dummies tend to be correlated with the regional fixed effects which we include in the equation to account for the spatial differences between housing markets in different parts of the research area. As a consequence, identification of the amenity distance dummy effects apart from the regional dummies may in this setting be difficult and we need another approach to model the dependence between residential price and proximity to the station.

Modeling a parametric dependence between the housing price and the distance to railway stations allows to tackle the above specified problem of multicollinearity. Usual parametric specifications applied in the hedonic price equations (double-log, semi log, Box-Cox, logistic) do however not take account of the possibility of a limited geographical range of the proximity effect. In other words, in these specifications, the proximity effect never vanishes completely. To allow for the possibility of a limited geographical range, we construct the functional dependence between the residential price and the distance to the railway station to be a combination of a decreasing continuous function within the geographical range and a constant beyond the geographical range. To minimize the restrictions imposed on the data, we specify a Box-Cox type of proximity effect within the geographical range.[12] The value of the geographical range is determined endogenously from the data. Furthermore, it is determined

[12] The Box-Cox specification includes the standard semilog (γ=1) and double-log ($\gamma \rightarrow 0$) specifications as special cases.

simultaneously with the magnitude of the proximity effect, what allows us to make inference for the magnitude and the geographical range simultaneously.[13]

This results in the following hedonic price equation:

$$\begin{cases} \ln P = \beta_1^{'} \ln X_1 + \beta_2^{'} X_2 + \delta \ln d_{CBD} + \alpha \dfrac{D^{\gamma} - 1}{\gamma} + \varepsilon, \\ D = d_{station} \ if \ d_{station} < \tau; D = \tau \ if \ d_{station} \geq \tau. \end{cases} \tag{3.2}$$

where X_1 is a vector of dimensional attributes (including among other things: the size of the living area and the number of rooms), and X_2 is a vector of all other attributes, d_{CBD} and $d_{station}$ are distances to the central business district (centre of Amsterdam in our case) respectively to the nearest railway station, and β_1, β_2, δ, α, γ, τ are the parameters to be estimated. The parameters β_1 and δ in (3.2) can be interpreted as elasticities of the sales price with respect to dimensional attributes of a home and with respect to the distance to the central business district, the parameters β_2 can be interpreted as marginal price effects of a unit change in the attributes of the home and surroundings. Parameters α, γ and τ describe the station proximity effect. The 'transformation parameter' γ of the Box-Cox specification determines whether the function is concave or convex, and specifies the degree of concavity, the 'elasticity parameter' α determines the size of the proximity effect,[14] and the parameter τ specifies the geographical range of the effect.

We expect the 'elasticity parameter' α in the station proximity effect in (3.2) to be negative. This negative dependence between the property price and the distance to the station may within the first hundreds meter to the station however be counteracted by a nuisance effect (noise, crime, etc). To take account of this we adapt (3.2) in the following way. We assume that the Box-Cox functional dependence between the ln price and the distance holds outside the immediate proximity of the station and include a dummy for the dwellings located within the immediate proximity. Debrezion et al. (2006) finds a negative nuisance effect within the first 500 meter from the railway, so we experiment with different values ranging from 100 to 500 meter and choose the value of 400 meter as providing the best fit.

A similar argument as for the distance to the railway station holds for the distance to the center of Amsterdam. We correct for the strong negative distance effect that is postulated by (3.2) for dwellings in the direct vicinity of the CBD by including a dummy for residential properties in the downtown and modeling a double log dependence between sales price and

[13] In this, we improve on the methodology of Gibbons and Machin (2005) who determine the geographical range of the railway access effect separately from the magnitude of the effect. Furthermore, Gibbons and Machin use a log-linear specification for the effect, while we allow for a flexible specification. As will be clear from the results a log-linear specification is not supported by our data.

[14] The parameter α can be formally interpreted as elasticity if the double-log specification applies ($\gamma \rightarrow 0$).

distance outside the downtown. Furthermore, to control for not observed differences in regional housing markets we estimate system (3.2) with fixed effects including 29 regional dummies.

This results in the following hedonic price equation to be estimated:

$$\begin{cases} \ln P = \beta_1' \ln X_1 + \beta_2' X_2 + \delta I_{-CBD} \ln d_{CBD} + \alpha \dfrac{D^{\gamma}-1}{\gamma} + \rho' R + \psi I_{d_0} + \varepsilon, \\ D = d_0 \ if \ d_{station} < d_0; D = d_{station} \ if \ d_0 \leq d_{station} < \tau; D = \tau \ if \ d_{station} \geq \tau. \end{cases} \quad (3.3)$$

where d_0 is the radius of the immediate proximity of the station (400 meter in our case); I_{d0}=1 if the property sold lies in within this radius and I_{d0}=0 otherwise; I_{-CBD}=0 if the property sold is located in downtown of Amsterdam and I_{-CBD}=1 otherwise; R is the vector of the regional fixed effects (the downtown of Amsterdam is here the reference; see Appendix for further information on these dummies), ρ is the vector of coefficients to be estimated. As the equation to be estimated is not linear, we use the maximum likelihood approach to estimate it.

Finally, as our data has been geocoded on the level of a postcode unit, the distance to the station and other location characteristics of the dwelling will be fixed for all observations located within the same postcode unit. This results in a spatial correlation between residuals within a single postcode unit. We can write the residual ε_i as a sum of $v_{g(i)}$, a random component specific to the postal unit area g where the dwelling i is located, and η_i, a mean-zero individual component: $\varepsilon_i = v_{g(i)} + \eta_i$. An estimation that does not correct for this grouped structure of residuals will result in too small standard errors. Following Angrist and Pischke (2009) we use two approaches to tackle this problem: correction of the standard errors and aggregation of the data to the level of the postcode unit.

4 Estimation results

This section reviews our findings. First, we present the results of a 'naive' estimation that does not account for the group structure of residuals. Second, we present corrected estimates and show that the main insights stay unchanged. Finally, we perform a robustness check on the estimated proximity effect by using station distance dummies instead of the Box-Cox functional specification of this effect.

4.1 'Naive' estimation

Table 4.1 below reports the coefficients and corresponding standard errors from equation (3.3) estimated on individual data with standard assumptions concerning the residuals. The estimated coefficients for housing and neighborhood attributes are significant at a 1% significance level, with the exception of the dummy for ground rent, which is not significant. The coefficients have the expected signs and magnitude. Sales price rises by about 0.73% for every one percent increase in the size of the living area, 0.03% for every one percent increase in the number of rooms, 10% with the addition of a built-in garage and 8% with the addition of hot-water heating. Pleasant view on water, park or open space adds another 3% to the sales price. Finally, sales price falls by about 0.08% for every one percent increase in the distance to the center of Amsterdam.

Of central interest for our study are the magnitude and the geographical range of the railway station proximity effect. The estimated geographical range $\hat{\tau}$ equals 1.13 km and is statistically significant at 1% level. This implies that for dwellings located beyond this distance from a railway station no significant relationship between residential price and distance to the station could be found. The estimated relationship between residential price and proximity to the station, which holds for dwellings within the geographical range, is described by the estimated 'elasticity parameter' $\hat{\alpha}$=-0.092 and the estimated 'transformation parameter' $\hat{\gamma}$=19.76 and is illustrated in figure 4.1 below. The figure shows the price index of an apartment located within the geographical range in terms of the price of precisely the same apartment located beyond the geographical range of the station. This price index is calculated according to the following formula that follows from (3.3):

$$PI(d_{station}) = \frac{P(\Theta, d_{station})}{P(\Theta, \hat{\tau})} = \exp[\frac{d_{station}^{\hat{\gamma}} - \hat{\tau}^{\hat{\gamma}}}{\hat{\gamma} / \hat{\alpha}}] \qquad (4.1)$$

In (4.1) Θ stands for all the determinants of the price from (3.3) excluding the distance to the station; $\hat{\alpha}$, $\hat{\gamma}$ and $\hat{\tau}$ are the estimates of the parameters α, γ and τ in (3.3).

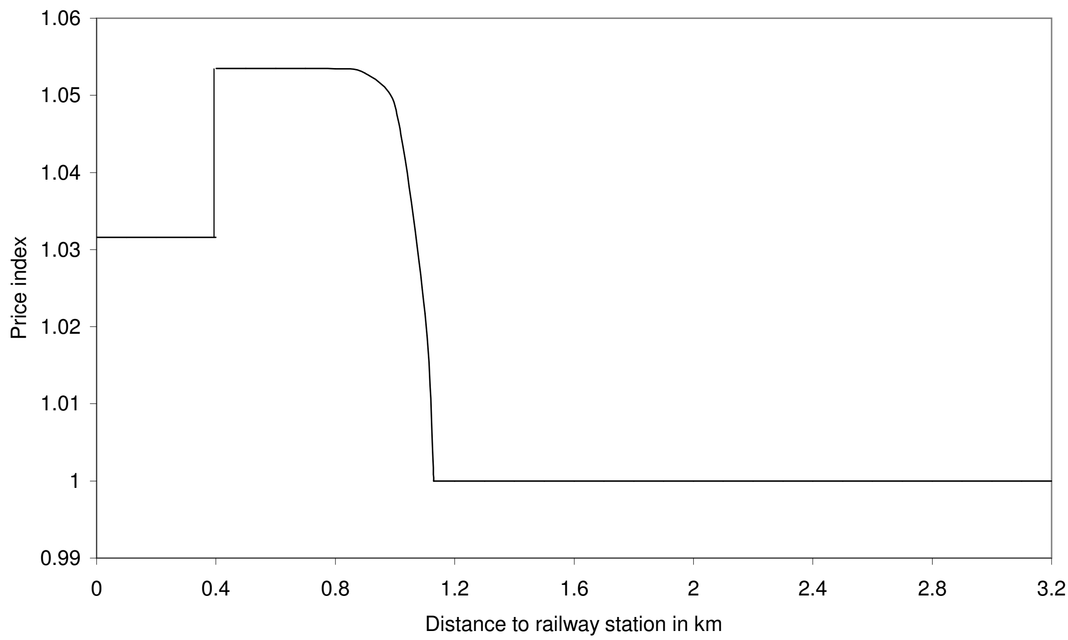
Table 4.1	Hedonic price regression (3.3), the estimation uses standard assumptions on the residuals	
Variable	Coefficient	Standard error
Structural attributes		
Living area in m² (ln)	0.733***	0.0047
Number of rooms (ln)	0.028***	0.0042
Dummy built-in garage	0.098***	0.0044
Dummy hot water heating	0.078***	0.0031
Dummy ground rent	– 0.003	0.0028
Dummy pleasant view (water, open space)	0.025***	0.0021
Dummy year of construction <1905	– 0.063***	0.0043
Dummy year of construction 1906-1944	– 0.094***	0.004
Dummy year of construction 1945-1970	– 0.251***	0.0038
Dummy year of construction 1971-1989	– 0.166***	0.0037
Social-economic characteristics of the neighborhood		
Percentage immigrants	– 0.002***	0.0002
Population density (thousands per km²)	0.001***	0.0003
Per capita income in € thousand	0.021***	0.0007
Land use in the radius of 500 meter around the property		
% Land under transport infrastructure	– 0.004***	0.0003
% Land under industrial zones	– 0.001***	0.0002
% Land under shops and restaurants	0.001***	0.0004
% Land under open space	0.001***	0.0002
Distance variables		
Ln distance to the center of Amsterdam	– 0.084***	0.0058
Nuisance dummy (distance to railway station <400m)	– 0.021***	0.0055
Station proximity effect		
Elasticity parameter	– 0.092***	0.032
Transformation parameter	19.759***	5.5116
Geographical range	1.131***	0.0107
Year dummies (2003 is reference)		
Sold in 2004	0.039***	0.0025
Sold in 2005	0.081***	0.0025
Constant	9.000***	0.0245
Explanatory value	85.6%	
Number of observations	24133	

Our findings suggest that an average dwelling located within the estimated geographical range of 1.13 kilometer and outside the immediate proximity of the station sells for approximately 5% more than an equal dwelling located beyond the geographical range. In monetary terms this price premium amounts to the average of €208000*5%=€10400 for our dataset.[15] This effect is significant at 1% level. The magnitude of the price premium stays relatively constant within most of the geographical range and falls sharply near its border. Within the immediate proximity of the station (defined as the radius of 400 meter) the price premium is lower and

[15] €208000 is the average sales price in our data set.

equals approximately 3%. This is likely to be the consequence of the nuisance that immediate proximity of the station causes.[16]

Figure 4.1 **The estimated impact of the distance to the railway station on the property price. The average price of properties lying beyond the geographical range is taken as a reference (with a price index equal to 1)**



4.2 Correcting for the group structure of the residuals

We use two approaches to correct for the group structure of the residuals within one postcode unit. First, we perform an estimation with corrected (clustered) standard errors using the Stata-option 'cluster'. Second, we perform a weighted estimation on a dataset aggregated to the postcode unit level, using as weights the inverse of the number of observations in each postcode unit. Table 4.2 below presents the results of the two estimations.

The general picture that arises from the results in table 4.2 is the same as in the 'naive' estimation of the previous section. Proximity to station has a significant positive effect on residential sale prices, this effect can be observed within the geographical range of 1.13 kilometer. As could be expected, the parameters of the non-linear Box-Cox function that describes the behavior of the proximity effect within the geographical range, are estimated with less precision when the group structure of residuals is accounted for. The high significance level of the estimated geographical range does however not change in comparison with the 'naive' model.

[16] Our regression controls for the nuisance effect due to proximity to the rail, so the negative price premium in question is likely to reflect the pure nuisance effect of the station.

Table 4.2 Hedonic price regression (3.3), the estimation accounts for the group structure of residuals

	Estimation with clustered standard errors		Estimation using aggregated data	
Variable	Coefficient	St. error	Coefficient	St. error
Structural attributes				
Living area in m^2 (ln)	0.733***	0.0077	0.759***	0.0094
Number of rooms (ln)	0.028***	0.0064	0.028***	0.009
Dummy built-in garage	0.098***	0.0082	0.123***	0.0089
Dummy hot water heating	0.078***	0.0041	0.086***	0.0066
Dummy ground rent	– 0.003	0.0034	– 0.008	0.0054
Dummy pleasant view (water, open space)	0.025***	0.0029	0.036***	0.004
Dummy year of construction <1905	– 0.063***	0.0076	– 0.044***	0.0075
Dummy year of construction 1906-1944	– 0.094***	0.0068	– 0.084***	0.0066
Dummy year of construction 1945-1970	– 0.251***	0.0075	– 0.247***	0.0061
Dummy year of construction 1971-1989	– 0.166***	0.0072	– 0.159***	0.0059
Social-economic characteristics of the neighborhood				
Percentage immigrants	– 0.002***	0.0003	– 0.002***	0.0002
Population density (thousands per km^2)	0.001**	0.0005	0.001***	0.0005
Income per person in € thousand	0.021***	0.0017	0.022***	0.0011
Land use in the radius 500 meter around the property				
% Land under transport infrastructure	– 0.004***	0.0005	– 0.003***	0.0004
% Land under industrial zones	– 0.001***	0.0003	– 0.001***	0.0002
% Land under shops and restaurants	0.001*	0.0007	0.001**	0.0005
% Land under open space	0.001***	0.0004	0.001***	0.0003
Distance variables				
Ln distance to the center of Amsterdam	– 0.084***	0.009	– 0.076***	0.0086
Nuisance dummy (distance to station <400m)	– 0.021**	0.0106	– 0.020**	0.0082
Station proximity effect				
Elasticity parameter	– 0.092*	0.0485	– 0.096**	0.0451
Transformation parameter	19.759**	7.9055	19.468***	6.2508
Geographical range	1.131***	0.0195	1.130***	0.0004
Constant	9.000***	0.0485	8.927***	0.0421
Explanatory value	85.6%		88.6%	
Number of observations	24133		7127	

Comparison of the two models reported in table 4.2 suggests that the estimated size (around 5% of the sales price) and the geographical range of the station proximity effect are robust to the level of aggregation of our data. This does not hold however for the price effects of several other characteristics of the dwellings. Coefficients by structural housing characteristics differ significantly between the two models. This is not surprising as working with aggregated data loses part of the information on these characteristics. The point estimates of the effect of proximity to Central Amsterdam differ as well between the two models, but this difference is not significant.

4.3 Robustness check

Results of the previous section suggest that the station proximity effect falls sharply nearby the geographical range of 1.13 kilometer. To check the robustness of this conclusion we perform the estimation of the station proximity effect using a hedonic price regression with a number of station distance dummies. The following hedonic price regression is estimated:

$$\ln P = \beta_1^{'} \ln X_1 + \beta_2^{'} X_2 + \delta I_{-CBD} \ln d_{CBD} + \xi' I_{st\_dist} + \rho' R + \varepsilon \quad (4.2)$$

I_{st_dist} is a vector of dummy variables representing the distance category at which a dwelling is located from a station. To start with, we define 16 distance categories: [0m, 200m), [200m,400m), …, [3000m, 3200m).

Table 4.3 Hedonic price regression (4.2) with station distance dummies for the distances [0-3200m)

	"Naïve" estimation with standard assumptions about the residuals		Estimation with clustered standard errors	
Variable	Coefficient	Standard error	Coefficient	Standard error
Station proximity effect:				
Station distance [0m, 200m)	0.013	0.0121	0.013	0.0304
Station distance [200m, 400m)	0.042***	0.0082	0.042***	0.0166
Station distance [400m, 600m)	0.063***	0.0069	0.063***	0.0149
Station distance [600m, 800m)	0.045***	0.0065	0.045***	0.0143
Station distance [800m, 1000m)	0.063***	0.0063	0.063***	0.0136
Station distance [1000m, 1200m)	0.016***	0.0062	0.016	0.0133
Station distance [1200m, 1400m)	0.001	0.0062	0.001	0.0138
Station distance [1400m, 1600m)	0.009	0.0060	0.009	0.0128
Station distance [1600m, 1800m)	0.012*	0.0062	0.012	0.0127
Station distance [1800m, 2000m)	0.009	0.0076	0.009	0.0157
Station distance [2000m, 2200m)	– 0.010	0.0078	– 0.010	0.0140
Station distance [2200m, 2400m)	– 0.011	0.0076	– 0.011	0.0139
Station distance [2400m, 2600m)	0.006	0.0074	0.006	0.0121
Station distance [2600m, 2800m)	0.018*	0.0106	0.018	0.0150
Station distance [2800m, 3000m)	– 0.005	0.0083	– 0.005	0.0156
Station distance [3000m, 3200m)	– 0.023***	0.0082	– 0.023	0.0144

Table 4.3 reports the estimated coefficients for these 16 station distance dummies for two cases: naïve estimation without correction for the standard errors and estimation with clustered standard errors. We do not report other estimated coefficients from the regression (4.2) as their values experience practically no change in comparison with the results reported in tables 4.1 and 4.2.

Both, the naïve estimation and the estimation with corrected standard errors suggest existence of a significant station proximity effect within the geographical range of between 1 and 1.2 kilometer. This is in line with the geographical range of 1.13 kilometer that was estimated in previous section. While the results of the 'naïve' estimation show some significant effects at further distances ([1600m, 1800m), [2600m, 2800m), [3000m, 3200m), these are too scattered to suggest existence of a pattern of any kind; besides the first two of these effects have rather low 10% significance levels. These effects are thus likely to be caused by data irregularities. Indeed, when estimation with corrected standard errors is performed, all the distance dummies beyond 1 kilometer become insignificant. Table 4.4 reports results of the estimation in which only station distance dummies within the range [0, 1000m) are included. As could be expected, the estimated magnitude of the station proximity effect is in line with the results of the previous section. Beyond the distance of 400 meter a station proximity effect of on average 5% is observed. Point estimates within 400 meter from the station suggest existence of a nuisance effect.

Table 4.4 Hedonic price regression (4.2) with station distance dummies for the distances [0-1000m)

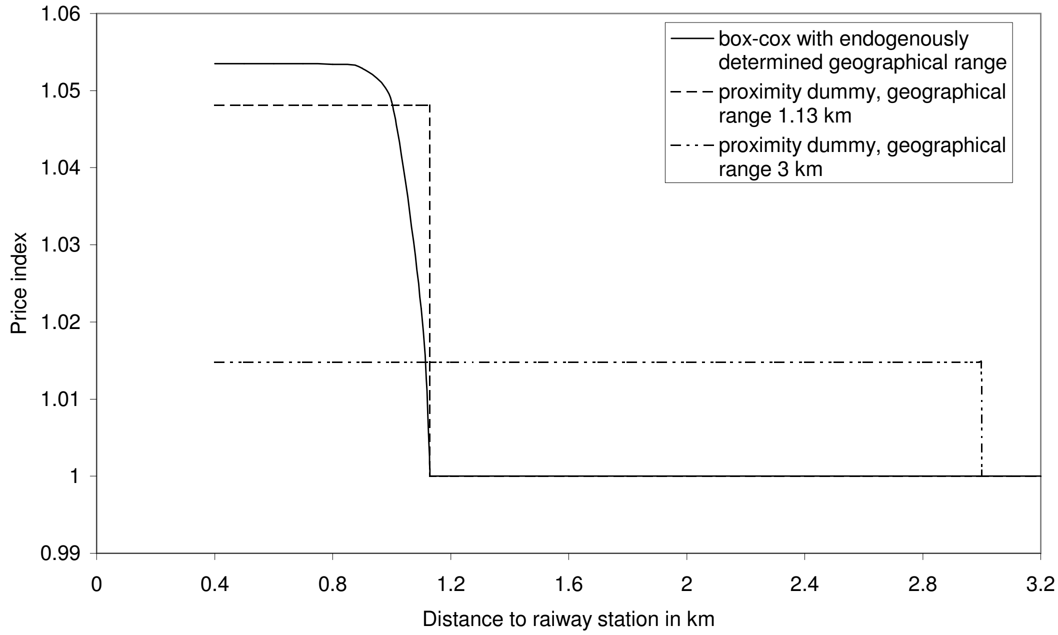
	"Naïve" estimation with standard assumptions about the residuals		Estimation with clustered standard errors	
Variable	Coefficient	Standard error	Coefficient	Standard error
Station proximity effect:				
Station distance [0m, 200m)	0.004	0.0110	0.004	0.0275
Station distance [200m, 400m)	0.032***	0.0065	0.032***	0.0121
Station distance [400m, 600m)	0.053***	0.0047	0.053***	0.0095
Station distance [600m, 800m)	0.036***	0.0039	0.036***	0.0083
Station distance [800m, 1000m)	0.055***	0.0037	0.055***	0.0066

5 Discussion

In the hedonic price literature, not much attention has been given so far to the determination of the geographical range of amenity benefits. In most studies, the geographical range is chosen exogenously. In figure 5.1 below, we illustrate the implications of an exogenously determined geographical range for our estimation. We estimate the station proximity effect for two alternative specifications of the functional dependence between ln residential price and distance to the station: (i) a station proximity dummy with the correctly specified geographical range of 1.13 kilometer, (ii) a station proximity dummy with an incorrectly specified geographical range of 3 kilometer. The results as illustrated in figure 5.1 suggest that when the geographical range is correctly set to 1.3 kilometer, the coefficient by the station proximity dummy (4.7%) does not differ much from the Box-Cox estimate (average effect of 5%). However, when the geographical range is incorrectly set to 3 kilometer, the estimated size of the proximity effect drops considerably to 1.3%. The intuition is clear: the coefficient 1.3% comes out as a result of weighting together the proximity effect of 5% within the geographical range of 1.3 km, and the insignificant proximity effect beyond the geographical range. As a result, we get an underestimation of the proximity effect within the geographical range and an overestimation of the effect beyond the geographical range.

Estimates of the amenity proximity effects from hedonic price analyses are often used as a proxy for the benefits people experience from amenities. Reason is that many amenities have a public good character and these benefits cannot be observed through prices. Consequently, the price premium the real estate market pays for proximity may serve as an indicator of the size of the benefits. The above results illustrate that an inappropriately chosen value of the geographical range of the amenity benefits may lead to a severe under- of overestimation of the magnitude of these benefits within the geographical range and an overestimation of the effect outside the range. This may result in an incorrect valuation of the total benefits from the amenity, especially when the dwellings are not uniformly distributed over distances to the amenity, and to an incorrect estimate of the benefits of a reduction of the distance to the amenity. Our results suggest thus that planners and developers need to account for the localized character of the amenity benefits when deciding on policies concerning provision of local public goods.

Figure 5.1 **Estimated railway station proximity effect under different specifications of the dependence between the residential price and the proximity to the station**



The estimated geographical range of 1.13 kilometer suggests that in our research area the majority of the benefits from station proximity that are reflected in housing prices, is realized within a walking distance from the station. This geographical range falls short of the average range of railway station benefits (2.5 kilometer) that the Dutch Railways apply in their calculations[17]. Several explanations are possible for this. First, the effects we have measured in this paper are the proximity benefits of a railway station in the wider metropolitan area of Amsterdam. In this area there are relatively many railway stations and people who use the railway frequently may be expected to live on a shorter distance to the station than on average in the country. This is likely to lead to smaller station proximity effects than on average in the country. Second, in the Amsterdam region the public transport net is rather well developed and those living beyond a walking distance to the station may use this net to get to the station. This suggests that the transport cost curve beyond the walking distance to the station may in our research area be rather flat which is likely to result in no significant effect of distance on housing prices.

Furthermore, it is useful to compare the results of our study with the insights of Debrezion et al. (2006) who has studied the effects of railway station proximity on housing prices for the Netherlands as a whole. The authors used 31 station distance dummies and took dwellings located at a distance of more than 15 kilometer from the nearest station as a reference group. They found significant coefficients for all the station distance dummies, falling gradually from 0.32 (32% price premium with respect to the reference group) for the dwellings within 250

[17] The so-called Kringenmethodiek of the Dutch Railways.

meter from the station, to around 0.07 (7% price premium compared to the reference group) for the dwellings at the distance 10.5 to 11 kilometer from the station, and fluctuating around 0.03 (3% price premium) for the dwellings at the distances 11-15 kilometer. Although Debrezion and his coauthors do not make any conclusions about the geographical range of the station proximity effect, their results support the intuition that the average range of station benefits will be larger when calculated for the whole of the Netherlands than when calculated for the wider metropolitan area of Amsterdam.

6 Conclusions and policy implications

In this paper, we have analyzed the geographical range and magnitude of the benefits from proximity to local public goods that provide consumption amenities. In contrast to what is usual in the literature, we allowed for the possibility of a limited geographical range of these amenity benefits. In a simple theoretical residential location model, we showed that the amenity benefits are capitalized in the residential rents and that the geographical range of these benefits can be determined as the minimal distance to the amenity beyond which residential rents are independent of the changes in this distance. We applied this insight in a hedonic analysis of residential property transaction data in the region of Amsterdam, the Netherlands, in order to estimate the effect of proximity to the railway stations on sales prices of apartments. We estimated the average geographical range of railway station benefits to equal 1.1 kilometer. Within this geographical range and outside the immediate proximity of the station, apartments are sold at a price premium of approximately 5%. Within the immediate proximity where people are likely to experience nuisance from the station, this price premium is lower and equals approximately 3%. Finally, we illustrated that failing to account for the geographical range of railway station benefits may lead to misestimating severely the magnitude of the proximity benefits.

This study can be extended in several possible directions. First, a relevant extension of the theoretical model would be to analyze the effect of differences between individuals (in income or utility from consumption of the amenity) on the geographical range and magnitude of the amenity benefits. In our model it can be expected that households with a higher preference for the amenity will self-select to locations with shorter distances to the amenity thus influencing the slope of the rent gradient curve and possibly the geographical range of the benefits. Second, a useful empirical extension would be to analyze the effect of the accessibility level the station provides (measured e.g. by the frequency of trains) and the home location and surroundings on the magnitude and range of the proximity benefits. One could argue for example that larger stations can be expected to have a larger magnitude and range of the proximity effect. Also, in some neighborhoods (for example those with a smaller density of public transport and less alternative transportation possibilities) the geographical range of railway station benefits may be larger than in other neighborhoods. Finally, for practical applications in urban planning it may be relevant to extend the estimation of the geographical range and the magnitude of amenity benefits to various other types of amenities such as, for example, schools, parks, etc.

Policy implications

The insights from this paper may be applied in designing urban development policies. In the Netherlands, where (local) governments decide on locations for land development for housing construction, residential construction in railway station areas has been given much attention recently. Results of this paper provide some support for this policy: we argue that by internalizing station proximity benefits residential development of railway station areas can yield additional revenues in comparison with residential development elsewhere. To illustrate the possible size of these extra revenues consider a project involving construction of 1000 apartments nearby a railway station in the region of Amsterdam. If these apartments are built outside the immediate proximity of the station (or if the nuisance in the immediate proximity can be thought of as negligible, for example because the station and the railway are under the ground), then one can expect this project to bring in on average some €226000*5%*1000 ≈ €11 mln extra[18] in comparison with the situation when these apartments are realized at a similar location but beyond the 1.1 kilometer distance to the railway station. If the apartments are constructed in the immediate proximity of the station and the nuisance effects can not be thought of as negligible, the expected additional revenues will be lower: €226000*3%*1000 ≈ €7 mln.

Railway station area development is however often accompanied by considerable costs, with the costs of tunneling the rail to create new construction ground being an extreme example. A careful comparison of costs and benefits of residential construction in railway station areas is necessary in every specific case to make a well-considered decision about area development.

Another implication of this research concerns the financing of railway stations and other similar amenities. Railways are supra local amenities and these are usually financed by the central government. Railway stations have however apart from supra local benefits also purely local benefits, which can be internalized by local governments with the help of land development. Our research suggests a way to determine the size of the local benefits of railway stations in order to formulate a reasonable division of investment expenses between the local and the central government levels.

[18] € 226000 is the average price of an appartement in the Amsterdam area in the fourth quarter of 2009, according to the figures of the Dutch Association of Real Estate Brokers (NVM), 5% is the estimated station proximity effect.

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Appendix Regional effects

For the purpose of econometric estimation of the hedonic equation (3.3), we have divided the research area in 29 homogeneous regions, each of which contains between 1 en 7% of the observations in our dataset. Within the municipality of Amsterdam, the regions are defined as (parts of) Amsterdam boroughs, outside the municipality of Amsterdam the regions consist of one or more municipalities. Table A1 below reports the percentage of home sales in our dataset that belongs to each of the regions, the average distance from the centre of each region to the center of Amsterdam and the estimated price effect in differences to the centre of Amsterdam. The estimated price effect is calculated as a sum of: (i) the estimated regional dummy and (ii) the estimated effect of the distance to Amsterdam (which is a product of the elasticity parameter of - 0.084 and the ln distance to Amsterdam).

Figure A1 illustrates the regional price effects on a map of the wider metropolitan region of Amsterdam. As could be expected, the *ceteris paribus* highest prices are observed in the centre of Amsterdam and borough Oud Zuid. The lowest prices are observed in the municipalities to the north of Amsterdam, Almere and, surprisingly, the rich region Het Gooi. The last result can be explained by the fact that the estimation in question is based on sales of apartments. Apartments in Het Gooi are evidently not seen as very attractive by housing consumers, this in contrast to the single family dwellings.

Table A1 Regional fixed effects residential sales, estimation using standard assumptions about residuals

Regions	Observations in the district in %	Coefficient	Mean distance to center Amsterdam (km)	Price effect relative to reference region in %
Boroughs of Amsterdam				
Central Amsterdam inside the downtown (reference region)	2.6	0	0.63	0
Central Amsterdam outside the downtown	7.1	0.59	1.28	– 1.2
Bos en Lommer	2.9	0.48	2.91	– 17
De Baarsjes	3.7	0.5	2.68	– 15.3
Geuzenveld en Slotermeer	1.7	0.48	4.8	– 20.7
Noord	2.7	0.43	4.33	– 23.9
Oost en Watergraafsmeer	4.9	0.56	3.04	– 10.9
Osdorp	2.8	0.43	6.96	– 26.9
Oud-West	4.7	0.58	2.09	– 6.1
Oud-Zuid northern part	5.2	0.65	2.14	0.5
Oud-Zuid southern part	5.9	0.63	3.58	– 5.2
Slotervaart e.o.	1.9	0.39	5.04	– 27.7
Westerpark	3.7	0.55	1.81	– 7.7
Zeeburg	4.6	0.51	3.18	– 15
Zuideramstel	6	0.52	3.88	– 15.7
Zuidoost	3	0.36	8.2	– 32.6
Regions outside Amsterdam				
Almere	2.3	0.31	23.09	– 41.1
Amstelveen	5.5	0.49	8.44	– 23.5
Diemen	1.3	0.39	5.84	– 28.5
Haarlem east	6.8	0.46	17.05	– 29.6
Haarlem west	5	0.45	17.8	– 31
Heemstede and Bennebroek	1.1	0.55	19.08	– 24
Municipalities north of Amsterdam (Purmerend, Landsmeer, Oostzaan, Waterland)	2.3	0.44	15.52	– 31.1
Zaanstad	4	0.4	11.45	– 31.8
Naarden, Bussum	2.6	0.43	21.92	– 33.6
Weesp, Muiden	1.5	0.46	11.73	– 27.6
Abcoude, Aalsmeer and Oudeamstel	0.6	0.48	9.59	– 24.7
Hoofddorp	1.7	0.49	16.65	– 28
Badhoevedorp	1	0.43	8.44	– 28.1
Haarlemmermeer and Haarlemmerliede	0.8	0.53	16.66	– 25

Figure A.1 Price effects regional dummies