WORKING PAPER

The relationship between housing prices and transport improvements: a comparison of metropolitan and rural areas in a large but thinly populated European country

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Abstract: In this paper, I examine the relationship between housing prices and transport improvements. Due to the general consumer preference for access over amenity value, there is a relationship between distance and house prices. Thus, it is reasonable to believe that transportation improvements tend to influence house prices. It has been documented that the relationship between distance and house prices is negative for a densely populated area with one central business district (CBD). I will examine whether this relationship holds for a thinly populated area with one CBD, and will test whether this relationship is marginally different between locations. A macro panel data set from Iceland will be used. It provides several essential variables for 19 counties in Iceland from 1981 through 2005.

Keywords: house prices, transportation improvements, distance gradient, local

Ágrip: Samband fasteignaverðs og samgöngubóta er rannsakað í þessari tímaritsgrein. Vild neytenda er undirliggjandi þáttur fyrir því að fjarlægð hefur áhrif á fasteignaverð. Þess vegna er ástæða til þess að gera ráð fyrir að samgöngubætur hafi bein áhrif á fasteignaverð. Það hefur oft verið sýnt fram á að samband fasteignaverðs og fjarlægðar fasteigna frá borgarmiðju er neikvætt í þéttbýlum samfélögum með einum borgarkjarna. Í þessari rannsókn verður kannað hvort þetta samband sé til staðar í strjálbýlum samfélögum og það sé breytilegt frá einum stað til annars. Makró panel gögn frá Ísland sem ná yfir nokkrar lykilþætti fasteignamarkaðarins verða nýtt í rannsókninni. Þar er Íslandi skipt upp í 19 sýslur á tímabilinu 1981 til 2005.

Lykilorð: fasteignaverð, samgöngubætur, fjarlægðarstigull, nærlægt

JEL Classifications: R40; R21; R41; C23

Introduction

Does travel distance have an impact on housing prices in a thinly populated country? Iceland is an interesting subject for this question because it is large but thinly populated, it is geographically isolated, it has one single central business district (CBD), and a data sample for the entire country is available for a long period of time. This paper examines this relationship in order to capture the effect of transportation improvements in a thinly populated country and to test whether its location makes any marginal difference to the results.

Iceland is an island of 103,000 km^2 in the North Atlantic Ocean. A large part of Iceland (principally the highlands) is not suitable for people to live in due to the harsh climate, especially during the winter. Thus, relatively few of Iceland's inhabitants live more than 200 meters above sea level. Only 24,700 km^2 of Iceland's land area is below 200 meters above sea level[1] (see Figure 1); the higher elevations are mostly in the center of the island. The population was fairly evenly distributed along the coastline until the beginning of the 20th century, when a relatively large and steady flow of migration to the capital area in the southwest corner of Iceland began. Today, almost 70% of the total population lives in the capital and adjacent municipalities. This includes Reykjavík, the largest town in Iceland, with 113,000 inhabitants; Kópavogur, the second largest, with 25,800; and Hafnarfjörður, the third largest, with 22,000 residents. The fourth largest town in Iceland, Akureyri, has 16,300 inhabitants and is located on the northern coast. In total, there were 293,291 inhabitants in Iceland in December 2005 (reaching 300,000 in January 2006).

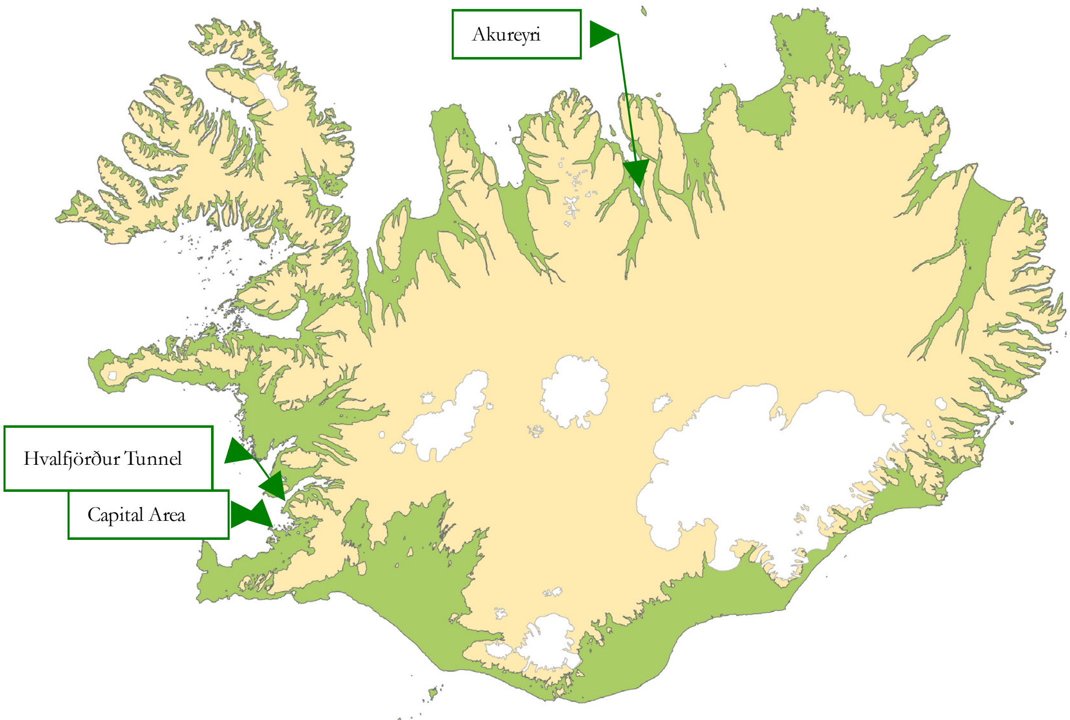

Figure 1: Lowlands of Iceland. Lowland is defined as land with an elevation of 0-200 meters above sea level (green shaded area). Source: National Land Survey of Iceland.

1 43,100 km^2 of Iceland's land mass is at an elevation of less than 400 meters.

The towns and villages outside the capital area are still evenly spread around the coastline, but they now have fewer inhabitants in total than do the four largest towns of Iceland (Table 1). Many farms have been completely or partly abandoned. The remaining population centers are small. Though this analysis concentrates on the lowlands, where population is denser relative to other areas, Iceland is a very thinly populated country compared to other European countries.

Table 1. Size and location of towns in Iceland - December 2005. Source: Statistics Iceland.

Town's population	Total	South coast	West coast	North coast	East coast
Population of 0-500	60	13	19	18	9
Population 500-1,000	17	5	3	4	3
Population 1,000-10,000	25	13	5	4	5
Population over 10,000	4	3	0	1	0
Total	105	34	27	27	17

There are approximately 100 towns and villages in Iceland (Table 1). The capital area is the only business center that is large enough to be able to offer a wide variety of goods and services. Therefore, access to the capital area brings benefits to the residents of rural Iceland. Since public transport in rural Iceland is very limited, inhabitants rely on their own vehicles. Several types of export industries, evenly spread along the coastline, are dependent on speedy and efficient transportation, such as tourism, agriculture, and the fishing industry. Thus, the transportation system appears extremely important to the Icelandic economy, especially in order to improve local scale economies. However, travel in Iceland has long been very hazardous. A harsh climate, high mountains, deep fjords, and bad roads have made for poor driving conditions. Icelandic roads have been primitive compared to those in other European countries. But transportation improvements over the past 25 years have been considerable (Table 3). It is very interesting to investigate how valuable improved access to the capital area has been to the residents of rural Iceland. Many wide rivers, along with other characteristics of the landscape and a limited road works budget, have made Iceland's road network unusually circuitous. Furthermore, narrow gravel roads have been the most common type of thoroughfare until recently, especially in the rural areas. As a result, transportation improvements in Iceland have generally aimed at shortening distances (Table 3) by building larger bridges and tunnels, and making roads safer by replacing gravel surfaces with pavement[2] – rather than building expressways and increasing the number of lanes, as in other developed parts of the world.

2 According to the Icelandic Road Administration and Statistics Iceland, only about 800 km of state-administered roads were paved in the year 1981, rising to 4,400 km at the beginning of the year 2007, or approximately 50% of major and collector roads.

According to Fujita and Thisse (2002, pp. 78-91), McCann (2001), and Fujita (1989), the price of land and real estate is highest in city centers and decreases with every unit of distance from the city center. Thus, when some areas are pulled closer to the city center through an improvement in transportation, land values in these areas increase. These researchers based their analyses on the newest extension of von Thünen's theory, the model of land rent or the bid-rent curve. The essence of the bid-rent curve reflects the fact that consumers prefer the accessibility of cities rather than the amenity value of rural districts. The formation of the bid-rent curve is sometimes called the distance gradient.

According to Baldwin et al. (2001; 2003), transportation improvements lead to higher local real house prices in the peripheries affected, due to the increased demand which follows in the wake of lower transportation costs and the improved access they offer to the labor market and the markets for goods and services. Baldwin et al. (2001; 2003) used the core-periphery model in their analyses, which Krugman (1991), as cited in (Baldwin et al., 2003), has called the core of the new geographical economics. However, in this article, the relationship between transportation improvements and real house prices will be investigated on the basis of the von Thünen theory. A hedonic price model will be implemented to estimate the distance gradient.

This article discusses distance from the capital area using two terms: *conurbation* and *periphery.* The conurbation is the area surrounding the capital city, more precisely within 120 kilometers from it. The periphery includes the rest of the country beyond the conurbation area. The research question of this article is as follows: *Do transport improvements between conurbation and periphery areas on the one hand, and the capital area on the other, affect the local price of houses*? This could also be phrased as follows: Do rural areas benefit from better access to relatively large urban areas due to an improved transportation system? This will be tested by an estimation of the distance gradient in Iceland. In doing so, an interesting issue is whether these benefits differ depending on the proximity of the area involved to the capital. Thus, I try to answer another research question: *Is there a difference in the marginal rate with which transportation improvements impact local housing prices in the conurbation and periphery areas of Iceland?*

The organisation of the study is as follows. Section 1 includes an introduction and description of the paper's purpose, as well as its relation to the recent literature in spatial economics, and discusses the construction of the research question. Section 2 contains a short overview of the recent literature, with emphasis on empirical studies, their methods, and main conclusions. Section 3 is a theoretical discussion of the model and several other possible approaches. Section 4 stresses the data sources, definition, construction, and transformation of the data. Section 5 contains the analysis and results, while Section 6 consists of a summary and concluding remarks.

Literature review

Many studies have documented the relationship between local house prices and the travel distance to some desirable or undesirable phenomenon, such as a central business district (CBD), an attractive view, or a source of pollution. A large number of studies have been devoted to the relationship between property value and distance from a new railway station, or access to similar additional transportation possibilities. Gibbons and Machin (2005) evaluated the benefits of railway access in London by looking at house prices. Their general finding was that house prices rose by 9.3% following transportation improvements of this kind. Comparable conclusions were presented in a very similar study by Bae et al. (2003) of Seoul's subway line 5. Smersh and Smith (2000, p. 195) estimated the effect of a new bridge in Jacksonville, Florida on property values. Jacksonville lies on both sides of the river and the effect was larger on the north side, due to the location of the city center. Bowes and Ihlanfeldt (2001) studied the impacts of railway transit stations on residential property values; the results were very different from station to station due to the wide range of positive and negative externalities, such as retail service and criminal activity.

Several empirical studies have documented the impact of travel distance to the CBD on local house prices. Empirical studies devoted to researching the effects of access improvements from large outlying areas to a relatively strong CBD were not easily found. However, Archer et al. (1996) explored such a topic using data from Dade County, Florida (which contains the city of Miami). According to Archer et al. (1996, p. 334), house price appreciation has spatial aspects. The result suggests that price appreciation depends on municipalities' distance from the CBD, housing units, local changes in population, and ethnic mix. Sheppard and Stover (1995) discussed a suitable method for estimating the economic impact of inner city transportation improvements. The method emphasizes changes in the price level of real estate following a transportation improvement, and reflects the total benefit of transportation improvements. According to Sheppard and Stover (1995), this method is applicable and practical, though several economists doubt its reliability. McDonald and Osuji (1995) presented results from a similar study based on an 11-mile long freeway between Chicago's center and its airport, which was finished in 1993. The results indicated that the land value started to increase before the freeway opened, and rose a total of 17% in real terms. Haurin and Brasington (1996, p. 351) used this theoretical framework to test whether school quality has a positive influence on real house prices. The study was based on primary source data from the six largest metro areas in Ohio (Haurin & Brasington, 1996, p. 356). School quality was found to be positively correlated with real house prices, as were arts and recreational opportunities, while the crime rate was negatively correlated with housing prices (Haurin & Brasington, 1996, p. 351). Cunningham (2006, p. 27) applied a similar approach in his investigation of real options in the Seattle house market. Allowing parameter estimates to vary by distance from the CBD, his results suggest that real options in the real estate markets appear only in the vicinity of the urban-rural frontier, i.e. the area which is 12 to 20 miles distant from the city center. My study seems to be most comparable to McMillen's (2003) study, in which the researcher evaluated the return of centralization in Chicago using a repeat sales model, and concluded that house prices decline by more than 8% for every mile from the CBD. In a similar study, Case and Mayer (1996) analyzed house price dynamics in the Boston metropolitan area using data from 1982 to 1994 and found that the spatial disparity of house prices can be explained by differences in new construction, demographic variables, manufacturing employment, proximity to downtown, and aggregate school enrollment. In another investigation of spatial variation in housing prices by De Bruyne and Van Hove (2006), the data sample represented every municipality in Belgium. An increase in travel distance by 1 kilometer was found to lower the housing price by 0.001 to 0.002% (De Bruyne & Van Hove, 2006, p. 11).

As mentioned earlier, empirical studies devoted to the relationship between house prices and travel distances for a large area around a relatively strong CBD were not as easily found as expected. The studies listed above are the closest matches. My study is different from previous studies in five ways. First, an analysis of the distance gradient using a panel data sample for an entire country has never been implemented before. Secondly, no study has compared the marginal impact of distance on local house prices in areas close to the CBD and areas a great distance away. Thirdly, no study has focused on a thinly populated country such as Iceland and the question of whether this relationship will be significant, given the circumstances. Fourthly, Iceland is, among islands, unusually isolated geographically. Finally, the data sample represents avery long period, from 1981 through 2005.

The model

The empirical model is based on von Thünen's theory of land rent, extended by Alonso (1964), Mills (1969; 1970), Muth (1969), and Evans (1973) for the house market, as mentioned before. Since distance between localities is the essence of this theory, its model becomes an appropriate tool for the estimation of transportation improvements, which is the main purpose of this paper. A theoretical derivation of this model is included in Appendix II. According to Fujita (1989, pp. 16, 26) and Kiel and McClain (1995a, pp. 314-315), the general context from the basic model in Eq. 12 (see Appendix II) can be derived through a log linear utility function into an equation of the following form:

$$h(r) = Ae^{-br} \qquad (1)$$

where h is the land value, r is the distance between the land location and the CBD, and A and b are positive constants. By taking the natural logarithm of both sides, Eq. 1 becomes

$$\ln h(r) = \ln A - br \qquad (2)$$

This equation has been frequently used in various versions in house price research. Furthermore, it is the most common form of the equation in comparable and related studies, e.g. in the papers of Cunningham (2006, p. 6; Kiel & McClain, 1995a, pp. 314-315), Gibbons and Machin (2005, p. 152), McMillen (2003, pp. 289, 293), Haurin and Brasington (1996, p. 356), Kiel and Zabel (1996, p. 148), and Kiel and McClain (1995a, p. 319; 1995b, p. 248). The equation describes a non-linear relationship of the semi-logarithmic type. Instead of estimating a simple model, as follows,

$$\ln h_{it} = \alpha + r_{it}\beta_1 + \varepsilon_{it}$$

economists frequently implement an extended model,

$$\ln h_{it} = \alpha + r_{it}\beta_1 + cx'_{it} + \varepsilon_{it}$$

where x'_{it} is a vector of relevant additional explanatory variables and c is a vector of coefficients. Selected additional explanatory variables from former studies include several local demographic factors, such as population or a change in it (Archer et al., 1996; Cunningham, 2006; De Bruyne & Van Hove, 2006), demographics (Case & Mayer, 1996), population density (De Bruyne & Van Hove, 2006; McDonald & Osuji, 1995), the presence of a park or school nearby (McDonald & Osuji, 1995), and ethnic mix (Archer et al., 1996; De Bruyne & Van Hove, 2006; McDonald & Osuji, 1995).

Indicators for house quality are relevant explanatory variables in hedonic price models, such as lot size (Cunningham, 2006; Kiel & McClain, 1995b; McMillen, 2003), house age (Archer et al., 1996; De Bruyne & Van Hove, 2006; Kiel & McClain, 1995b; McMillen, 2003, 2004; Tyrvainen & Miettinen, 2000), indicators for house building material and type of construction (McMillen, 2004; Tyrvainen & Miettinen, 2000), number of rooms (Kiel & McClain, 1995b), number of bathrooms (Kiel & McClain, 1995b), number of storage areas (McMillen, 2003, 2004), existence of a garage, attic, basement, central air conditioning, fireplace, or land area (McMillen, 2004), and the existence of a building area (McMillen, 2003, 2004).

Furthermore, local economic factors can be among the relevant explanatory variables, such as the supply of houses (Archer et al., 1996; Case & Mayer, 1996; De Bruyne & Van Hove, 2006), manufacturing employment (Case & Mayer, 1996), importance of agriculture (De Bruyne & Van Hove, 2006), household income (De Bruyne & Van Hove, 2006; McDonald & Osuji, 1995), unemployment rate (De Bruyne

& Van Hove, 2006), municipal tax rate (De Bruyne & Van Hove, 2006), aggregate school enrollment (Case & Mayer, 1996), school quality (Haurin & Brasington, 1996, p. 351), and interest rate (Cunningham, 2006).

Finally, the distance gradient can be affected by local amenity values, such as the presence of a lake or an attractive view (Cunningham, 2006; De Bruyne & Van Hove, 2006; Kiel & McClain, 1995b; Tyrvainen & Miettinen, 2000), arts and recreational opportunities (Haurin & Brasington, 1996, p. 351), any kind of local dangers (Cunningham, 2006), and the crime rate (Haurin & Brasington, 1996).

$$\ln h_{it} = \alpha + r_{it}\beta_1 + x'_{it}\beta_2 + d'_{it}\beta_3 + \varepsilon_{it} \tag{3}$$

However, standard panel data models, such as fixed and random effect models, generally return more efficient estimators than pooled ordinary least square (POLS) models. Furthermore, since the relationship of local house prices and transportation improvements is the present focus, the fixed effect model is more appropriate where the variable coefficient returns a within-individual variation and the between-individual variation is left to the individual constant term. Thus, it is reasonable to apply the following fixed effect model,

$$\ln h_{it} = \alpha_i + r_{it}\beta_1 + x'_{it}\beta_2 + d'_{it}\beta_3 + \varepsilon_{it} \tag{4}$$

where the natural logarithm of house price, h, is dependent on the distance, r, to the capital area or CBD, several other explanatory variables, x', dummy variables, d', and relevant residuals, ε, of every county, i, in every single period, t. Note that α_i is the individual constant term. Total household income, age and size of the buildings, and population are other explanatory variables. There are two dummy variables, one for S-Múla County and another for the Hvalfjörður Tunnel. The dummy variable for the Hvalfjörður Tunnel is intended to capture the effect of a transportation improvement financed by a road toll; Hvalfjörður Tunnel was the only such transportation improvement in Iceland between 1981 and 2005. The dummy variable for S-Múla County is intended to reflect the fact that an unusually large-scale local investment project has been underway there since 2003. Unfortunately, limitations of the data prevented any possible estimation of the compensated good, z, lot size, s, and mortgage interest rates.

Another version of the model could be more appropriate to the data sample than the semi-logarithm version (Eq. 4). It is a quadratic distance model, which has been implemented at least once before by McDonald and Osuji (1995). The model is as follows:

$$\ln h_{it} = \alpha_i + r_{it}\beta_1 + r_{it}^2\beta_2 + x'_{it}\beta_3 + d'_{it}\beta_4 + \varepsilon_{it} \tag{5}$$

The model is identical to the semi-logarithm model except for an additional variable for quadratic distance, r_{it}^2 . The reason for its appropriateness is the potential existence of different marginal impacts in different locations.

These fixed effect models (Eq. 4 and 5) are suitable for the evaluation of the relationship between house prices and transportation improvements, because the distance parameter, *r*, captures the relative influence of the respective factors on real house prices, and the data used to represent distance is the length of the roads between the center of each county and the center of the capital area, expressed in kilometers (further description of the data is in the next section). Icelandic highway improvements have often involved straightening roads and shortening distances, and the distance parameter reflects the relative influence of shortened distances on the real unit price of houses, *ceteris paribus*. It is important to understand that this investigation takes into account only those transportation improvements which involve a reduction in driving distance.

Data

The data for this analysis comes from Iceland. Iceland is divided into 19 counties[3] in this paper (Figure 2), all of which are real counties, except for the capital area. The capital area is not a clearly defined selection of municipalities with a definition by Statistics Iceland, as are the other counties in this study.

Figure 2. Counties of Iceland.

3 There is a two-tier governmental system in Iceland, with a central and a local level, i.e. a central government and municipalities. Counties are no longer an important part of the system. The role of counties was more important historically, but now county boundaries are mainly used to determine jurisdictions for Iceland's courts and police. Counties, rather than municipalities, were selected as the unit of analysis in this paper due to the lack of reliable data for the vast majority of Iceland's smallest municipalities, as mentioned in the body text of this paper.

The data on house prices[4] in this study come from the Land Registry of Iceland. The data sample includes the monthly averages for all Icelandic municipalities from 1981 to 2005. The data was processed to give annual averages for counties rather than municipalities, for reasons of comparability and due to a lack of housing market turnover in several municipalities. In order to do this, monthly average cash prices were transformed into annual average cash prices, taking care to weight each month's average according to the number of contracts concluded:

$$\overline{h_y} = \sum_{m=1}^{12} \overline{h_m} \left(\frac{c_m}{\sum_{m=1}^{12} c_m} \right) \quad (7)$$

The annual average cash price, $\overline{h_y}$, is the sum of the weighted monthly average cash price, $\overline{h_m}$, defined by the notation above. The weight is calculated by the number of contracts in each month, c, divided by the total number of contracts each year.

House prices vary substantially both within and between counties. As shown in Table 2, the average house price from 1981 to 2005 was highest in the capital area and lowest in Dala County. The lowest annual average price for a single year was in Skagafjarðar County, and the highest in the capital area. The development of house prices during the period from 1981-2005 varied. The most marked changes were in the capital area, Borgarfjarðar, Árnes, and Þingeyjar Counties. House prices increased in real terms by 1,936.7 krónur per m^2 in the capital area annually during the period, at the price level of 2004. House prices, however, decreased in real terms by 1,022.5 krónur per m^2 annually during the period in Þingeyjar County. Note that data for some years are missing for seven counties out of nineteen during the period under study. Thus, the present study is based on an unbalanced panel data sample.

4 The Land Registry of Iceland collected these data from the original source: written contracts between home sellers and buyers. The data were available both in terms of contract prices and cash prices. The contract price is the total house price according to the written contract between a seller and buyer. However, it is common for the contract price to be paid in several payments over a certain period. Both the duration and number of payments vary substantially from contract to contract. In order to make housing price data more comparable, the Land Registry of Iceland calculates a so-called cash price for every contract. This is, in fact, the present value of the the contract price. The dependent variable in this paper is the cash price divided by the house size in square meters.

Table 2. Real house prices per m^2 in each Icelandic county from 1981 through 2005. Annual average house prices in Icelandic krónur based on the total sample. Source: Land Registry of Iceland.

County	Average	Max	Min	StDev	Years	Trend
Capital area	106,415	183,587.6	83,335.8	21,572.2	25	1936.7
Gullbringu County	73,582	109,003.2	62,096.1	11,404.7	25	726.2
Borgarfjarðar County	67,336	112,343.5	45,851.0	16,476.0	25	1632.5
Mýra County	67,599	95,608.1	49,963.7	12,365.7	25	121.0
Snæfellsnes County	52,096	76,374.8	38,768.4	8,427.2	25	525.9
Dala County	38,485	58,254.0	25,163.1	10,389.5	15	560.1
Barðastrandar County	38,774	61,010.1	24,460.6	9,561.9	25	-1014.7
Ísafjarðar County	57,307	78,787.0	41,962.5	9,050.6	25	-996.0
Stranda County	44,251	64,073.7	28,679.1	11,163.2	15	-188.7
Húnavatns County	41,926	48,570.0	31,971.9	4,718.2	23	-27.1
Skagafjarðar County	60,428	77,022.1	17,897.5	11,795.6	24	256.3
Eyjafjarðar County	76,932	110,416.1	59,016.2	10,525.0	25	988.0
Þingeyjar County	56,681	105,581.5	43,942.1	12,496.6	25	-1022.5
N-Múla County	43,105	62,101.1	29,813.4	8,469.6	20	-276.5
S-Múla County	60,149	98,694.7	28,029.9	16,079.3	25	148.2
A-Skaftafells County	68,729	94,843.8	33,288.6	13,776.9	20	-218.7
V-Skaftafells County	39,290	55,412.2	23,974.9	10,034.4	15	201.9
Rangárvallar County	54,071	66,269.6	43,821.7	4,950.2	25	493.8
Árnes County	69,828	118,934.1	53,060.3	14,678.9	25	1048.6

The data in this table, i.e. average, max, min, standard deviation, and trend, is based on annual averages transformed by means of Eq. (7).

Table 3 shows the development of the road distance between each county and the capital area from 1981 through 2005. The distance between counties and the capital area varies substantially, from 49.3 to 704.8 kilometers. This distance, however, has been reduced in almost every county. The reductions have been relatively small on the south coast of Iceland, primarily due to the absence of deep fjords and high mountains, which have presented the greatest opportunities for shortening road distances in Iceland. In other regions, the distance has been reduced by two to four kilometers annually. Ísafjarðar County had the greatest degree of reduction in travel distance during the period: 4.3 kilometers annually.

Table 3. Road distance between the capital area and each Icelandic county, showing changes due to transportation improvements during the period from 1981 through 2005. Source: Fjölvís and Icelandic Road Administration.

County	Average	1981	2005	StDev	Trend
Capital area	0.0	0.0	0.0	0.0	0.0
Gullbringu County	49.3	49.7	48.4	0.2	0.0
Borgarfjarðar County	92.9	108.8	50.8	27.0	-2.8
Mýra County	104.4	117.0	74.0	19.4	-2.1
Snæfellsnes County	218.8	235.9	185.6	20.9	-2.4
Dala County	185.0	198.0	153.0	19.8	-2.1
Barðastrandar County	430.5	457.5	380.9	30.0	-3.6
Ísafjarðar County	510.4	543.3	456.4	34.9	-4.3
Stranda County	314.1	332.7	281.9	20.6	-2.4
Húnavatns County	267.1	284.2	234.0	20.4	-2.3
Skagafjarðar County	351.2	371.0	293.3	23.1	-2.6
Eyjafjarðar County	425.7	445.8	390.3	21.0	-2.4
Þingeyjar County	537.9	562.8	498.4	24.0	-2.8
N-Múla County	697.7	723.1	659.8	25.7	-3.1
S-Múla County	704.8	727.5	675.9	21.4	-2.7
A-Skaftafells County	466.5	474.5	457.6	7.5	-0.9
V-Skaftafells County	212.7	213.0	209.9	2.7	-0.3
Rangárvallar County	102.0	103.0	100.4	0.7	-0.1
Árnes County	57.8	58.6	57.4	0.6	-0.1

The data in this table, i.e. average, maximum, minimum, and standard deviation, is based on annual averages transformed by means of Eq. (7).

The explanatory variables included in Eq. (3) to (6) are shown in Table 4. They are drawn from various sources, including the Commissioner of Inland Revenue, Statistics Iceland, and the Icelandic Road Administration. Information on home age and size was obtained from the Land Registry of Iceland, along with house price data, as mentioned before. Data on road distances was obtained from Fjölvís Publishing Company, but was originally collected by the Icelandic Road Administration. The data on population and total income were obtained from Statistics Iceland. The Commissioner of Inland Revenue is the primary source for total income. The data series were annual averages, except for population and road distance, which were static variables. Data on population is for December 1 of each year, and data on road distance is for January 1 of each year. The data series were spatially classified by municipality, except for data on road distance. Data on road distance was classified by locality. The data series were then transformed to relate to counties rather than municipalities and localities.

The averages and the standard deviation of the explanatory variables as well as of the dependent variable show considerable variation (Table 4). The standard deviation of house prices is approximately ⅓ of the mean and of road distance more than ⅔ of the mean. This is evidence of large differences which show potential for robust explanations.

Table 4. Variable description and sample statistics.

Variable (acronym)	Description	Mean	Standard deviation
House price (HPRI)	Real price per m^2, in Icelandic krónur	58,967.8	18,790.5
Road distance (RDIS)	Average distance in kilometers of each county from the capital area, in absolute terms	299.7	216.6
Total Income (TINC)	Total income per capita, in thousands of Icelandic krónur	1,934.3	343.0
House age (HAGE)	Average age of houses sold, in absolute terms	31.8	8.4
House size (HSIZ)	Average size of houses sold, in square meters	136.35	28.6
Population (POPU)	County population, in absolute terms	15,333.2	36,326.8
Tunnel (TUNN)	Dummy variable for a large transportation improvement, Hvalfjörður Tunnel	0.276	0.448
Aluminum East Coast (ALEA)	Dummy variable for a large-scale local investment (a new aluminum smelter on the east coast of Iceland)	0.003	0.055

The data in this table, i.e. mean and standard deviation, is based on annual averages transformed by means of Eq. (7).

Estimating the result

The empirical model was set forth in Chapter 3 (Eq. 4). Three versions of a fixed effect model will be tested, the semi-logarithm type (SLM) and two of the quadratic distance type – that is, Eq. (4) and (5). The versions of the quadratic distance model will be both of the second (QDM-2) and third degree (QDM-3). Furthermore, all versions will be tested against data from two areas, the conurbation area and the entire country, in order to enlarge our understanding and strengthen the international comparison. The results are presented in Table 5, including parameter coefficients, t-value, number of observations, *n*, R square, adjusted R square, F-value, the Durbin-Watson parameter, log likelihood, a special t-statistic for testing serial correlation in panel data as recommended by Wooldridge (2002, pp. 176-177), and the Jarque-Bera probability for testing the residual's normal distribution.

Initially, the analyses suffered from serial correlation, which was sufficiently eliminated by a lagged variable of the residual. Though Bae et al. (2003, p. 11) argued that one should not worry too much about spatial autocorrelation, spatial multicollinearity, and heteroscedasticity in studies of this type, by referring to Oliver Blanchard (1987, p. 449), it was possible to confirm that none of these problems were observable in the final results, except for multicollinearity in the models for the conurbation area.

Table 5. Relationship between housing prices and transportation improvements. A fixed effect panel data model comparing two approaches: a semi-logarithm model (SLM) and a quadratic distance models (QDM).

	Model 1 Every county of Iceland included, SLM.	Model 2 Only capital area and adjacent counties included, SLM.	Model 3 Every county of Iceland included, QDM-2.	Model 4 Only capital area and adjacent counties included, QDM-2.	Model 5 Every county of Iceland included, QDM-3.	Model 6 Only capital area and adjacent counties included, QDM-3.
α_i	Appendix	Appendix	Appendix	Appendix	Appendix	Appendix
RDIS	0.002079	-0.002635	-0.002742	-0.018596	-0.007786	0.558169
	(2.69)	(-3.88)	(-2.70)	(-2.30)	(-5.83)	(0.97)
RDIS^2			5.97E-06	9.73E-05	2.35E-05	-0.007176
			(5.76)	(2.01)	(6.13)	(-0.99)
RDIS^3					-1.57E-08	2.93E-05
					(-4.33)	(1.01)
TINC	0.000292	0.000361	0.000275	0.000357	0.000266	0.000363
	(6.55)	(9.16)	(6.22)	(9.02)	(6.07)	(9.05)
HAGE	-0.009054	-0.002354	-0.008556	-0.002865	-0.008680	-0.001798
	(-6,56)	(-0.96)	(-6.32)	(-1.15)	(-6.51)	(-0.74)
HSIZ	-0.000849	-0.002234	-0.000749	-0.001823	-0.000797	-0.001761
	(-2.11)	(-2.48)	(-1.93)	(-2.01)	(-2.08)	(-1.87)
TUNN	0.031764	-0.006577	0.016628	0.026244	0.011325	0.021737
	(0.80)	(-0.16)	(0.45)	(0.84)	(0.31)	(0.70)
POPU	2.19E-06	-4.14E-07	2.29E-06	-4.51E-07	2.50E-06	-7.28E-07
	(1.48)	(-0.34)	(1.55)	(-0.37)	(1.69)	(-0.59)
ALEA	0.328458		0.435592		0.353118	
	(6.11)		(7.49)		(7.56)	
E1(-1)	0.379309	0.533804	0.331772	0.528700	0.302645	0.509294
	(4.76)	(5.02)	(4.36)	(4.82)	(4.04)	(4.35)
AMPD, 0-728 km	0.002079		0.001604		0.009322	
AMPD, 0-120 km	0.002079	-0.002635	-0.002044	-0.007212	-0.005036	-0.281423
n	402	144	402	144	402	144
R^2	0.80	0.87	0.81	0.87	0.82	0.87
Adjusted R^2	0.79	0.85	0.80	0.86	0.81	0.85
F-value	60	71	61	67	61	60
Durbin Watson	1.74	1.71	1.73	1.69	1.72	1.69
Log-likelihood	216	134	225	135	232	134
Serial correlation (t-statistics)	0.62	0.59	0.81	0.63	0.87	0.56
Jarque-Bera probability	0.000000	0.000010	0.000000	0.000001	0.000000	0.000051

Dependent Variable: LOG (HPRI). Method: Pooled least squares. White Heteroscedasticity-Consistent Standard Errors & Covariance. Values in parentheses are t-statistics. Wald test rdis^2: F-value 33.17. Wald test rdis^3: F-value 18.77. AMPD = Average marginal propensity to distance. Jarque-Bera probability > 0.05 confirms the null hypothesis.

The results suggest that the semi-logarithm version of the model is appropriate for the conurbation area, but the quadratic distance model is appropriate for the entire country. There are several reasons for this. Previous studies, whose results are based on data samples geographically limited to cities or conurbation areas, have used the semi-logarithm model, and my results for the conurbation area also show high levels of significance when using the semi-logarithm model (Model 2 in Table 5). However, when used on data for the entire country, the semi-logarithm model returned a correlation coefficient with the reverse sign from what was expected. This shifted attention towards the quadratic distance model, and indeed, both a better fit to the distance parameter and better general relevance of the results supported the quadratic distance model's suitability for the entire country (Model 5). Furthermore, a Wald test was performed in order to confirm the relevance of the additional variable of the second-order quadratic distance model (Model 3), rdis^2. It returned a satisfactory F-value of 33.17. A corresponding test was performed for the third-order quadratic distance model (Model 5) and an F-value of 18.77 confirmed further improvement. However, according to Jarque-Bera probability, the residuals are not normally distributed.

The result of the analysis using data from all counties shows a significant negative relationship between housing prices and the distance between counties and the capital area. The marginal impact of a reduction in distance of 0-120 kilometers is 0.5%, *ceteris paribus*. This relationship is convex. According to these results, transportation improvements between counties and the capital area seem to have limited positive impacts on local house prices. These impacts are visible within a distance of approximately 165 kilometers away from the capital area; beyond that they become negative (Table 5 and Figure 3). The real price of houses clearly reveals a diminishing marginal rate of return with respect to decentralized locations. This could be rephrased by saying that the value of a central location in Iceland has an increasing marginal rate of return.

The relationships between house prices on the one hand and total income, house age, and population on the other hand are also significant. The results indicate that house prices in a given county increase by 2.66% for every 100,000 Icelandic krónur in total income per capita, *ceteris paribus* (Model 5 in Table 5). This is an interesting result because the spatial disparity of average income in Iceland is large, due to the various combinations of industry and productivity in the different counties. Wages tend to be lower in primary industries, compared to knowledge-based industries, due to differences in the actual and potential growth of labor productivity. Traditional primary industries tend to dominate in rural Iceland, while knowledge-based industries tend to dominate in the capital area.

Furthermore, the age of a house influences its real price. As a house gets older, the house price decreases by 0.9% in real terms for every year, *ceteris paribus*. House size has a significant negative impact on local housing prices: the price drops by 0.08% for every square meter of house enlargement. The population of a given county also influences the local real price of houses. For every additional 1,000 inhabitants in a county, housing prices increase by 0.3%, *ceteris paribus*. The house prices in S-Múla County are significantly higher than in other counties (about 35%), due to a large-scale local investment. The relationship between house prices and the dummy variable for the Hvalfjörður Tunnel was, however, not significant, *ceteris paribus* (Model 5 in Table 5).

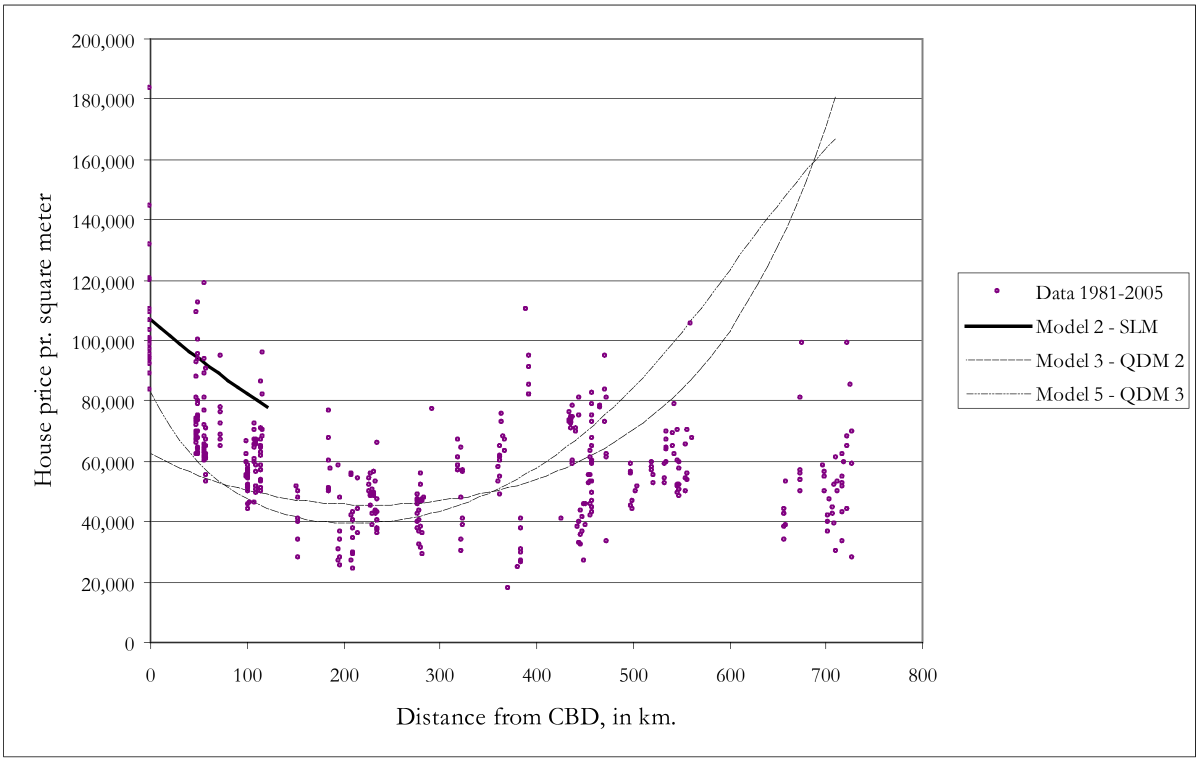

Figure 3. The distance gradients for Iceland according to the fixed-effect model. A simulation of the result of Model 5 for all counties and Model 2 for the conurbation area. The average individual constant is employed in this simulation (see Table 5).

Now, it is interesting to stress the results of my second analysis, based only on data from the capital area and adjacent counties. Within the range of 0-120 km from the CBD, housing prices decline by 0.26% for each additional kilometer of distance from the center of the capital area. In this analysis, the relationship between housing prices and total income is stronger, but there is no significant relationship between housing prices and the age of the property, which is difficult to explain.

This result is in line with many other studies. McMillen (2003, p. 287) evaluated the relationship between price and central location in Chicago using a repeat sales model and concluded that house prices decline by more than 8% for every mile away from the CBD. That is approximately 5% per kilometer. This is an unusually large distance gradient and not a reliable figure, since the same author (2004) presented opposite results for the same area one year later. In other studies, the distance gradient is generally closer to my result. McDonald and Osuji (1995, p. 261) found it to be approximately 1% for the city of Chicago. A 0.7% distance gradient was among Cunningham´s (2006, p. 18) results for the CBD of Seattle. Tyrvainen and Miettinen (2000, p. 215) concluded that house value decreases by 0.11% for every 1% increase in the distance away from the center of the Salo district in Finland. De Bruyne and Van Hove (2006) came up with a rather different figure for Belgium, with a gradient of somewhere between 0.001 and 0.002%. The present figure for Iceland’s CBD, 0.26-

0.50%, is close to other published results, while the lower figures for the rest of the country are closer to the Belgian result. This is to some extent a logical difference, as the data sample for Belgium represented the entire country while other studies only included conurbation areas.

When the results (Models 2 and 5) are compared, it is obvious that distance has a stronger effect in the conurbation area than in other counties. Furthermore, it is interesting to observe how the relationship between local house price and distance is negative around the CBD but positive in the all-county model. This is hard to explain, but it could reflect spatial variation in the populations' preferences. The negative relationship reflects a population dominated by individuals with a higher preference for access over amenity value. When the distance exceeds a certain limit, the population becomes dominated by individuals with a preference for amenity value over access. Thus, the distance gradient becomes gradually positive beyond that limit. This limit is located at a distance of approximately 165 kilometers from the CBD in the model for all counties within Iceland (Figure 3). This is in line with other results in which the distance gradient is generally steeper in studies representing only cities and their suburbs, such as McMillen (2003), McDonald and Osuji (1995), and Cunningham (2006), and relatively gentler in studies covering larger areas, such as Tyrvainen and Miettinen's (2000) study of a large district in Finland and De Bruyne and Van Hove's (2006) study of Belgium. However, even though similar differences between the conurbation and rural areas were detected in other studies, the relationship was never positive in rural areas, as in the present study.

Another and in fact more likely explanation is related to labor market boundaries and other development factors, particularly counterurbanization. Counterurbanization is urban out-migration motivated by changes in household economy or preferences such as relative housing prices, amenity values and the like. It has been detected for several decades both in Europe and USA, especially in a certain range from the CBD (Dahms & McComb, 1999; Mitchell, 2004; Stockdale, Findlay, & Short, 2000). Thus, when the distance between the CBD and other rural localities becomes shorter, it makes commuting more profitable, increasing the wealth of the existing rural population and supporting any additional counterurbanization. This development decreases marginally by distance from the CBD. This causes the negative relationship between house prices and distance to have certain limits.

This result suggests that transportation improvements, including those that shorten distances, have an impact on the local real prices of houses. Furthermore, such improvements have a generally greater marginal impact on the local price of houses close to CBDs than those which are farther away. This means that two identical transport investment opportunities of different locations would have different returns, *ceteris paribus*. The return would be higher for the one which is closer to the CBD. This is logically related to the fact that the inhabitants of areas adjacent to the CBDs have higher preferences for access over amenity values compared to inhabitants of more distant areas.

Table 6. Relationship between housing prices and transportation improvements. A fixed-effect panel data model comparing two approaches: a semi-logarithm model (SLM) and a quadratic distance model (QDM), including data on the mortgage interest rate during the period 1994-2005.

	Model 7 Every county of Iceland included, SLM.	Model 8 Only capital area and adjacent counties included, SLM.	Model 9 Every county of Iceland included, QDM-2.	Model 10 Only capital area and adjacent counties included, QDM-2.	Model 11 Every county of Iceland included, QDM-3.	Model 12 Only capital area and adjacent counties included, QDM-3.
α_i	Appendix	Appendix	Appendix	Appendix	Appendix	Appendix
RDIS	0.000182	-0.001012	-0.002898	-0.014536	-0.005733	-0.379451
	(0.29)	(-2.10)	(-3.27)	(-3.31)	(-4.60)	(-0.57)
RDIS^2			4.76E-06	8.09E-05	1.55E-05	0.004684
			(4.06)	(3.14)	(3.84)	(0.56)
RDIS^3					-9.94E-09	-1.85E-05
					(-2.56)	(-0.55)
TINC	0.000211	0.000360	0.000189	0.000375	0.000176	0.000370
	(3.55)	(7.09)	(3.21)	(7.83)	(3.01)	(7.36)
HAGE	-0.009154	-0.008640	-0.009493	-0.010205	-0.009489	-0.010678
	(-3.86)	(-2.14)	(-4.38)	(-3.10)	(-4.33)	(-3.36)
HSIZ	-0.000469	-0.001160	-0.000506	-0.001076	-0.000541	-0.001068
	(-1.34)	(-1.53)	(-1.48)	(-1.44)	(-1.57)	(-1.42)
TUNN	-0.015257	-0.013945	-0.005254	-0.003126	-0.005441	-0.002379
	(-0.42)	(-0.48)	(-0.14)	(-0.12)	(-0.15)	(-0.09)
POPU	1.10E-05	2.41E-06	1.17E-05	1.66E-06	1.22E-05	1.90E-06
	(3.37)	(-0.48)	(3.67)	(0.64)	(3.84)	(0.70)
ALEA	0.158767		0.220563		0.221995	
	(3.02)		(3.90)		(4.13)	
INBA	-9.499603	-5.351593	-9.078067	-5.481211	-9.036768	-5.236690
	(-6.67)	(-3.21)	(-6.49)	(-3.31)	(-6.55)	(-3.54)
HNPP	-2.191608	0.033016	-1.500418	-0.193376	-1.187269	0.019051
	(-2.53)	(0.02)	(-1.52)	(-0.15)	(-1.18)	(0.02)
E1(-1)	0.374623	0.543351	0.348526	0.543893	0.331588	0.550398
	(3.18)	(3.86)	(2.97)	(3.49)	(2.75)	(3.37)
AMPD, 0-728 km	0.000182	-0.001012	0.000567		0.005551	
AMPD, 0-120 km	0.000182	-0.001012	-0.002341	-0.005071	-0.003919	0.168577
n	207	66	207	66	207	66
R^2	0.91	0.96	0.91	0.96	0.91	0.96
Adjusted R^2	0.89	0.95	0.90	0.95	0.90	0.95
F-value	62	89	63	88	61	81
Durbin Watson	1.87	2.13	1.88	2.18	1.88	2.15
Log-likelihood						
Serial correlation (t-statistics)	-0.06	-1.85	-0.06	-2.37	0.02	-2.15
Jarque-Bera probability	0.000000	0.214581	0.000000	0.111670	0.000000	0.110077

Dependent Variable: LOG (HPRI). Method: Pooled least squares. White Heteroscedasticity-Consistent Standard Errors & Covariance. Values in parentheses are t-statistics. AMPD = Average marginal propensity to distance. Jarque-Bera probability > 0.05 confirms the null hypothesis.

A reasonable criticism of this analysis is that data for mortgage interest rate, lot size and the supply side of the housing market are absent. Reliable data for lot size was not available. Its absence is however not so serious for this analysis as one could expect, due to the homogeneity of lot sizes in the Icelandic real estate market. Furthermore, reliable data on mortgage interest rates and the supply side were not available for the entire period. Reliable data was available for the mortgage interest rate (INBA) from 1990-2005 and for the supply side (HNPP) from 1994-2005. Therefore, the analysis was repeated along with an explanatory variable for the mortgage interest rate and the supply side in order to improve the estimation (Table 6).

The results were in line with the previous results. The parameters were slightly different, but the signs were still the same. The quadratic distance model still seems to be the most appropriate one for the entire country and the semi-logarithm model most appropriate for the conurbation area.

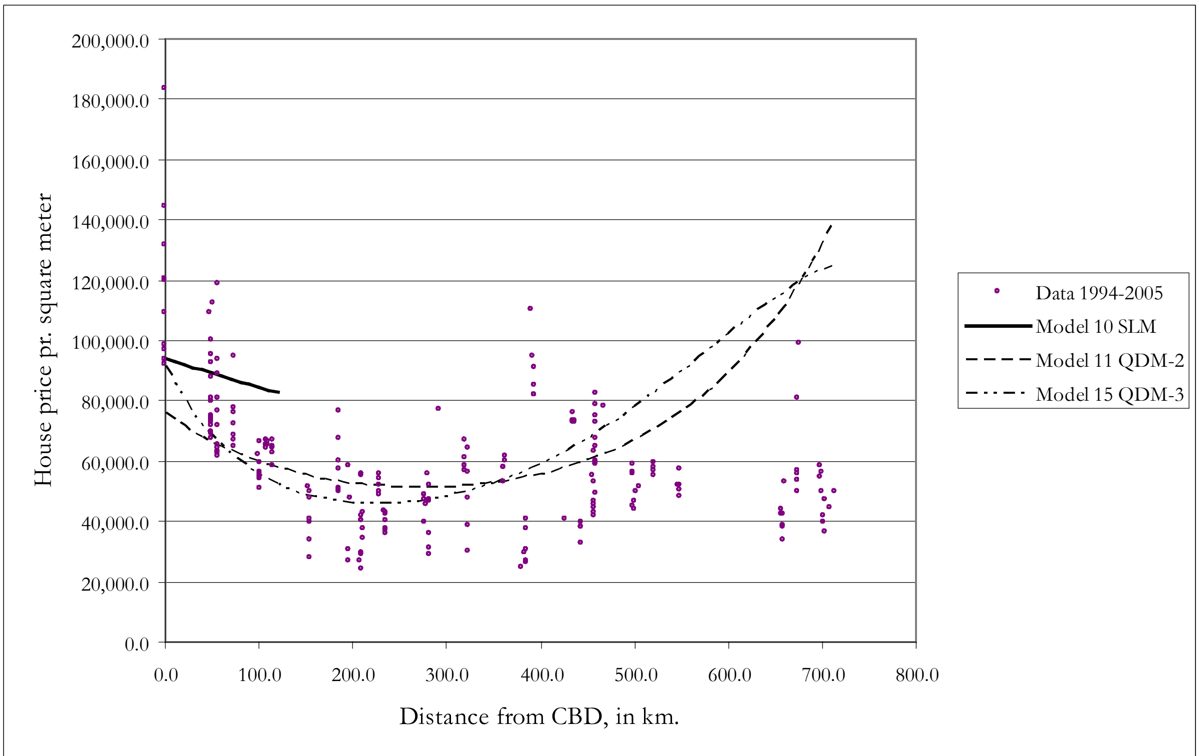

Figure 4. The distance gradients for Iceland according to the fixed effect model, with the addition of the mortgage interest rate. A simulation of the result of Model 11 for all counties and Model 10 for the conurbation area.

A Wald test was performed in order to confirm the relevance of the additional variable of the second-order quadratic distance model (Model 3), rdis^2. It returned an F-value of 16.49, which was the expected outcome and confirms the relevance of rdis^2. Comparable tests were performed for the third-order quadratic distance model (Model 5) and an F-value of 6.56 confirmed further improvement. However, according to the Jarque-Bera probability, the residuals are normally distributed only for the model of the conurbation area but not in the case of all counties (Table 6).

The presence of the mortgage interest rate and the supply of houses reduced the impact of reduced distance, as suggested by Capozza and Helsley (1989). Overall, however, the model is relatively stable.

The results are, however, to some extent inconclusive when it comes to the behavior at the far end of the distance scale. The relationship becomes strongly positive, which is not easily explained. Informal observation and professional intuition suggested a much weaker positive slope or a slope close to zero. Further analysis would be needed to resolve this question. The problem may be traceable to the spatially scattered data sample. A sample of municipalities rather than counties might return more conclusive and logical results.

Conclusion

The aim of this study was to measure the influence of transportation improvements on the local real price of houses in Iceland. The analysis was based on annual average house prices, distance from the CBD (the capital area), total household income, and several other relevant explanatory variables for all counties in Iceland from 1981 through 2005. Furthermore, separate analyses were carried out for the entire country and for the conurbation area only, in order to gain a better understanding of the situation and to strengthen the international comparability of the results. The data were analyzed with a fixed-effect model in several different versions. A semi-logarithm version of the model was most appropriate for the conurbation area, while a third-degree quadratic distance model was most appropriate for the all-county analysis.

The analysis clearly shows that the relationship between local real house prices in Iceland and each county's distance from the CBD is statistically significant and negative. This means that transportation improvements which reduce the distance from the CBD increase the local price of houses. This generalization is subject to certain limitations. A decrease of one kilometer in the distance between a county and the CBD increased the real price of housing in that county by 0.26% when the model was used to analyze the conurbation area only – that is, counties within the range of 0-120 km from the CBD. When the geographical scope of the model was extended and the model was tested for all counties, the corresponding figure was 0.5% in the range of 0-120 km from the CBD. Beyond 120 km, this negative correlation continued only until the distance reached 165 km from the CBD; beyond 165 km, the correlation became positive. The result for all counties implies that the relationship is strictly convex with respect to distance, especially in the range of 0-165 km from the CBD. This means that transportation improvements close to CBDs generally have a greater marginal impact on the local real price of houses than those which are farther away. A logical explanation of this is that the inhabitants of the areas adjacent to the capital area have higher preferences for access over amenity values than inhabitants of more distant areas. Furthermore, there are practical limits on the distance from the CBD to which commuting behavior and counterurbanization can extend.

The general hypothesis that stems from this analysis is that in thinly populated countries with only one CBD, such as Iceland, transportation improvements which reduce the distance from a county to the CBD tend to increase local house prices within the range of 165 kilometers from the CBD, but reduce house prices beyond that. The results suggest that the increase will be largest for counties close to the CBD than those which are farther away. However, given reasonable skepticism regarding the results for locations beyond 165 km from the CBD, further analysis would be recommended. The author himself is attempting to collect data for a comparable analysis based on Icelandic municipalities rather than counties. This would enlarge the number of data points (especially regarding distance) and improve their density.

Appendix I: Multicollinearity

The following tables show the correlation coefficients between the explanatory variables of the data samples behind the present analyses, one for each period and geographical area. The periods involved are 1981-2005 and 1995-2005. The areas are the entire country and the conurbation area. The correlation coefficients confirm that there are negligible internal correlations and there is no serious threat of multicollinearity (Table 7 and Table 8). However, in the sample for the conurbation area only, the test suggests multicollinearity between the variables for local population (POPU) and road distance (RDIS, see Table 9 and Table 10). No attempts were made to compensate for this, for several reasons. One of the reasons was that the model for the conurbation area was not essential for confirming the convexity of the relationship between local house prices and transportation improvements.

Table 7. Correlation test between explanatory variables for all counties, 1982-2005. 419 observations.

	RDIS	TINC	HAGE	HSIZ	TUNN	POPU	ALEA
RDIS	1.0000						
TINC	-0.0569	1.0000					
HAGE	0.0445	0.4132	1.0000				
HSIZ	0.0795	0.1096	0.1997	1.0000			
TUNN	0.1138	0.4898	0.4026	0.3443	1.0000		
POPU	-0.3530	0.1829	-0.0638	-0.2700	-0.1591	1.0000	
ALEA	0.1210	0.1484	0.0115	0.0087	0.1205	-0.0122	1.0000

Table 8. Correlation test between explanatory variables for all counties, 1995-2005. 208 observations.

	RDIS	TINC	HAGE	HSIZ	TUNN	POPU	ALEA	INBA	HNPP
RDIS	1.0000								
TINC	-0.0596	1.0000							
HAGE	0.1453	0.1025	1.0000						
HSIZ	0.1232	-0.2126	-0.0238	1.0000					
TUNN	0.2601	0.2348	0.2715	0.2239	1.0000				
POPU	-0.3448	0.2768	-0.1748	-0.3065	-0.2551	1.0000			
ALEA	0.1852	0.1543	-0.0451	-0.0264	0.0985	-0.0158	1.0000		
INBA	0.0212	-0.3581	-0.0525	0.0249	-0.1475	-0.0059	-0.1712	1.0000	
HNPP	0.2275	0.0350	0.2479	0.2083	0.3518	-0.0682	-0.0442	-0.1926	1.0000

Table 9. Correlation test between explanatory variables for the conurbation area, 1982-2005. 144 observations.

	RDIS	TINC	HAGE	HSIZ	TUNN	POPU	ALEA
RDIS	1.0000						
TINC	-0.3550	1.0000					
HAGE	0.0139	0.5748	1.0000				
HSIZ	0.2541	0.3304	0.5025	1.0000			
TUNN	0.0091	0.2923	0.3567	0.4449	1.0000		
POPU	-0.7977	0.2662	0.0236	-0.3817	-0.1826	1.0000	
ALEA	.	.	.	.	.	.	.

Table 10. Correlation test between explanatory variables for the conurbation area, 1995-2005. 66 observations.

	RDIS	TINC	HAGE	HSIZ	TUNN	POPU	ALEA	INBA	HNPP
RDIS	1.0000								
TINC	-0.4406	1.0000							
HAGE	0.4811	0.2040	1.0000						
HSIZ	0.5402	-0.1722	0.1630	1.0000					
TUNN	0.1114	0.0467	0.2635	0.3976	1.0000				
POPU	-0.7970	0.3617	-0.2661	-0.5686	-0.2928	1.0000			
ALEA	.	.	.	.	.	.	.		
INBA	0.0599	-0.4134	-0.0265	-0.0396	-0.0846	-0.0130	.	1.0000	
HNPP	-0.1402	0.2502	-0.0100	0.1263	0.2355	0.3623	.	-0.4028	1.0000

Appendix II: Theoretical model

According to Fujita (1989), the consumer maximizes his utility by choosing the best combination of lot size, *s*, and compensated goods, *z*, with respect to distance, *r*, when it comes to the choice of residence.

$$\max_{r,z,s} U(z,s),$$

The consumer maximizes his utility with respect to his budget constraint. The total expenditures are divided between the house price, *h*, compensated goods, *z*, and transport cost, *T*. Furthermore, house prices are dependent on the lot size, *s*, and distance, *r*, and the transport cost is obviously dependent on distances. Thus, the maximum problem becomes subject to the following constraint,

$$z + h(r)s = Y - T(r)$$

The bid-rent curve will be found by solving the following maximization problem, defined by the following Lagrange function,

$$L = U(z,s) - \lambda(Y - T(r) - z - h(r)s)$$

Thus, the first order condition becomes:

$$\frac{\partial L}{\partial z} = \frac{\partial U}{\partial z} + \lambda = 0 \quad (9)$$

$$\frac{\partial L}{\partial s} = \frac{\partial U}{\partial s} + \lambda\big(h(r)\big) = 0 \quad (10)$$

$$\frac{\partial L}{\partial \lambda} = Y - T(r) - z - h(r)s = 0 \quad (11)$$

Eq. 9 can be rewritten as:

$$\frac{\partial U}{\partial z} = -\lambda$$

Furthermore, Eq. 10 can be rearranged as follows,

$$h(s) = -\frac{\frac{\partial U}{\partial s}}{\lambda}$$

Thus, by embedding (6) into (7)

$$h(s) = \frac{\frac{\partial U}{\partial s}}{\frac{\partial U}{\partial z}}$$

Eq. 11 can be rewritten as

$$h(s) = \frac{Y - T(r) - z}{s}$$

The following definition is helpful at this point: “the bid rent *ψ(r,u)* is the maximum rent per unit of land that a household can pay for residing at distance *r* while enjoying a fixed utility level, *u*” (Fujita, 1989). Thus the relationship for the bid-rent curve becomes

$$\psi(r,u) = \max_{z,s}\left\{\frac{Y - T(r) - z}{s}\middle| U(z,s) = u\right\} \quad (12)$$

It can be confirmed, and should be rather obvious, that the maximum rent per unit of land is positively related to income, *Y*, and negatively related to distance, *r*, transport cost, *T*, compensated goods, *z*, and lot size, *s*.

According to Fujita (1989, pp. 16, 26; Kiel & McClain, 1995a, pp. 314-315) and Kiel and McClain, the general context from the basic model in Eq. 12 can be derived through a log linear utility function into an equation of the following form:

$$h(r) = Ae^{-br} \quad (13)$$

where *h* is the land value and *A* and *b* are positive constants. By taking the natural logarithm of both sides, Eq. 13 becomes

$$\ln h(r) = \ln A - br \quad (14)$$

This equation is commonly known in this field of research, as argued before.

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