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Effects on housing prices of urban attraction and labor-market accessibility

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Abstract. Through a hedonic approach the authors focus primarily on how house prices vary systematically with respect to some general spatial structure characteristics in a Norwegian region. The introduction of a gravity-based labor-market accessibility measure contributes significantly to explain variation in housing prices, and is used in a model formulation where the distance from the city center is accounted for. Based on these results we suggest a distinction between an urban-attraction effect and a labor-market accessibility effect. Quantitatively, the two distinct effects are found to contribute about equally to intraregional variation in housing prices.

1 Introduction

It is well recognized in the literature that house prices vary systematically with respect to some general characteristics of the spatial structure in a region. One such characteristic is the location of jobs. For a long time the relationship between labor-market accessibility and housing prices has been given a lot of attention in the housing-market literature, and it is often a basic part of spatial equilibrium models in regional science and urban economics. The standard theoretical reference for the relationship is the 'access – space-trade-off' model of Alonso (1964). This model is based on the assumption that all jobs are located in the city center, and labor-market accessibility is represented by the distance to this central business district (CBD). Although the modeling framework has been extended in several directions and adapted for regions with multiple centers (see, for instance, Richardson, 1988), many theoretical and empirical studies are pivoted on the central idea of the access – space-trade-off model, which suggests that house prices fall with increased distance from the city center.

The analysis in this paper is based on data from the southern parts of Rogaland County in the southwest of Norway. This region represents a relatively self-contained labor market, with a dominating city (Stavanger) which influences the economic situation and labor-market decisions in all other parts of the region. Since our analysis is focused on the interaction between the labor market and the housing market, it is reasonable to consider a regional rather than an urban perspective. Our study area is also very appropriate because topographical barriers deter interaction with adjacent areas.

Job opportunities are definitely not completely concentrated in the Stavanger CBD, even in this rather monocentric geography. Motivated by this fact, we introduce a gravity-based labor-market accessibility measure in an attempt to deal explicitly with polycentric tendencies in the spatial structure. Our basic hypothesis is that this measure is a better representation of the trade-off between community costs and housing consumption than is distance from the CBD.

It is intuitively reasonable that labor-market accessibility and potential commuting distances are important determinants of how readily saleable a house is, and the price that is achieved. It is also obvious that households also value high accessibility to activities other than their job. Our data do not allow us to enter into details concerning nonwork activities, but we proceed through the hypothesis that the dominating city center has a particularly high density of relevant attractions. We attempt to find how this is reflected in house prices when labor-market accessibility is accounted for by a separate measure. Are both the labor-market accessibility measure and the distance from the CBD relevant spatial characteristics in an explanation of housing prices? Do housing prices also tend to be negatively related to the distance from the CBD in such an approach? If so, how does this fit with the standard interpretation that housing-price gradients falling with increasing distance from the CBD reflect the trade-off between housing consumption and commuting costs? By addressing such questions, we aim to contribute to an improved understanding of systematic spatial variation in housing prices.

In addition, it is also our aim to offer quantitative estimates of how general spatial structure characteristics affect housing prices. The market evaluation of accessibility represents an important input in urban and regional planning in, for instance, the development of decentralized employment centers. Research based on the hedonic framework in general offers useful information on the valuation of goods which are not directly bought and sold in markets.

In section 2 we review some relevant contributions in the literature. The region and our data are described in section 3, and the basic modeling setup is presented in section 4. The results are presented in section 5 and in section 6 we offer some concluding remarks.

2 Some relevant contributions in the literature

The Alonso (1964) model has increasingly been criticized by researchers who claim that workplaces are not solely located in the city center, and that trips to work encompass a declining share of overall household traveling. Experience has also proved that making reliable empirical studies of the relevant relationship is not straightforward. The polycentric nature of many housing-market areas represents one kind of complexity, affecting in particular the use of one-dimensional separation measures like physical distance and traveling time from a distinctly defined center. The presence of multiple-worker households and multiple workplaces motivate the use of alternative separation measures. As stated by Heikkila et al:

> "with multiple-worker households, multiple workplaces are common; given a high degree of residential mobility, sites offering accessibility to many employment nodes are more valuable because it is not very likely that successive owners will work in the same workplace" (1989, page 222).

With a very spatially dispersed distribution of employment opportunities it might even prove difficult to find a significantly falling housing-price gradient within an area. Heikkila et al (1989), for instance, using data from the Los Angeles (LA) area, found that distance to the CBD had a very low *t*-value and unexpected sign, and they claimed that the impact of workplace accessibility has been overemphasized. Richardson et al (1990) found a significantly negative value of the coefficient related to distance from the LA CBD in 1970; and this variable was found not to influence house prices in 1980. More recently, McMillen (2003) has discussed the steady decline in the importance of the CBD in American cities in the 1980s, while data from the 1990s show the opposite. Waddell et al (1993) emphasized the importance of including the distance to secondary employment centers, and Dubin and Sung (1987) have advocated the use of alternative measures of employment accessibility other than one-dimensional measures of distance.

An appealing hypothesis is that model performance improves substantially if a gravity-based accessibility measure is introduced to account for the possibility that the relevant kind of spatial pull originates from several locations. Adair et al (2000) introduced a sophisticated gravity-based measure of transport accessibility in a hedonic model to explain house prices in the Belfast urban area. Their measure distinguishes between two person types (according to car availability) and three trip purposes (work, nonhome based, and others). They found that transport accessibility had a minimal effect upon house prices in the Belfast urban area. In a logarithmic model specification, the accessibility index appeared to be significant but accounted for a very small percentage of the variation in housing prices: specific physical housing attributes and socioeconomic variables appeared to be a lot more influential. Nevertheless, they found that transport accessibility did have a considerable impact on housing prices within some submarkets.

As stated by Cheshire and Sheppard (1997), data used in hedonic studies often lack information on location characteristics. In studies where such characteristics are accounted for, the conclusion frequently is that accessibility to different services and amenities only marginally affects housing prices (see, for instance, Adair et al, 2000; Henneberry, 1996). Cheshire and Sheppard conclude that potential buyers do not put much weight on characteristics of the road transportation network, implying that investments in road infrastructure only marginally increase property values. According to Laakso (1997), the majority of studies are of cities and urban areas in the USA. Laakso offers a summary of eighteen empirical studies on housing prices, rents, and land prices in the urban economics literature since 1979. All these studies use hedonic models. According to Laakso (1997) and Sandberg (2004), the number of published empirical studies on European cities is small. Combined with the fact that approaches and results vary considerably, this explains the need for further research in this area.

3 The region and the data

3.1 The region

The southern parts of Rogaland represent an integrated region with a connected road transportation network. There are thirteen municipalities in the region, and each municipality is divided into postal delivery zones. Altogether the region is divided into ninety-eight postal delivery zones, as indicated in figure 1. The appendix provides a list of municipalities and postal delivery zones, with corresponding figures of population and employment in 2001. As an indicator of commuting distances, it is 79 km from the center of Stavanger to the center of Eigersund in the south.

The region is delimited by the North Sea in the west, fjords in the north and the northeast, and the southern and southeastern delimitation is an administrative county border in a sparsely populated, mountainous area. Hence, the demarcation of the region is mainly determined by natural boundaries. This is advantageous, since it is thus reasonable to ignore effects from circumstances outside the region (see, for instance, Upton and Fingleton, 1985). The areas in the region are heavily interrelated through significant commuting flows. This also makes the region well suited to studies focusing on the relationship between the labor and housing markets. The region is also relatively monocentric, in the sense that the city center of Stavanger has a dominant position concerning the supply of specific urban facilities, represented for instance by leisure and cultural services, and by shopping opportunities. The area has not developed into the characteristic multinodal structure observed in many metropolitan areas. As indicated by the figures in the appendix, however, the spatial distribution of jobs does not correspond to the assumption of concentration underlying the basic version of the 'access – space-trade-off' model. The region we are studying is economically the most prosperous in Norway. Property-tax rates are uniformly distributed over the area, crime rates are low, and systematic variation in the quality of primary and middle schools can be ignored. For more details, see Osland et al (2005).

Figure 1. The division of the southern Rogaland region into municipalities, and postal delivery zones (indicated by numbers).

3.2 Data

The housing-market data comprise transactions of privately owned single-family houses in the period from 1997 through the first half of 2001. Our sample of 2788 property transactions represents approximately 50% of the relevant population. The reason why the sample is not larger relates mainly to missing information on independent variables. It may be that missing information could be somewhat more prevalent among the oldest houses in the sample. For the remaining variables we have no reason to believe that there is a sample-selection bias. The data on housing prices and housing attributes come from two different sources: Statistics Norway and the national land register in Norway. The data from Statistics Norway come from a questionnaire that is sent to everyone who has bought a freehold dwelling in Norway. According to Statistics Norway, the response rate on this questionnaire is 80%. The data are hence considered to be very reliable. The representativeness of the sample and the quality of the different data sources have been evaluated by comparison with a third data source, provided for us by local real estate agents. For further details on the data, descriptive housing market statistics for separate parts of the region, and on the region in general, see Osland et al (2005).

The division of the region into zones corresponds to the most detailed level of information that is officially available on the residential and work locations of each individual worker within the region. The information is based on the Employer–Employee register, and was provided by Statistics Norway. Data restrictions represent the main reason why we consider a relatively macroscopic description of the geography. Nevertheless, we doubt that the additional insight and explanatory power resulting from a more disaggregated representation of the geography would reflect the massive effort and resources required in collection of these data.

The matrices of Euclidean distances and traveling times were prepared for us by the Norwegian Mapping Authority, which has at its disposal all the required information on the road network and spatial residential pattern. The calculations were based on the specification of the road network into separate links, with known distances and speed limits, and accounted for the fact that actual speeds depend on road category. Information about speed limits and road categories was converted into traveling times via a method worked out by the Institute of Transport Economics, with adjustment factors for specific road categories. The center of each postal delivery zone was found from detailed information on residential densities and the road network. Both the matrix of distances and the matrix of traveling times were constructed from a shortest-route algorithm.

4 The modeling framework

In this section we start by presenting the list of structural nonspatial attributes that are incorporated in the alternative model formulations. As a next step, the specific functional representation of distance from the CBD is explained before we suggest alternative measures of labor-market accessibility for the empirical analysis.

4.1 The basic setup

In this paper we focus on the impact of the housing location relative to the CBD and to labor-market opportunities, rather than on specific nonspatial attributes of a residence. We do not attempt to account, for example, for accessibility to recreational facilities and shopping opportunities, and we do not account for environmental conditions, location-specific amenities, or aesthetic attributes. This is partly because we are concerned with interzonal rather than intrazonal variations in housing prices. If variations in housing prices within a postal delivery zone were to be considered, it would be relevant to account for the position relative to shopping and recreational facilities, schools, main roads, environmental conditions, the view, etc. Our approach is implicitly based on the assumption that such housing-specific and location-specific (microlocational) attributes do not vary systematically across the zones: they are reasonably equally present in most of the postal delivery zones that we consider. In other words, we implicitly assume that the regional variation in such attributes can also be found within a zone, and that there is insignificant spatial variation in zonal average values. Hence, we do not account for the impact of intrazonal location-specific amenities and services in our macroscopic approach to the problem. Similarly, we do not model the impact on housing prices of systematic variation in zonal socioeconomic characteristics. This may lead to minor problems with spatial autocorrelation in the residuals. Labor-market accessibility, on the other hand, represents a location-specific characteristic with considerable interarea variation that is accounted for in our explanation of housing prices.

We distinguish between two categories of attributes. One category is the physical or structural attributes of the specific dwelling; the other concerns its location relative to the CBD and to labor-market opportunities. In a corresponding general form, the hedonic price equation can be written as follows:

$$P_{it} = \mathrm{f}(z_{sit}, z_{lit}) \ , \tag{1}$$

where

P_{it} is the price of house i in year t;

z_{sit} is the value of dwelling-specific structural attribute s for house i in year t; $s = 1, \ldots, S$, $i = 1, \ldots, n$;

z_{lit} is the value of location-specific attribute l for house i in year t; $l = 1, \ldots, L$, $i = 1, \ldots, n$.

The rest of this section is organized according to this distinction between the two categories of attributes. For a separate discussion of nonspatial modeling alternatives, see Osland et al (2007). In this paper the challenge is how to represent characteristics of the geography in spatial modeling alternatives. Osland et al (2007) also considered model performance for different spatial delimitations of the housing market, and experimented with different mathematical representations of the relationship between dependent and independent variables, as well as different measures of spatial separation (physical distance and traveling time). In this paper we take as our starting point a model specification in which spatial separation is measured by traveling time. The dependent variable and all nonspatial independent variables, except the dummy variables are represented by their logarithms in the hedonic regression model. Table 1 gives a list of nonspatial dwelling-specific attributes incorporated in our modeling framework.

In addition to the dwelling-specific attributes, we introduce the variable RURLOT into our regression model specifications. This variable is based on a stratification of the

Table 1. List of nonspatial dwelling-specific variables.

Variable	Operational definition
REALPRICE	selling price deflated by the consumer price index, base year is 1998
AGE	age of building
LIVAREA	living area measured in square meters
LOTSIZE	lot size measured in square meters
GARAGE	dummy variable indicating presence of garage
NUMBTOIL	number of toilets in the building
REBUILD	dummy variable indicating whether the building has been rebuilt or renovated

geography into rural and urban areas. The rural areas include four municipalities: Gjesdal, Bjerkreim, Lund, and Sokndal (for details and criteria see Osland et al, 2005). RURLOT is defined to be the product of the dummy variable representing rural areas (RUR) and the variable LOTSIZE, defined in table 1. Osland et al (2007) found that this variable, reflecting characteristics of the spatial structure, increased the explanatory power of the model significantly and reduced the problems of spatial heterogeneity. Testing the joint significance of the two variables LOTSIZE and RURLOT by a Wald test indicated significant differences in the elasticities of LOTSIZE in the rural and nonrural areas.

4.2 A model incorporating the traveling time from the CBD

The journey to work is an important kind of spatial interaction that is explicitly included in this paper. Despite the tendency for workplace traveling to represent a relatively small part of total traveling, such trips are more tied up than other trips in the time and money budgets of households. Osland et al (2007) offer results of an empirical housing-market study based on a hedonic function where the spatial separation between jobs and houses is represented by the distance from the CBD. Distances are measured relative to the core of the Stavanger CBD. The region has to a large degree developed with employment growth in and close to the dominating city center (Stavanger). It is probably hard to find geographies that come much closer to the construction in the access – space-trade-off model than this monocentric city in a featureless plain landscape. This means that even an approach based on a one-dimensional representation of spatial separation potentially offers reliable parameter estimates reflecting the access – space-trade-off, rather than local characteristics of the central place system.

Osland et al (2007) found that the use of more complex and flexible functional specifications of traveling time contributes significantly to explanatory power compared with a one-parameter approach. In addition, the more flexible forms are found to represent a more reliable basis for predicting housing-price gradients. The results presented in Osland et al (2007) do not distinguish clearly between the alternative flexible function approaches. Based on explanatory power in combination with pragmatic, theoretical, econometric, and interpretational arguments, however, they recommended a power function specification supplemented by a quadratic term. According to this approach, traveling time appears in the regression equation through the following expression:

$$\mathrm{h}(d_{ij}) = d_{ij}^{\beta}[(d_{ij})^2]^{\beta_q} ,$$

where d_{ij} is the distance (measured in minutes) between zone j (in this case the CBD) and zone i; the β are parameters to be estimated: β_q is the estimated parameter in relation to (distance)^2.

The results achieved from this model specification are shown below in table 2, as a benchmark for evaluating models incorporating characteristics of spatial structure other than traveling time to the CBD. Hence, model M1 in the table is defined as follows:

Model M1: traveling time to the CBD is represented by a power function that is supplemented by a quadratic term.

4.3 Models incorporating a measure of regional labor-market accessibility

Our main aim is to reveal and explain systematic spatial variation in housing prices. According to the idea of a trade-off between housing prices and commuting costs, we need a measure representing the spatial separation between residents and job opportunities. As was made clear in the introduction, many authors have focused on the fact that not all workers commute to the CBD. One approach to this problem is to define employment rings around the CBD, combined with information about systematic spatial variation in individual incomes (see Yinger, 1979). We have not accounted for socioeconomic characteristics in specific location alternatives, since we doubt that strongly regular and systematic spatial patterns can be found in this economy with its rather uniform distribution.

Though the geography that is considered is appropriate for empirical studies of the access – space-trade-off model, there area some multicentric and multinodal tendencies. Rather than introduce employment rings around the city center we attempt to capture the impact of such characteristics through a gravity-based accessibility measure. The basic hypothesis is that workers prefer a location with favorable job opportunities within a reasonable distance of their home. Hence, labor-market accessibility influences the number of households bidding for a house that is for sale—explaining spatial variation in housing prices. The standard type of accessibility measure refers to Hansen (1959). Assume that distance appears through a negative exponential function, and let σ_e be the weight attached to distance; $\sigma_e < 0$. The Hansen type of accessibility measure, S_j is then defined as follows:

$$S_j = \sum_{k=1}^{w} D_k \exp(\sigma_e d_{jk}) \ . \tag{2}$$

Here, D_k represents the number of jobs (employment opportunities) in destination (zone) k, and d_{jk} is the distance between zones j and k (measured in minutes). The measure S_j is based on the principle that the accessibility of a destination is a decreasing function of relative distance to other potential destinations, where each destination is weighted by it size or, in other words, the number of opportunities available at the specific location. Hence, it can be interpreted as an opportunity-density function, and used to account for the possibility that the relevant kind of spatial pull originates from several destination opportunities. In the appendix we give estimates of the relative labor-market accessibility of all the zones in our study, defined by

$$S_j \Big/ \frac{1}{98}\sum_{j=1}^{98} S_j \ .$$

Accessibility measures are widely used in the literature on spatial interaction problems. The concept was first explicitly introduced by Fotheringham (1983), who defined the so-called 'competing destinations' model of spatial interaction. Several parametric and functional formulations of accessibility measures can be found in the literature. On the basis of commuting-flow data from Western Norway, Thorsen and Gitlesen (1998) demonstrated that the evaluation of a spatial interaction model depends on the formulation of the accessibility measure. They argued, for instance, that a parameter should be attached also to the number of job opportunities, D_k, and the introduction of this parameter was found to add significantly to the explanation of the commuting-flow pattern. With an interpretation in terms of the access – space-trade-off theory this also represents a natural alternative in an explanation of spatial variation in housing prices, corresponding to the accessibility measure

$$S_j^e = \sum_{k=1}^{w} D_k^{\gamma_e} \exp(\sigma_e d_{jk}) \ .$$

Another class of accessibility measures are the cumulative-opportunities measures. As formulated by Handy and Niemeier (1997), such a measure is defined by the number of opportunities reached within a given travel time (or distance). Given our rather aggregate subdivision of the geography, with some zones covering large areas, this very simple definition of accessibility is not appropriate for an accurate specification of regional accessibility. An alternative, gravity-based specification is to introduce the weighted average distance to job opportunities as a measure of labor-market accessibility. Let each zone be weighted by the fraction between the number of jobs located here and the total number of jobs in the region (D). The average distance to job opportunities is then defined by

$$\bar{d}_j = \sum_k \frac{D_k}{D} d_{jk} ,$$

and this intuitively appealing measure can be introduced as an independent variable in the model formulation.

The average distance of job opportunities, $\bar{d}_j$, can be used as a starting point for defining other labor-market accessibility measures. A parameter can be attached to distance, reflecting the possibility that nearby potential labor-market destinations are not given the same weight as more distant potential labor-market destinations in the definition of accessibility. This leads to a measure of labor-market accessibility that is numerically equivalent to S_j in equation (2), apart from the fact that the distance term is now represented by a power-function specification. In our empirical studies we also add a parameter to the number of job opportunities in this power function approach, defining the accessibility measure

$$S_j^{\mathrm{p}} = \sum_{k=1}^{w} D_k^{\gamma_{\mathrm{p}}} d_{jk}^{\sigma_{\mathrm{p}}} .$$

Corresponding to the alternative measures of labor-market accessibility proposed above, we test the following model alternatives:

Model M2—labor-market accessibility is represented by a traditional Hansen accessibility measure S_j;

Model M3—labor-market accessibility is represented by S_j^{e};

Model M4—labor-market accessibility is represented by the weighted average distance to job opportunities, $\bar{d}_j$;

Model M5—labor-market accessibility is represented by S_j^{p};

Model M6—M1 extended by the labor-market accessibility measure S_j^{e};

Model M7—M1 extended by the labor-market accessibility measure S_j^{p}.

The alternative accessibility measures are introduced log-linearly in the corresponding hedonic regression models. Referring to M6 as an example, this means that the hedonic regression formulation is given by:

$$\begin{aligned} \ln P_{it} = {} & \beta_0 + \beta_1 \ln \mathrm{LOTSIZE}_i + \beta_2 (\mathrm{RUR} \ln \mathrm{LOTSIZE})_i + \beta_3 \ln \mathrm{AGE}_i \\ & + \beta_4 (\mathrm{REBUILD} \ln \mathrm{AGE})_i + \beta_5 \mathrm{GARAGE}_i + \beta_6 \ln \mathrm{LIVAREA}_i \\ & + \beta_7 \ln \mathrm{NUMBTOIL}_i + \beta \ln \mathrm{TIMECBD}_i + \beta_q (\ln \mathrm{TIMECBD}_i)^2 \\ & + \beta_8 \ln \mathrm{ACCESSIBILITY}_i + \sum_{t=97}^{01} \beta_t \mathrm{YEARDUM}t_i + \varepsilon_{it} , \end{aligned} \qquad (3)$$

where TIMECBD is the distance from the CBD (measured in minutes traveling by car and accounting for speed limits); ACCESSIBILITY is access to workplaces; YEARDUM is a dummy variable indicating the year a house is being sold; and ε_{it} is the error of disturbance for a specific observation.

Except for M1 and M4, which are estimated by ordinary least squares (OLS) estimation, the models are estimated by the method of maximum likelihood. The reported statistics corresponding to those models are computed by way of OLS estimation, on the basis of imputed values of the estimated parameter(s) inside the different accessibility indicators. Contrary to, for instance, Adair et al (2000) and Handy and Niemeier (1997), all parameters are estimated simultaneously rather than through a stepwise procedure in which values of the accessibility measure are estimated from commuting-flow data before they are entered into the hedonic housing model.

5 Results

5.1 An evaluation of the alternative model formulations

Our estimation results are presented in table 2. For the model evaluation we report the values of alternative goodness-of-fit statistics. Besides R^2 (and the adjusted R^2) we have included the log-likelihood value (L), the average prediction error

$$\text{APE} = \frac{1}{n}\sum_i |\hat{P}_i - P_i| ,$$

where $\hat{P}_i$ is the predicted price of house i, and n is the observed number of houses, and the standardized root mean square error (SRMSE). We obtain positive values of log-likelihood, reflecting a case where the density function has a very small variance, allowing for density values exceeding 1.0. Such cases are typically met in problems where dependent variables are defined for a relatively small range of high values. The logarithm of housing prices defines a function that is very flat for the relevant range of values, with correspondingly small variance.

The analysis below is based on the use of pooled cross-section data. This explains the introduction of the time dummies in our models. The advantage of this procedure is that it enables an increase in sample size, and greater variations in the independent variables.

Consider first the modeling alternatives M1 – M5. According to these results, approaches based on an accessibility measure lead to poorer goodness of fit than the approach based on the one-dimensional measure of spatial separation underlying M1. In addition, the accessibility measure does not reduce problems related to spatial autocorrelation in the residuals to the same degree as does travel time from the CBD. Hence, labor-market accessibility is not a satisfactory alternative to travel time to the CBD in explaining variation in housing prices in our data. An accessibility measure probably adds more to the explanatory power in a more multicentric geography than the one we consider here.

Besides this general conclusion, we also comment on some specific results in table 2. Notice first that the estimated impact of attributes other than those related to spatial separation and accessibility appears to be relatively invariant with respect to how spatial characteristic are introduced into the model. In particular, the differences are small when we compare the models that perform best with respect to explanatory power: M1 and M6, for instance, only result in minor differences in nonspatial parameter estimates. The differences are larger when M6 estimates are compared with the less satisfactory M4: see, for example, the parameter estimate reflecting the partial impact of LOTSIZE on housing prices. It is in general reasonable that any parameter estimate is more reliable the better the model captures relevant determinants of the dependent variable. Since LOTSIZE is positively correlated with travel time to the CBD, it is also reasonable that the estimated parameter attached to LOTSIZE is negatively biased—especially in approaches where the travel time to the CBD is not accounted for.

The additional parameter related to the number of employment opportunities in the Hansen measure of labor-market accessibility was found to add significantly to the goodness of fit. All the measures of explanatory power have more satisfying values in M3 than in M2. According to our results, the choice between a power-function and an exponential-function specification of distance in the accessibility measure is essentially a pragmatic one. Nevertheless, the approach based on the exponential

Table 2. Results based on alternative specifications of spatial separation and spatial structure characteristics, with robust standard errors shown in parentheses.

	Model						
	M1	M2	M3	M4	M5	M6	M7
Constant	11.9236	9.1807	11.0212	13.1237	31.6836	11.1835	31.1404
	(0.0892)	(0.1147)	(0.0873)	(0.1064)	(0.6256)	(0.1687)	(4.6024)
LOTSIZE	0.1259	0.0958	0.1057	0.0816	0.0988	0.1308	0.1302
	(0.0101)	(0.0098)	(0.0098)	(0.0097)	(0.0097)	(0.0099)	(0.0099)
RURLOT	−0.0299	−0.0269	−0.0315	−0.0390	−0.0355	−0.0271	−0.0297
	(0.0032)	(0.0032)	(0.0032)	(0.0032)	(0.0031)	(0.0031)	(0.0031)
AGE	−0.0828	−0.0677	−0.0717	−0.0632	−0.0701	−0.0849	−0.0852
	(0.0066)	(0.0064)	(0.0064)	(0.0064)	(0.0064)	(0.0066)	(0.0066)
AGE × REBUILD	0.0106	0.0116	0.0119	0.0131	0.0124	0.0104	0.0107
	(0.0029)	(0.0031)	(0.0030)	(0.0031)	(0.0031)	(0.0029)	(0.0029)
GARAGE	0.0677	0.0527	0.0549	0.0553	0.0562	0.0645	0.0658
	(0.0110)	(0.0115)	(0.0113)	(0.0116)	(0.0114)	(0.0108)	(0.0109)
LIVAREA	0.3583	0.3755	0.3643	0.3733	0.3697	0.3552	0.3572
	(0.0177)	(0.0182)	(0.0179)	(0.0183)	(0.0180)	(0.0177)	(0.0176)
NUMBTOIL	0.1516	0.1475	0.1454	0.1531	0.1499	0.1475	0.1495
	(0.0147)	(0.0153)	(0.0151)	(0.0154)	(0.0152)	(0.0146)	(0.0146)
TIMECBD(β)	−0.0679	–	–	–	–	−0.1095	−0.0941
	(0.0213)					(0.0218)	(0.0216)
$(\text{TIMECBD})^2(\beta_q)$	−0.0298	–	–	–	–	−0.0104	−0.0185
	(0.0041)					(0.0053)	(0.0047)
ACCESSIBILITY	–	0.2410	0.2352	−0.4541	2.6071	0.0776	2.7270
		(0.0083)	(0.0067)	(0.0145)	(0.0790)	(0.0159)	(0.6520)
σ_e	–	−0.0862	−0.1442	–	–	−0.1088	–
		(0.0051)	(0.0108)			(0.0403)	
γ_e	–	–	0.0637	–	–	1.0963	–
			(0.0534)			(0.2452)	
σ_p	–	–	–	–	−0.1685	–	−0.0320
					(0.0202)		(0.0133)
γ_p	–	–	–	–	0.3997	–	0.3683
					(0.1004)		(0.1050)
YEARDUM97	−0.1333	−0.1370	−0.1343	−0.1337	−0.1340	−0.1362	−0.1342
	(0.0135)	(0.0140)	(0.0138)	(0.0141)	(0.0139)	(0.0135)	(0.0134)
YEARDUM99	0.1294	0.1297	0.1308	0.1325	0.1329	0.1297	0.1303
	(0.0137)	(0.0144)	(0.0142)	(0.0142)	(0.0143)	(0.0136)	(0.0136)
YEARDUM00	0.2686	0.2721	0.2692	0.2700	0.2713	0.2700	0.2700
	(0.0135)	(0.0142)	(0.0138)	(0.0143)	(0.0140)	(0.0135)	(0.0135)
YEARDUM01	0.3029	0.2984	0.3016	0.2979	0.3003	0.3030	0.3039
	(0.0136)	(0.0144)	(0.0140)	(0.0145)	(0.0142)	(0.0136)	(0.0136)
n	2788	2788	2788	2788	2788	2788	2788
R^2	0.7381	0.7123	0.7212	0.7061	0.7157	0.7409	0.7401
R^2-adjusted	0.7368	0.7110	0.7205	0.7048	0.7144	0.7396	0.7387
L	281.65	150.79	197.39	121.18	167.29	296.79	292.27
APE [a]	217094	234171	229605	241484	235102	215690	216469
SRMSE [b]	0.2046	0.2186	0.2147	0.2235	0.2186	0.2035	0.2040
White test statistic	264.59	268.74	259.53	258.90	258.90	281.47	293.38
Moran's I	0.0189	0.0804	0.0551	0.0926	0.0708	0.0080	0.0056
Standard normal deviate (z_1)	7.13	43.36	29.86	49.94	38.26	5.28	3.95
LM-ERROR [c]	32.79	1500.87	704.26	1988.76	1161.40	14.87	7.39
LM-LAG	7.98	127.91	40.99	147.34	75.14	8.04	4.58
RLM-ERROR [d]	26.54	1374.86	663.73	1842.137	1086.55	10.33	4.97
RLM-LAG	1.73	1.90	0.47	0.72	0.29	3.51	2.16
Ramsey reset test (p value)	0.8287	0.004	0.4673	0.1856	0.3503	0.8572	0.8883
VIF, average value [e]	4.22	1.49	1.48	1.47	1.48	5.83	4.86

Note: Results based on observations from the period 1997–2001. The null hypothesis of no spatial effect is rejected at the 5% significance level if $z_t > 1.645$; the critical value of the LM test statistics are 3.84 at the 5% significance level. [a] APE—average prediction error. [b] SRMS—standardized root mean square error. [c] LM—Lagrange multiplier. [d] RLM—robust Lagrange multiplier. [e] VIF—variance inflation factor.

function specification (M6) performs marginally better in all the goodness-of-fit indices. Hence, in the rest of this paper we use M6 rather than M7 to discuss the impact of labor-market accessibility on housing prices.

White's general test (see, for instance, Greene, 2003) was performed to test for heteroskedasticity. Since $\chi^2_{0.05} = 16.919$ it follows from table 2 that the hypothesis of homoskedasticity is rejected in all model specifications. In order to make reliable inferences on the least-square estimates when heteroskedasticity is present, the reported standard errors in all models were estimated by a robust estimator of variance. In our data, however, this robust estimator of variance did not produce results that deviate much from estimates based on the ordinary least squares estimator.

Moran's I statistic was used to test for spatial effects in the residuals (Anselin, 1988). This statistic was calculated from a binary row standardized weight matrix, where zones were defined as neighbors if they have a common border. All observations within a postal delivery zone were also defined as neighbors. The standard normal deviate z_i is constructed from the mean and the variance of the Moran statistic (Anselin, 1988). According to the results in table 2, this null hypothesis is rejected in all models. The Moran's I test results do not point to any specific alternative hypothesis, and further testing is therefore needed in order to be able to determine whether the result stems from spatial autocorrelation in the dependent variable or spatial heterogeneity. Lagrange multiplier (LM) tests and robust LM (RLM) tests are commonly used for this purpose. The values of those test statistics are reported in table 2. For more information on those test statistics see, for instance, Florax and de Graaff (2004). According to the values reported in table 2, spatial heterogeneity is a problem in all the models. Notice, however, that the values of the relevant test statistics show that the introduction of an appropriate measure of spatial structure reduces the problems related to spatial autocorrelation in the residuals.

The reasons for spatial heterogeneity could be incorrect functional forms, spatially varying parameters, heteroskedasticity, measurement errors, and/or the use of more ad hoc spatial units of observations; and spatial heterogeneity is almost certain to be found in this kind of analysis (Anselin, 1988). To test for possible effects of spatial heterogeneity we also performed experiments in which a spatial autoregressive process was included in the error. The results from these experiments indicate that spatial heterogeneity does not have noticeable effects on the estimated parameters and their standard errors: the estimates do not differ significantly from the OLS estimates. We do not enter into details on those experiments in this paper.

We also report the p-values of the Ramsey reset test (see, for instance, Davidson and MacKinnon, 1993; Wooldridge, 2002). This is a misspecification test of neglected nonlinearity in the specified model. The null hypothesis of a correctly specified linear model is rejected in M2. Given the existence of spatial autocorrelation in the residuals, the result of this F-test should, however, be treated with care.

Table 2 also shows the average variance inflation factor (VIF) values for the alternative model formulations. It can be shown that VIF values indicate how much the variances of the estimated coefficients are inflated by multicollinearity (Greene, 2003): a value of 1 indicates no multicollinearity. According to Studenmund (2001), multicollinearity is often characterized as severe is VIF > 5; Kennedy (2003) suggests that VIF > 10 indicates harmful collinearity. In our study, VIF values naturally are highest in M1, M6, and M7, due to the high correlation between the variables travel time to the CBD and its square. Another reason for the high VIF values is the relatively high correlation between zonal values of travel time to the CBD and the labor-market accessibility measure. The individual VIF values for the labor-market accessibility measure and the travel time to the CBD are estimated to be 7.71 and 22.25, respectively.

Multicollinearity is, however, defined for linear relationships between independent variables. If the quadratic term is excluded from the calculations, the VIF values are 4.13 for the accessibility measure and 4.22 for the travel time to the CBD. Due to the presence of the quadratic term in the specification of spatial separation, the average VIF values reported in table 2 represent a positive bias of the multicollinearity involved. Since our results still do not indicate harmful collinearity, we do not discuss those matters in any detail. We would mention, however, that the correlation between zonal values of the labor-market accessibility measure and the travel time to the CBD is 0.859. As indicated by the figures in the appendix, the proportion of work trips directed to the CBD is not particularly high in this region; the concentration of 'urban attractions' in the CBD is considerably higher.

Osland et al (2007) demonstrated that explanatory power increased considerably when the distance from the CBD was represented in the regression equation by a more flexible mathematical function than the simple exponential or power function. We have also experimented with the mathematical specification of the accessibility measure in the regression equation, for example, by supplementing by a quadratic term for a power function representation. Such attempts, however, only resulted in very marginal changes in explanatory power and estimated coefficients.

As mentioned above, our results do not recommend a labor-market accessibility measure as an appropriate alternative to travel time to the CBD in the regression model. This does not mean, however, that such a measure is not relevant in a model explaining spatial variation in housing prices. Compared with a nonspatial approach, a model with labor-market accessibility as the only measure of spatial structure contributes considerably to explaining variations in housing prices [results based on nonspatial approaches are presented in Osland et al (2007)]. R^2 increases from around 0.52 in a nonspatial model formulation to around 0.72 when labor-market accessibility is included (M3). This increase in goodness of fit might, of course, be explained to some degree by a tendency that labor-market accessibility captures effects of omitted variables, like the distance from the CBD.

In comparing M6 with M1, it is seen that labor-market accessibility also contributes significantly to the explanatory power in a model that tests for the simultaneous impact of labor-market accessibility and the relevant one-dimensional measure of spatial separation (TIMECBD). The value of the likelihood ratio test statistic is 30.28, which clearly exceeds the critical value of a χ^2 distribution with three degrees of freedom. It also follows from table 2 that labor-market accessibility is statistically significant. The two coefficients in the accessibility measure are also estimated to be statistically significant, with values of the *t*-statistic of 2.7 (t_{σ_e}) and 4.5 (t_{γ_e}). Hence, our results indicate that a measure of labor-market accessibility captures relevant characteristics of the geography that are not captured by travel time to the CBD. As mentioned in the introduction, Adair et al (2000) for instance concluded that transport accessibility has a minimal effect upon house prices in the Belfast urban area. This conclusion is reached despite the fact that location was not taken into account through other variables such as, for instance, the distance from the city center. Hence, Adair et al's results are strongly contradicted in our study, which is based on observations from a regional labor-market and housing-market area. In our opinion it is important to specify a connected labor market area in a study focused on the trade-off between commuting costs and housing prices, and we find our study area to be very appropriate for this purpose.

5.2 A decomposition of the spatial variation in housing prices

Our sample size is large enough to allow us to distinguish between the impact both of the labor-market accessibility measure and of travel time to the CBD. As mentioned above (section 5.1), multicollinearity does not represent a serious problem in our study.

Despite the fact that the region is relatively monocentric, jobs are considerably more evenly scattered across space than are specific urban services and facilities, such as cinemas and restaurants. The trade-off theory is basically motivated by labor-market considerations. Hence, a reasonable hypothesis is that the estimated impact of labor-market accessibility reflects the trade-off between housing prices and commuting time. The estimated partial impact of distance from the CBD then reflects a general urban attraction effect; the proximity to specific urban facilities and urban services represent an attribute that increases the willingness to pay for a house, ceteris paribus.

Our point is illustrated in figure 2, in which both lines refer to a standard house. The standard house is defined as not being rebuilt, having a garage, not located in a rural area, and the price refers to the year 2000. Lot-size, age, living area, and the number of toilets are given by their average values. The solid line in this figure represents a prediction of how the price of the standard house depends on the travel time to the CBD in a case where no explicit measure of labor-market accessibility is taken into account. In other words, this predicted housing price gradient is based on parameter estimates from M1.

The dashed line in figure 2 is based on parameter estimates from M6. This line is not an ordinary housing price gradient, however, and should be interpreted with care. It refers to the same standard house described above, but the corresponding low values of housing prices reflect that the accessibility index is given the value of zero. Hence, attention should be paid to the predicted *changes* in housing rather than to the price level. The changes in housing prices predicted by the dashed line in figure 2 correspond to the urban attraction effect rather than the effect of variation in labor-market accessibility. According to our results, the urban attraction effect explains housing price variations within a range of about 700 000 NOK (with 1998 as the base year). This means that a standard house costing 2.5 million NOK in the center of Stavanger would cost about 1.8 million NOK at a travel time of 100 minutes to the CBD, if labor-market accessibility was the same in the two locations.

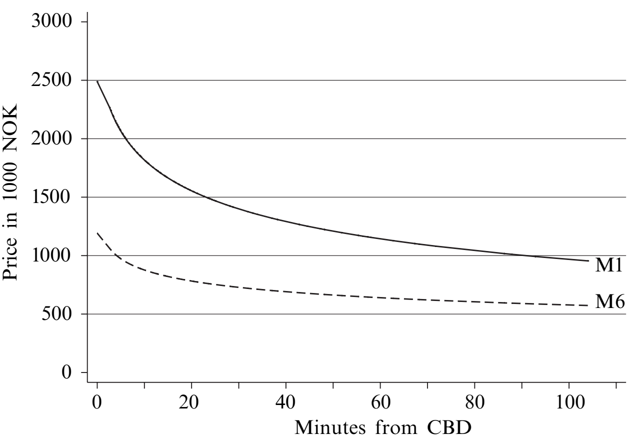

Figure 2. The solid line represents a predicted housing price gradient in an approach where spatial separation is measured only by the distance to the CBD (M1). The dashed line reflects the urban attraction effect, that is, the effect of variations in the distance from the CBD when the value of the labor-market accessibility index is given a value of 0 in M6.

It seems natural to interpret the distance between the two lines in figure 2 as a prediction of the impact of variations in labor-market accessibility. Based on such an interpretation, the figure can be said to decompose spatial variation in housing prices into a labor-market accessibility effect and an urban attraction effect. The solid line is, however, based on a misspecified model formulation, with biased parameter estimates, and we cannot be sure that this line adequately captures the aggregated effect of urban attraction and labor-market accessibility.

The dashed line in the two parts of figure 3 represents a predicted accessibility gradient based on M3; the solid lines are based on M6. The variables on the horizontal axis represent the labor-market accessibility index: a value of 1.2, for instance, represents a location with a 20% higher labor-market accessibility than the average location in the region. According to the dashed line, the price of a standard house is predicted to fall from about 2.15 million NOK in the most accessible location to about 1 million NOK in the location with the lowest observed value of the accessibility index.

Since the dashed line is based on a misspecified model formulation, however, it does not represent a reliable prediction of a labor-market accessibility gradient. The line also captures an urban attraction effect. Like the line based on M1 in figure 2, it is included to reveal the nature and the consequences of the misspecification. The solid lines in figure 3, in contrast, are based on M6, which explicitly adjusts for the urban attraction effect. The solid line in part (a) of the figure refers to a standard house located in the center of Stavanger (travel time to the CBD is set equal to zero), with (hypothetical) variations in the labor-market accessibility index. The solid line in part (b) of the figure is also based on M6, but travel time to the CBD is now set equal to the average value. This offers a more transparent indication of the relative magnitude of the urban attraction effect. As seen from the figure, the gradient based on M6 defines a more narrow interval of accessibility index values than does that for M3.

According to figure 3, the labor-market accessibility effect explains housing price variations within the range of 800 000 NOK for a standard house. For such a house located in the CBD, hypothetical variations in labor-market accessibility could explain variations in housing prices from about 1.8 million NOK to about 2.6 million NOK.

Our results challenge the standard interpretation that housing price gradients related to distance from the CBD reflect the trade-off between commuting costs and housing consumption. We find it more reasonable to distinguish between an urban

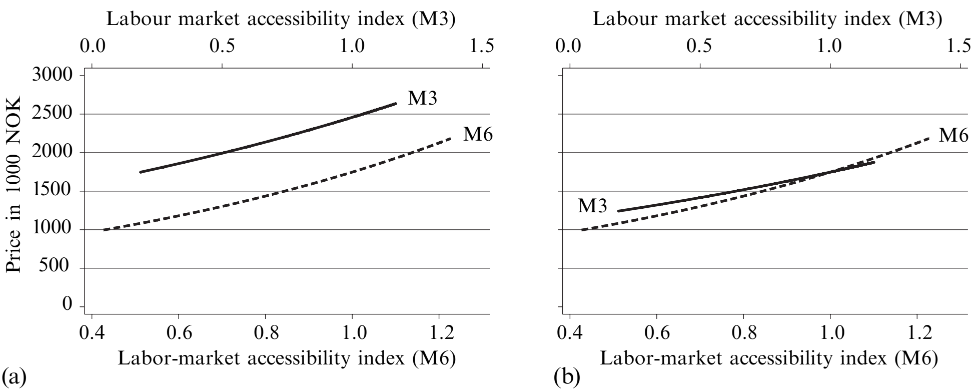

Figure 3. Accessibility gradients for a standard house. The dashed line is based on M3; the solid lines are based on M6. The solid line in part (a) of the figure is based on the assumption that the standard house is located in the center of Stavanger; while the solid line in part (b) is based on the assumption that the standard house is located in the observed average distance from the CBD.

attraction effect and a labor-market accessibility effect affecting trade-off. Graphically, the two effects are represented by the dashed line in figure 2 and the solid lines in figure 3, respectively. Quantitatively, we predict the two effects to be of the same order of magnitude. According to our predictions, a standard house at a price of 2.5 million NOK in the center of Stavanger would cost about 1.8 million NOK if it was located at a travel time of 100 minutes from the CBD if labor-market accessibility was the same in the two locations. If labor-market accessibility is at its maximum value in the CBD and minimum at the most distant intraregional location, the predicted housing price is reduced by 1.5 million NOK, to a level of 1 million NOK.

This is approximately the same range for spatial variation in housing prices that is predicted by the misspecified M1. This does not mean, however, that M1 is in general appropriate for prediction purposes, and the model is of course inadequate as a device to explain housing price variations as a result of different characteristics of the spatial structure. In general, our discussion has demonstrated how a misspecified model formulation might result in a false prediction of how a specific attribute affects the dependent variable.

A potential bias in our approach is related to the calculations of traveling times. We used off-peak, uncongested, estimates. It is not straightforward to predict how congestion problems might affect housing prices in alternative locations. This is a complex problem that involves both the willingness to pay for residential locations close to the CBD and effects due to the location pattern of firms. Nevertheless, we doubt that the rather modest congestion states in the region at the time we consider represent a significant determinant of housing prices.

6 Concluding remarks

One empirical finding in this paper is that housing prices fall with increasing distance from the CBD even when labor-market accessibility is accounted for. This we interpret to represent an urban attraction effect, reflecting households' evaluation of urban amenities in general. The effect of labor-market accessibility was captured through the introduction of a gravity-based accessibility measure, which accounts for the fact that jobs are by no means entirely concentrated within the CBD—even in the relatively monocentric geography that we consider. In other words, we find it appropriate to distinguish between labor-market accessibility and centrality relative to urban activities in our model formulation. Our results indicate that the urban attraction effect and the labor-market accessibility effect contribute about equally quantitatively to intraregional variation in house prices.

It is intuitively reasonable that the urban attraction effect is represented by an isotropic and ring-like CBD gradient: it is traveling distance rather than direction that matters. The situation is not analogous for the spatial distribution of employment: the non-CBD employment cannot in general be expected to be evenly spread in rings of employment around the CBD. Some (local sector) employment tends to be spatially distributed according to population densities [see, for instance, Gjestland et al (2006) for a theoretical discussion], whereas some employment is more concentrated in activity centers, due to agglomeration economies (see, for instance, Guiliano and Small, 1991). Our study indicates that such irregular tendencies are adequately represented by the gravity-based accessibility measure.

Housing price gradients are often estimated from models where spatial separation is represented only by the distance from the CBD (see, for instance, Osland et al, 2007). In a relatively monocentric kind of region like the one we consider here, this might be a reasonable approach if, for instance, data are not available on the spatial distribution of employment and population. The results presented in the preceding section indicate that such gradients might offer reliable predictions of housing prices in specific locations. Since labor-market accessibility covaries with travel time to the CBD, the gradients capture the aggregated effect of the urban attraction and the labor-market accessibility forces. It is important, however, that the gradients are interpreted with care, especially in causal terms. The results presented in this paper challenge the standard interpretation that falling housing price gradients as one moves away from the CBD reflect the trade-off between housing consumption and commuting costs.

As mentioned in the introduction, Adair et al (2000) studied the impact of transport accessibility within supermarkets and subareas of the urban area. Our study refers to a regional rather than an urban context, with zones covering considerably larger areas. In addition to the rural/urban dichotomy, we have no other spatial information of the zones than the (average) position relative to the CBD and an accessibility measure reflecting the position relative to job opportunities in the regional labor market. Through this approach we have primarily focused on the impact of general spatial characteristics, rather than explaining housing prices in this specific region. Unlike Adair et al (2000), we also find that the accessibility measure contributes considerably to explaining variations in housing prices. An estimation of the urban attraction effect and the labor-market accessibility effect probably requires that data refer to a connected labor and housing market, rather than just an urban area. Studies restricted to specific urban areas cannot be expected to provide unbiased estimates of the mentioned effects. In general, labor-market accessibility is relatively invariant across zones within an urban area, and studies ignoring this characteristic might still explain a very large proportion of intraurban variation in housing prices. In a regional setting, we find that the labor-market accessibility measure is not an adequate alternative to the distance from the CBD, but is does appear to be a very useful supplement in the hedonic model equation.

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Appendix

Table A1. Zonal data.

Zone	Working population	Jobs	Observations	Relative accessibility [a]
Rennesøy				
1	725	552	16	0.8946
2	98	24	4	0.9346
3	354	145	5	0.9267
4	127	23	4	0.9388
Randaberg				
5	3748	2195	89	1.0403
Stavanger				
6	328	4961	12	1.1390
7	95	4058	1	1.1331
8	769	1736	11	1.1140
9	688	1586	36	1.1322
10	1021	328	47	1.1343
11	1177	1630	41	1.1292
12	863	3905	23	1.1245

Table A1 (continued).

Zone	Working population	Jobs	Observations	Relative accessibility [a]
Stavanger				
13	1125	1 398	21	1.1277
14	555	2 339	34	1.1319
15	1274	2 864	41	1.1214
16	1382	396	26	1.1138
17	1518	4 695	8	1.1262
18	1151	2 141	29	1.1032
19	1750	407	47	1.0856
20	1637	392	16	1.1254
21	1777	1 751	102	1.1029
22	2367	1 627	40	1.1029
23	1340	627	45	1.1057
24	959	226	33	1.1018
25	846	271	16	1.1202
26	1042	341	27	1.1028
27	1001	132	23	1.1021
28	997	254	46	1.0930
29	1662	239	42	1.0777
30	945	1 746	29	1.0707
31	1212	630	28	1.1118
32	2436	11 309	10	1.1154
33	1719	529	44	1.0937
34	760	930	24	1.1147
35	240	583	4	1.0925
36	999	101	35	1.0677
37	919	147	28	1.0703
38	284	14	14	1.0622
39	1106	338	16	1.0550
40	1169	110	22	1.0506
41	4674	968	135	1.0642
42	237	37	13	0.7849
43	92	11	1	0.8779
Sola				
44	893	83	34	1.0961
45	2925	6 178	70	1.0825
46	945	115	34	1.0902
47	497	63	22	0.9935
48	514	131	11	1.0236
49	2681	5 423	74	1.0519
Sandnes				
50	1215	4 870	22	1.1073
51	1338	1 506	43	1.0900
52	1090	218	16	0.9432
53	371	147	8	1.0458
54	1383	240	57	0.9348
55	1150	302	40	0.9308
56	543	214	4	1.0501
57	788	6 151	25	1.1017
58	1592	570	55	1.1014
59	651	1 515	10	1.0871
60	678	207	19	1.1012
61	1280	175	10	1.0795
62	1911	307	53	1.0795
63	966	1 355	23	1.1012

Table A1 (continued).

Zone	Working population	Jobs	Observations	Relative accessibility[a]
Sandnes				
64	824	537	21	1.0830
65	737	276	6	1.0627
66	1010	787	22	1.0684
67	979	380	21	1.0670
68	914	49	10	1.0746
69	960	574	25	1.0791
70	1198	477	23	1.0474
71	942	253	13	1.0180
72	668	240	24	1.0245
73	21	3	3	0.5834
Klepp				
74	429	158	5	0.9335
75	3034	2043	72	1.0093
76	1047	1502	16	1.0111
77	340	208	2	0.9911
78	1457	457	10	1.0015[b]
Gjesdal				
79	3354	1760	129	1.0046
80	336	184	16	0.8392
81	362	353	1	0.6896
Time				
82	5148	4343	93	0.9792
83	383	123	5	0.9036
84	1457	457	27	1.0015[b]
Hå				
85	1493	1106	35	0.8704
86	1021	525	12	0.8149
87	348	81	6	0.7830
88	376	289	10	0.7491
89	2795	2511	62	0.9074
Bjerkreim				
90	395	213	8	0.7926
91	540	511	8	0.8143
Eigersund				
92	4612	4830	148	0.8825
93	367	97	7	0.7448
94	342	106	1	0.7472
Lund				
95	742	920	10	0.7219
96	235	45	2	0.5864
97	152	53	1	0.6349
Sokndal				
98	1125	916	21	0.7294
99	17	1	3	0.5308

[a] The relative accessibility is found by dividing S_j [see equation (2)] by the mean value of this measure for all the zones.

[b] The two neighboring zones 78 and 84 have the same postal code, and appear as 1 of 98 zones in our estimation procedure.