Spatial Variation in Housing Prices: Econometric Analyses of Regional Housing Markets

Liv Osland

Dissertation for the degree philosophiae doctor (PhD)

at the University of Bergen

2008

ISBN 978-82-308-0586-2
Bergen, Norway 2008

Printed by Allkopi Tel: +47 55 54 49 40

Spatial Variation in Housing Prices:
Econometric Analyses of Regional Housing Markets

Thesis Submitted for the PhD Degree

Department of Economics

University of Bergen

by

Liv Osland

Abstract

This thesis consists of six empirically-based papers. Collectively, the papers contribute to the understanding of the spatial variation in housing prices within regional housing markets. The main ambitions have been to identify what contributes significantly to explain the spatial variation in housing prices within such markets, and to account for this variation in econometric models. The thesis focuses primarily on macroscopical and general spatial structural characteristics, rather than on characteristics relevant for a specific region or a specific neighborhood. A summary of the theory underlying hedonic models and a review of the relevant literature are included, in addition to a chapter on various estimators from the spatial econometrics literature.

According to the thesis there are two main global factors contributing significantly to explain the intraregional spatial variation in housing prices. These are the urban attraction effect measured by distance from the central business district (cbd), and labor market accessibility. The gravity-based labor market accessibility measure used in the thesis represents a useful approximation towards being able to study how changes in accessibility may manifest themselves and exert a spillover effect on housing prices throughout a region. Relevant kinds of experiments are performed in the thesis. As an example, these experiments show that an increase in the number of jobs in an urban area only marginally influences the spatial distribution of house prices. The impact on local housing prices is predicted to be considerably larger if the job growth is concentrated to the peripheral zones. The decentralization of jobs is hence found to contribute towards levelling out the differences in housing prices between the urban and peripheral zones.

Even though the two globally-defined measures of spatial structure characteristics explain a major part of the spatial variation in housing prices, we also find that some locally-defined measures are relevant. The existence of subcenters, for instance, contributes significantly towards explaining spatial variation in housing prices.

A model that includes both the urban attraction effect and labor market accessibility is shown to be useful for predictive purposes, particularly in relation to changes in the spatial distribution of jobs. In cases where one does not have detailed information on the spatial distribution of jobs, the cbd gradient captures both the urban attraction and the labor market accessibility effect. As an example, such a parsimonious model-formulation is demonstrated to offer reliable predictions of the variation in housing prices between a centre and the periphery. This conclusion might, however, be changed in a more polycentric area than the one studied here.

Acknowledgements

There are many supportive people who have enabled the completion of this thesis. First of all, I want to thank Inge Thorsen for his cooperation. His enduring encouragement, and focus on both important details and the governing idea have been invaluable. Jens Petter Gitlesen must also be thanked. His knowledge in a range of fields, and the fact that it is possible to call him at all times, makes working with him a pleasure.

I am indebted to my two supervisors. Espen Bratberg, at the Department of Economics, University of Bergen, has read through all the papers, both early drafts and final ones. His comments and advices have always been encouraging, elucidatory and to the point. Viggo Nordvik, at Norwegian Social Research, must be credited for commenting on drafts of papers, and also for introducing me to the European Network for Housing Research.

I am grateful to Professor Roger Bivand at the Norwegian School of Economics and Business Administration. His competence in spatial statistics and willingness to spend time with me discussing statistical questions, programming in R, and even developing algorithms in spdep suitable for the type of data used in the thesis, has been important. I also wish to thank real estate agents in Haugesund for providing data and for taking part in discussions regarding some of the results.

I have benefited from discussions with many good colleagues at Stord/Haugesund University College. I also want to thank Arnstein Gjestland and Gisle Kleppe for technical assistance. Paul Glenn has improved the English in various occasions. In general, it has been a pleasure to work with the librarians at the University College. They provide services beyond what could be expected. The deans at my department have been very accommodating, and any problem has been solved with ease. Stord/Haugesund University College has provided the necessary equipment, and has covered all my expenses during the project.

More privately, I am grateful to my mother and to Arne for practical ground support. This has contributed to our every-day life being much easier and far more pleasant. My thoughts also go to my husband, and to our two children. With the help of incentives but without arguing, Hanne and Torbjørn have helped with cleaning our house before weekends. Tor, I highly appreciate the delicious dinners that are ready when I come home from work. Thank you for your patience and caring support.

Haugesund, January 2008

Liv Osland

Contents

Introduction

Spatial Variation in Housing Prices: Econometric Analyses of Regional Housing Markets

1. Introduction

Approximately 80% of all households in Norway own their homes, and the homes are to a large extent financed by loans. This proportion is relatively high compared to other European countries where on average 60% of all households owned their homes in 1997 (Andersen 2002). For many home-owners the dwelling represents the dominating part of their wealth, and the holding of these homes will to a large extent form the long-term wealth of households. It has also been shown that changes in housing prices have a significant effect on consumption (Case et al. 2001). A household's housing career or life-phase housing consumption has altered in recent years, and is more unpredictable than it used to be. Based on this, variations in real house prices over time and the prediction of future developments in these prices have been the focus of attention by the general public in many European countries as well as in Norway. In the preface of his book Meen (2001) states that the "concern with house prices has become almost a national obsession and economists are not immune". A number of time-series models have hence been estimated in the research literature. The potential for short-run positive autocorrelation, a long-term mean reverting trend in house prices, and links between house prices and key macroeconomic magnitudes have been among the focal points (see for instance Englund and Ioannides (1997) and Hort (1997)).

An understanding of the time-serial dynamics in house prices is naturally fundamental. Other aspects related to the development of house prices are, however, also important. One such aspect is the spatial variation of house prices. Since housing is immobile, it is beyond question that location is an intrinsic attribute of housing. Following this thread, the prices of houses may vary systematically between distinct locations. Given this background, it is somewhat surprising that the question of what contributes to spatial variation in house prices has been

less dominant both among the general public and in the research literature (see Maclennan et al. (1994) and Meen (2001)). Identifying what causes the spatial variations is, however, not easily discernable, due to among other things the heterogeneity of housing itself, and a range of physical, environmental, social, and economic characteristics of neighborhoods and housing market areas (see Smith et al. (1988) for an overview).

The systematic explanation for the spatial variation in house prices and how to predict this variation is obviously of importance for households. It is, however, also important for other sectors in the economy. Meen (2003) cites several papers that find that differences in house prices are important in relation to the determination of wage claims, particularly for non-manual workers. High housing costs are therefore contributing to the existence of worker shortages in more central areas. Parallel to this, there is the literature stemming from the U.S. and Kain (1968) on the so-called spatial mismatch hypothesis. Assume groups of workers that are confronted with strong geographic barriers to finding and keeping jobs. In such cases the spatial mismatch between where these workers reside, and have a work potential may yield persistent unemployment. According to Thompson (1997), empirical research supports this hypothesis.

Spatial variation in house prices will also have an effect on commuting in an area, and it is well known that traffic issues are important in the development of sustainable regions. Finally, information on the effect of changes such as the geographical relocations of firms, and to what extent the construction of new roads, bridges, or tunnels capitalize into house prices may be valuable for both households, realtors, local housing developers, and governments. The research in this thesis provides empirical models that may be used in order to achieve input and more reliable information regarding such issues. To summarize, increased knowledge in the field of spatial variation in house prices is of great importance both from the viewpoint of households, firms, and policymakers.

2. Presentation of the Research Questions and Main Results

This thesis consists of six empirically based papers. Collectively, the papers contribute to the understanding of the spatial variation in housing prices within regional housing markets. The main ambitions have been to identify what contributes significantly to explain the spatial

variation in housing prices within such markets, and to account for this variation in econometric models. The thesis focuses primarily on macroscopical and general spatial structure characteristics, rather than on characteristics relevant for a specific region or a specific neighborhood.

According to the thesis there are two main global factors contributing significantly to explain the intraregional spatial variation in housing prices. These are the urban attraction effect measured by distance from the central business district (cbd), and labor market accessibility. This result supplements the standard monocentric model in urban economics where it is the falling cbd housing price gradient that reflects the trade-off with increased costs of commuting.

Even though the two globally defined measures of spatial structure characteristics explain a major part of the spatial variation in housing prices, we also find that some locally defined measures are relevant. The existence of subcenters, for instance, contributes significantly towards explaining spatial variation in housing prices.

A model that includes both the urban attraction effect and labor market accessibility is shown to be useful for predictive purposes particularly in relation to changes in the spatial distribution of jobs. In cases where one does not have detailed information on the spatial distribution of jobs, the cbd-gradient captures both the urban attraction and the labor market accessibility effect. As an example, such a parsimonious model-formulation is demonstrated to offer reliable predictions of the variation in housing prices between a centre and the periphery. This conclusion might, however, be changed in a more polycentric area than the one studied here.

The labor market accessibility measure used in the thesis represents a novel approximation towards being able to study how changes in accessibility may manifest itself and exerts spill-over effects on housing prices throughout a region, by the resulting changes in the values of the accessibility measure in different areas. Relevant kinds of experiments are performed in the thesis. As an example, these experiments show that an increase in the number of jobs in an urban area only marginally influences the spatial distribution of house prices. The impact on local house prices is predicted to be considerably larger if the job growth is concentrated to

the peripheral zones. The decentralization of jobs is hence found to contribute to level out the differences in housing prices between the urban and peripheral zones

3. Theoretical Approach and some Basic Assumptions

The theme of the thesis is related to a more general question that has been of importance for many empirical analyses on housing markets over the years: what are the causes of variations in housing prices, and what is the quantitative effect on housing prices of changes in its determinants. No single theory has yet been able to answer these two general questions (see Hwang and Quigley (2006) for an overview of different theories in this respect). Meen (2001) also showed that theoretical explanations between and even within countries vary, and that analyses on different spatial scales demand different analytical frameworks. One reason for this fact is the complexity of housing, which to a large extent influences the research approaches. By way of an example, the so-called user-cost approach (Poterba 1984) has proved to be useful. Among other things these models simultaneously account for the consumption perspectives related to housing in addition to the investment perspectives.

Although different modelling approaches are used, researchers in the field today mainly use the theory of competitive markets as a basis for their analysis (Whitehead 1999). The Norwegian housing market is dominated by small non-professional actors, and governmental regulation is not prevailing. Using theories that are based on market mechanisms is therefore suitable when studying markets in Norway.

Another important starting point when analysing housing markets is the definition of housing itself. There are two main directions in this respect (Whitehead 1999). On the one hand, there is the approach that follows Muth (1969) and defines housing as a one-dimensional good. According to this definition housing services are produced by bundles of components such as size and location. The “price” of housing is defined as the amount needed to buy different standardized quantities of those services. This definition frequently forms the basis of studies of, for instance, the income and price elasticities of housing. On the other hand, housing could be treated as a multidimensional or heterogeneous product. In these cases the hedonic theory is frequently used, which stems from Lancaster (1966) and Rosen (1974), and is recently

reviewed in Chin and Chau (2003). It is this approach that is used in the thesis. Further comments on the hedonic method are found in Section 6, in the summary of Paper 1.

Housing markets intervene in multiple ways with other markets, such as the market for land, labor markets, and financial markets. Given that only housing markets are being studied, the approach used here will be by means of partial analyses. This, for example, implies that only compensations for commuting in relation to housing prices will be considered. A potential relationship between wages and commuting is not considered (see Rosen (1979) and Roback (1982)).

It is the intraregional aspect that is the issue of the thesis. Meen (2001) studied, among other things, explanations for price differences between regions, where different economic conditions in addition to for instance the make-up of populations are important. Within a labor and housing market, different cyclical or time-related movements in housing prices are not expected to be prevailing, although the existence of submarkets may complicate these matters. Meen (2001) stated that within markets where "households are relatively mobile, relative changes in house prices can rarely persist for long (…), arbitrage will eliminate the variations, (…) and prices within the urban area will move together over time in line with the economic fortunes of the area" (page 22).

4. Possible Explanations of Spatial Variations in Housing Prices

The most widely accepted theory that links residential location to the price of housing is given by urban economic theory represented by the monocentric city model, which is based on Alonso (1964), Mills (1972), and Muth (1969). The background of this theory is Von Thünen's (1825) theory of agricultural land use. The main spatial attribute of the theory is distance from the central business district (cbd). It therefore represents the most basic way of introducing location into economic modelling. The relevant prediction of the monocentric model is that households that live far from the center of employment are compensated for higher time costs of commuting by way of lower price of a unit housing. Differences in access to workplace and hence commuting costs are important explanations for the spatial variation in the unit price of housing, and the model provides an important justification of the relationship between housing prices and workplaces.

One important reason why this model frequently has not consistently been supported by the empirical evidence is the polycentric pattern of employment (Arnott et al. 1998, Bender and Hwang 1985). Models developed in the tradition established by economic base theory and Lowry (1964) can handle urban areas with many employment centers. See Anas (1987) in addition to Wegener (1998) who review models that integrate transport and location models with the housing markets. Problematic points with the Lowry-models are that they are based on physics rather than microeconomic theory, there is no consensus regarding how to model polycentricism, and there is little empirical research accounting for how this may affect property values (Heikkila et al. 1989).

An additional explanation of the spatial variation in prices found in the housing market literature is the so-called location specific characteristics or amenities that are hypothesized to capitalize into house prices. Capitalization is here defined as when the existence of an amenity or a change in an amenity causes changes in house prices. See, however, Brasington (2002) for a discussion of divergent views of the existence of capitalization. Location-specific factors assumed to have an effect on house prices include *accessibility, neighborhood characteristics, and proximity externalities* (Basu and Thibodeau 1998). These three characteristics will be explained shortly in the following sections. Due to a range of different reasons, empirical studies vary in their support of the hypothesis of significance of these factors on housing prices (see for instance Jackson (1979), Dubin (1992), Adair et al. (2000) and des Rosiers et al. (2001)).

In the housing market literature *accessibility* has traditionally been accounted for by the one-dimensional measure of distance to cbd (Dubin 1992; Waddell et al. 1993). This variable is also included in the majority of the estimated models found in the thesis. In addition to this, access to a range of household activities could also be relevant. Examples are accessibility to recreation and shopping (see Vandell (1995) for a list of relevant examples). These are mainly not accounted for in the thesis. Discussions of the legitimacy of such a simplified approach are found in the relevant papers of the thesis.

Accessibility measures are frequently used in the literature on spatial interaction problems, and were first explicitly introduced by Fotheringham (1983), defining the so-called competing destinations model of spatial interaction. Various ways of measuring accessibility is found in

this literature. What is common for the different measures is that they integrate both a transportation aspect and an activity aspect (Handy and Niemeier 1997). One important type of accessibility measure in this case is the gravity-based measures or potential variables. To cite Anselin (2002), these variables are specified so that "the potential for interaction between an origin i and all destinations j (…) formulated as a sum of "mass" terms in the destination, suitably downscaled by a distance decay function" (page 250). Or as stated in Hansen (1959): "In general terms, accessibility is a measurement of the spatial distribution of activities about a point adjusted for the ability and the desire of people or firms to overcome spatial separation" (page 73). This thesis relates gravity-based accessibility measures to housing prices. The following measure of accessibility is used in several papers:

$$(1) \qquad S_j = \sum_{k=1}^{Z} D_k^{\gamma} \exp(\sigma d_{jk}) .$$

D_k represents the number of jobs in postal zone k, and d_{jk} represents the spatial separation between zones measured in minutes between zone j and k, travelling by car. Z is the total number of zones. σ and γ are parameters to be estimated. This accessibility measure consists of attraction forces, in this case represented by the number of jobs in each zone. The friction in the system is represented by travelling distances between zones. The importance of distance, or how severe the impediment of distance is, will be measured through the value of σ, the distance-deterrence parameter. The higher the absolute value of σ the more deterrent is travel distance on mobility. Thorsen and Gitlesen (1998) have demonstrated that the evaluation of a spatial interaction model depends on the formulation of the accessibility measure. They found that a parameter should be attached to the number of job opportunities.This forms the basis of estimating γ in S_j. Altogether, when using this measure, accessibility in one zone will be a weighted sum so that the importance of all the other places is accounted for.

The *neighborhood effects* are assumed to contribute to spatially varying housing prices in at least two different ways. On the one hand it could be explained by different types and amounts of attributes in different locations. Examples found in Can (1992) are socioeconomic characteristics, level of public services, access to parks, and the physical make-up of an area in general. See Dubin and Sung (1990) for a classification of these characteristics. In general

these effects are not directly accounted for in the thesis, given that the primary aim is to study macroscopical, and general spatial characteristics.

On the other hand this type of spatial variation in house prices may be attributed to the existence of submarkets. Within a submarket, there exists a single price of a standardised housing unit. Between the submarkets there will exist different prices for a standardised housing unit, or different implicit prices, due to structural differences between submarkets. This means for instance that the total price of two houses that are equal in all respects will be different, due to differences in implicit prices of certain attributes.

The literature on housing submarket is relatively comprehensive, and there exist various definitions of submarkets. Following Straszheim (1974) two conditions have to be met for the existence of submarkets. a) Purchasers in one segment of the market do not significantly take part in other segments. Relevant reasons for this are barriers to mobility or lack of information. b) The structure of demand (due to differences in demography, preferences, or income), supply (due for instance to inelastic supply), or both must vary between markets. If these conditions do not hold, differences in implicit prices will be arbitraged away. The market would be described by a single hedonic price function and interpreted by way of long-run equilibrium (Goodman 1981). If submarkets exist, the model is interpreted in short run terms, existing at a given point in time, at a certain geographical market (Goodman 1981). Maclennan et al. (1987), Maclennan and Tu (1996) and Tu (1997), on the other hand, claim that submarkets are evidence of disequilibrium rather than multiple equilibriums.

Finally, *proximity externalities* may be represented by, for instance, different levels of air or noise pollution at various locations (see for example Li and Brown (1980)). These could also be externalities arising from peer groups, or endogenous and exogenous amenities as described in Brueckner et al. (1999). See also Meen and Meen (2003) for an overview of social interaction-based externalities.

5. Spatial Econometrics

Altogether the listed characteristics will to various degrees and in various ways contribute to the spatial variation in house prices in a given housing market. Evidently, when performing empirical analyses, the most important relationships should be transformed to econometric

models. Most of the mentioned variables will, however, not be included in a parsimonious model, and one must consider the effect of such exclusions, and sometimes adjust for it, for instance by way of suitable lagging of the residuals in a regression model. An important tool for empirical analyses regional housing market analyses is therefore spatial econometrics, and this has been another focal point in the thesis. By spatial econometrics we mean "a collection of methods to deal with spatial effects in regression analysis. Spatial effects consist of spatial autocorrelation (cross-sectional dependence) and spatial heterogeneity (cross-sectional structural instability)" (Anselin 2006, page 901).

According to Goodchild (2004) spatial econometrics could be characterised as "fledgling discipline". Spatial econometrics is not treated thoroughly in traditional econometric textbooks (Arbia 2006), nor is suitable algorithms present in commonly used econometric software. Due to this the econometrics has been an interesting challenge during the work on this thesis. An exploration of the existence of spatial effects is fundamental when performing cross section analyses of housing markets. Important reasons are that this type of analysis may reveal substantial features regarding how the market works for instance by identifying and modelling potential spatial linkages or dynamics. It may also reveal spatial trends or structural differences between submarkets. In simpler terms, relevant questions are whether the price on one house correlates with the price achieved on adjacent houses and vice verse. Do missing spatially related variables create spatially correlated residuals, or is this correlation due to the existence of spatial submarkets? Spatial econometric methods should be used in the modelling process when studying spatial variation in housing prices, and they may lead to a discovery of important misspecifications, which otherwise, may bias estimates and/or lead to inefficient inferences (Anselin 1988).

6. Summary of the Papers in the Thesis

The following section summarizes the papers in the thesis. Briefly put, the first paper explains the theoretical foundation for the hedonic theory which is used throughout the thesis. The second paper studies the distance to cbd-gradient in more detail. The third paper introduces the global job-accessibility measure in addition to the cbd-gradient which in this case is interpreted as urban attraction. The fourth paper studies the existence of local structure characteristics in relation to housing prices. The fifth paper explores how well the different models predict house prices, and the effect on house prices of changes in the spatial

distribution of jobs. Finally, the sixth paper applies a number of relevant econometric estimators, spatial model alternatives, and tests that may be useful when performing spatial econometric analyses on housing markets. In general the papers study variation in housing prices in regions where such studies, to our knowledge, have not been carried out. Most empirical studies focus on metropolitan areas. Relatively few studies are European.

Paper 1: The Hedonic Method and Estimating Attribute Prices

The first paper aims at explaining the hedonic theory and its relevancy in relation to housing markets. This approach accounts for the heterogeneity of housing, and Paper 1 presents the hedonic theory in accordance with Rosen (1974). Although the method is data consuming, it is widely used within the field of housing economics and welfare analysis. Among other things, it enables the researcher to focus on the effect of single attributes that determines house prices, ceteris paribus. Through a revealed preference approach, it also enables measurements of the value of for instance non-traded goods such as the road transportation network or pollution.

Paper 1 focuses on a subject that has been a major concern when using the hedonic method. Which functional form should be used, given that theory does not provide clear cut answers? Paper 1 uses the so-called Box-Cox transformation, which may be used in order to test the functional form statistically, and reviews results found in the hedonic literature in relation to the choice of functional form.

In the empirical analysis a sample consisting of small houses sold in Haugesund in the period 1980-1987 is used. Estimated elasticities related to important housing attributes are in line with the few existing Norwegian studies found at that point in time. For instance, the hedonic price elasticity of living area was estimated to be 0.42. The same result was achieved in an empirical analysis from the city of Bodø (1977-81). These results indicate that for important and easily measurable housing attributes, the implicit price elasticities are remarkably similar across different markets.

Paper 2: Housing Price Gradients in a Region with One Dominating Center

The most prominent theoretical explanation for spatial variation in the unit price of housing is the monocentric model of urban economics. From the 1980's the empirical relevance of the prediction of this basic model has been questioned (McMillen 2007). More recently however, research has shown that the monotonically falling house price gradient has regained relevance, (see Paper 2 for details). Paper 2 reconfirms the empirical relevance of the monocentric theory, and develops log linear regression models to predict house prices in a monocentric region. The paper demonstrates the importance of incorporating a spatial dimension in the model, in addition to the house specific variables. The distance to the cbd has a strong significant negative effect on housing prices in the kind of region studied Tentative calculations show that the estimated results from our model do not strongly oppose the theoretical monocentric model. To some extent the price of a standard house falls with increased distance to the cbd, with an amount that balances the increased costs of commuting. The results are in accordance with McMillen (2004), who claim that researchers who reject the monocentric model misinterpret the empirical evidence. The paper also shows that information on the character of sub-areas such as a rural area, contributes to explain spatial variation in house prices.

One reason why it is possible to identify and estimate a continuously falling cbd-gradient in our data is an ideal study area. It is possible to give a clear-cut delineation between the housing and labor market in the Stavanger region and neighboring markets, mainly due to natural barriers between the markets. Mobility within the study area in the study period is also good. Given the indisputably dominating position of Stavanger, Paper 2 argues that it is probably hard to find geographies that come considerably closer to the theoretical construction of the monocentric model. Finally, the paper illustrates that using flexible functional forms on the specification of travelling time are particularly important when studying more polycentric geographies than the one we consider.

Paper 3: Effects on Housing Prices of Urban Attraction and Labor Market Accessibility

Paper 3 explores one of the most obvious weaknesses of the monocentric model, the assumption that firms and hence jobs are entirely located in the cbd. Given that jobs are not totally centralized, and that regions tend to be more or less polycentric, this makes the traditional interpretation and estimation of the house price gradient less suitable. Paper 3 extends the analysis found in Paper 2, and introduces a gravity-based labor market accessibility measure to account for these polycentric tendencies. House prices are shown to fall with increased distance to the cbd, even when labour market accessibility is controlled for. The paper suggests that this could be interpreted as an urban attraction effect, which together with the labor market accessibility effect, contributes to explain the major part of the intraregional spatial variation in housing prices. The price of a standard house in a given housing and labor market falls with increased distance to the cbd, and rises with increased labor market accessibility. This result supplements the standard monocentric model in urban economics where it is the falling cbd housing price gradient that reflects the trade-off with increased costs of commuting.

It is intuitively reasonable that the urban attraction effect is represented by an isotropic and ring-like cbd-gradient; it is the travelling distance and not the 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 spatially distributed according to population densities. Some employment is for instance more concentrated around activity centers due to agglomeration economies. Our study indicates that such irregular tendencies are adequately represented by a gravity-based accessibility measure.

In the paper we also argued that studies restricted to specific urban areas cannot be expected to provide reliable or unbiased estimates of the mentioned effects. In general, labor market accessibility is relatively invariant across zones within an urban area. Studies ignoring this spatial structure characteristic might still explain a large proportion of intra-urban variation in housing prices. In a regional setting, labor market accessibility is not found to be an adequate alternative to the distance to cbd-variable, but it appears to be a useful supplement in the hedonic price model.

Paper 4: Testing for the Impact of Local Spatial Structure Characteristics on House Prices

The two spatial variables included in Papers 2 and 3 are global in nature, they are relevant for the whole area. The question asked in Paper 4 is whether such measures capture the impact of the complex multipurpose decision processes in modern households. Should hedonic model formulations also incorporate local spatial structure characteristics, and if such characteristics are found to be relevant, how do they affect housing prices? A basis for the hypothesis that spatial structure characteristics should be defined at two separate spatial levels of aggregation is that residential location choices can be considered as a result of a hierarchical, stepwise decision process. As a first step of such a decision process, the households determine what parts or municipalities of a region that is relevant in their search for a house. The next step concerns the choice of residential site within the chosen search area.

In Paper 4 the existence of several alternative and possibly relevant local spatial structure characteristics are considered. These local structure characteristics are mainly related to local labor market opportunities in addition to population density measures and local services. By way of example we develop relative measures of accessibility, which measure accessibility in a zone relative to total accessibility in adjacent zones. In all, eight different proxies for local spatial structure characteristics are considered. Among these the inclusion of subcenters outside the central part of the study area contributes significantly to explain the spatial variation in housing prices. The subcenters exert an influence on housing prices similar to the variable distance to cbd. The results indicate to some extent that the quantitative impact of variations in distance from the subcenter is positively related to the distance from the cbd. We also find that spatial variation in housing prices is significantly influenced by a variable representing the administrative centers in the most centrally-located municipalities of the region, in addition to one specification of relative labor market accessibility.

The incorporation of local spatial structure characteristics only marginally improves the goodness-of-fit. Possible explanations could be harmful multicollinearity, and that the two globally defined measures capture most of the relevant spatial variation in house prices in this relatively monocentric area.

Paper 5: Predicting Housing Prices at Alternative Locations and in Alternative Scenarios of the Spatial Job Distribution

In Paper 5 previously estimated models are explored. The alternative hedonic models that are considered differ only with respect to how the spatial structure is represented. One ambition is to study the predictability of different models that vary with respect to the demand for data. Another important ambition is to study the effects on housing prices of the relocation of labor market opportunities. To our knowledge, there only exist a few empirical studies on the relationship between house prices and changes in the spatial distribution of jobs.

When considering predictability, the focus is on comparing a hedonic model where either a) the distance to the cbd is included or b) the access to labor markets is modelled, in addition to a model c) where both the accessibility measure and the distance to the cbd is included. Given a relatively monocentric region, the results in Paper 5 show that the choice between a) and c) for predictive purposes, is somewhat subordinate both as regards predicting the price of a standard house, and in predicting zonal average house prices, given that the aim is to provide more macroscopical predictions of housing prices. These conclusions might be reversed if the study area was more polycentric than the one studied here. In these cases model alternative b) might even be preferred.

By using model alternative c) above, the local impact on house prices of spatial intraregional redistribution of job opportunities tend to be negatively related to the degree of urbanization. The local increase in house prices is predicted to be considerably higher if new firms establish in more peripheral areas, compared to a situation where firms establish within reasonable distance from places where a major part of the firms in a region are already located. An intuitive explanation is that increased labor demand in highly accessible locations will be met through commuting flows from adjacent locations. This contributes to reduce the impact on the spatial pattern of housing demand. The adjustment can be argued to be different in a case where the job growth appears in a more peripheral location. Some of the employees will not be comfortable with long-distance commuting, and choose to move into the proximity of the expanding firm(s). Hence, the relevant location becomes more attractive for residential purposes, and house prices can be expected to rise. In other words, people tend to follow jobs

when the job growth occurs in a rural zone. For various reasons our results may to some extent contradict empirical results based on time-series data from US metropolitan areas (see Paper 5 for details).

Another kind of asymmetry relates to negative versus positive changes in accessibility. Assume that changes in intraregional accessibility occur due to intraregional redistribution of the number of jobs. The result found in the thesis shows that a reduction in the labor market accessibility has a substantially larger impact on house prices than a corresponding increase in accessibility. Finally, ignoring differences in the level of the predicted changes, the positive impact of local employment growth on house prices tends to extend over an equally large area for urban, semi-urban, and rural locations. Only marginal effects on house prices appear for zones located in travelling distances beyond 20 minutes from the place of employment growth.

Paper 6: An Application of Spatial Econometrics in Relation to Hedonic House Price Modelling

Paper 6 applies spatial econometrics in relation to hedonic house price modelling. We present and use some basic acknowledged spatial model alternatives and a battery of relevant tests. Geographically Weighted Regression (GWR), semiparametric analysis, and the spatial Durbin model are also applied. The motivation for the applied approach is that spatial econometrics is a fledgling discipline, and it is highly relevant for hedonic house price modelling. Another important motivation for this comprehensive approach is that misspecifications have been shown to give spurious results in relation to some frequently used tests for spatial effects. The problem of misspecification is also particular severe in spatial modelling since theory provides little guidance, spatial relationships are abundant and they are often highly nonlinear.

Significant model improvement is achieved through the modelling process. Submarkets related to lot-size and distance to the cbd, due to a spatial barrier, is identified. Although both the so-called adjacency and neighbourhood effects are recognized, the dominating feature in the data is the neighbourhood effects. This is probably due to less important missing spatially related local variables, which is accounted for by using a spatial autoregressive error model.

The paper illustrates that a useful feature with the spatial Durbin model is that significant lagged explanatory variables may reveal tendencies of spatial heterogeneity. The strength of the common factor hypothesis test is that it nests the spatial lag and the spatial error model. It tends, however, to favour the spatial lag structure, which makes it difficult to use for conclusive purposes. The semiparametric analysis is useful as an exploratory tool, due to its flexibility and robustness to multicollinearity. This simplifies the identification of nonlinearities, subcenters, or submarket boundaries. GWR is extremely sensitive to multicollinearity. However, related F-tests gave useful information regarding the existence of spatial heterogeneity in general. The analysis illustrates the importance of experimenting with different neighborhood structures when using the relevant Lagrange Multiplier tests. If the neighborhood structure in the weights is not representative, important spatial features in the data may not be discerned.

6. Future Research and Major Contribution of the Thesis

This thesis will be used as a basis for future research. An evident hypothesis is to study the relevance of more disaggregated accessibility measures. One way of disaggregating the gravity-based measure used in the thesis could be by accounting for job heterogeneity. For example, a distinction could be made between choices made by men and women, respectively. In this case it could be hypothesised that the distance-deterrence parameter is larger in absolute value for women compared to men.

The model developed in Paper 3 has been used to study the effect on house prices of changes in the distribution of jobs (see Paper 5 for details). This model could also be used to study the capitalization effect of changes in the road transportation network. Examples of such changes are islands being connected to mainland by a bridge, changes in speed limits, and the construction of new roads and new tunnels that decrease the travel time between geographical areas. In many of these cases it is also necessary to study more in depth the existence of submarkets, particularly at places where a connected road transportation network is not prevalent.

Another relevant hypothesis is to what extent the estimates developed on the basis of data from the Stavanger area can be transferred and used on a more general basis. The question is

whether the results found in the thesis are transferable geographically and to different periods of time. If the estimated parameters prove to be adequate for other regions in other time periods, the capitalization effects of planned projects on house prices may be predicted before transportation investments take place. Finally, inspired by large-scale models for urban areas, estimated parameters in the thesis could also be used as input in an extended model, or preferably a general equilibrium model suitable for regional economic development. In such a model the housing market constitutes an important sub-model of a more comprehensive equilibrium modelling framework.

On a more overall basis the thesis provides a foundation for an improved measure of the capitalization effect on house prices of changes in job accessibility. As mentioned in the introduction, most studies on housing markets include accessibility and spatial separation by way of one-dimensional measures only. This means that it is the distance between specific zones in the geography that is included. When studying capitalization effects in these cases, it is therefore mainly possible to study the effect in relation to the specific link where a certain change occurs. The introduction of the gravity-based accessibility measure on the other hand represents a first approximation towards accounting for how changes in the road transportation network may manifest itself and have spill-over effects throughout a region, through the changes in the values of the accessibility measure in different areas. As a consequence, arbitrary or subjective spatial boundaries of the created effects are avoided since the accessibility measure represents a continuous representation of the geography. The possibility for quantifying the capitalization effect of changes in transport infrastructure and the availability of jobs is hence improved. In addition, the introduction of this measure may serve as an important input in a study of how such changes affect the distribution of assets across the population.

References

Adair, A., McGreal, S., Smyth, A., Cooper, J. & Ryley, T. (2000). House prices and Accessibility: the testing of relationships within the Belfast Urban Area. *Housing Studies*, 15(5) pp. 699-716.

Alonso, A. (1964). *Location and land use. Toward a General Theory of Land Rent.* Harvard University Press. Cambridge, Massachusetts.

Anas, A. (1987). *Modelling in urban and regional economic. Fundamentals of pure and applied economics.* 26, Harwood Academic Publishers.

Andersen, A. (2002). Boforhold I Norge og Europa. Eget hus og hage. Statistics Norway. Accessible from: http://www.ssb.no/samfunnsspeilet/utg7200201/12/index.html [read 2003-06-11]

Anselin, L. (1988). *Spatial Econometrics: Methods and models*. Kluwer Academic Publishers.

Anselin, L. (2002). Under the hood. Issues in the specification and interpretation of spatial regression models. *Agricultural Economics,* 27 pp. 247-267.

Anselin, L. (2006). Spatial Econometrics. Ch. 26 in Mills T.C. and K. Patterson (eds). *Palgrave Handbook of Econometrics. Econometric Theory*. Palgrave Macmillan.

Arbia, G. (2006). *Spatial Econometrics. Statistical Foundations and Applications to Regional Convergence*. Springer.

Arnott, R.A., Anas, A. & Small, K. (1998). Urban Spatial Structure. *Journal of Economic Literatur*e, 36 pp. 1426-1464.

Basu, S. & Thibodeau, T.G. (1998). Analysis of spatial autocorrelation in house prices. *Journal of real estate Finance and Economics*, 17(1) pp. 61-85.

Bender, B. & Hwang, H. (1985). Hedonic housing price indices and secondary employment centers. *Journal of Urban Economics*, 17 pp. 90-107.

Brasington, D.M. (2002). Edge versus center: finding common ground in the capitalization debate. *Journal of Urban Economics,* 52 pp. 524-541.

Brueckner, J., Thisse, F.F. & Zenou, Y. (1999). Why is central Paris rich and downtown Detroit poor? An amenity-based theory. *European Economic Review,* 43 pp. 91-107.

Can, A. (1992). Specification and estimation of hedonic housing price models. *Regional Science and Urban Economics*, 22 pp. 453-474.

Case, K.E., Quigley, J.M. & Shiller, R.J. (2001). Comparing wealth effects: the stock market versus the housing market. National Bureau of Economic Research. Working Paper 8606/2001.

Chin, T. & Chau, K.W. (2003). A critical review of literature on the hedonic price model. *Journal of Housing Services,* 27(2) pp. 145-165.

Des Rosiers, F., Lagana, A. & Thériault, M. (2001). Size and proximity effects of primary shools on surrounding house values. *Journal of Property Research,* 18(2) pp. 149-168.

Dubin, R.A. (1992). Spatial autocorrelation and neighbourhood quality. *Regional Science and Urban Economics*, 22 pp. 433-452.

Dubin, R.A. & Sung, C. (1990). Specification of hedonic regressions: non-nested tests on measures of neighbourhood quality. *Journal of Urban Economics*, 27 pp. 97-110.

Englund, P. & Ioannides, Y. (1997). House price dynamics: An international empirical perspective. *Journal of Housing Economics*, 6(2) pp. 119-136.

Fotheringham, A.S. (1983). A new set of spatial-interaction models: the theory of competing destinations . *Environment and Planning A*, 15 pp. 15-36.

Goodchild, M.F. (2004). Foreword. In Anselin, L., Florax, R.J.G.M. & Rey, S.J. (eds.). *Advances in Spatial Econometrics. Methodology, Tools and Applications.* Springer.

Goodman, A.C. (1981). Housing submarkets within urban areas: definitions and evidence. *Journal of Regional Science*, 21(2).

Handy, S.L. & Neimeier, D.A. (1997). Measuring accessibility: an exploration of issues and alternatives . *Environment and Planning A*, 29 pp. 1175-1194.

Hansen, W.G. (1959). How accessibility shape land use. *Journal of the American Institute of Planners*

Heikkila, E., Gordon, P. & Kim J.I. (1989). What happened to the cbd-distance gradient? Land values in a polycentric city. *Environment and Planning A*, 21(2) pp. 221-32.

Hort, K. (1997). *On price formation and quantity adjustment in Swedish housing markets*. Doctoral Thesis, Department of Economics, Uppsala University.

Hwang, M. & Quigley, J.M. (2006). Economic fundamentals in local housing markets: evidence from US metropolitan regions. *Journal of Regional Science*, 46(3) pp. 425-453.

Jackson, J.R. (1979). Intraurban variation in the price of housing. *Journal of Urban Economics*, 6 pp. 464-479.

Kain, J.F. (1968). Housing segregation, negro employment, and metropolitan decentralization. *Quarterly Journal of Economics*, 82 pp. 32-59.

Lancaster, K.J. (1966). A new approach to consumer theory. *Journal of Political Economy*, 74 pp. 132-157.

Lowry I.S. (1964). A model of Metropolis. RM-4035-RC, Santa Monica, RAND Corporation.

MacLennan, D., Gibb, K. & More, A. (1994). Housing systems, regions and the national econom. *Economic Modelling*, 11(2) pp. 228-237.

Maclennand, D., Munro, M. & Wood, G. (1987). Housing choices and the structure of housing markets. In Turner, B., Kemeny, J. & Lundqvist, L.J. (eds). *Between State and market: Housing in the Post-industrial Era*. Almqvist & Wiksell International.

Maclennan, D. & Tu, Y. (1996). Economic perspectives on the structure of local housing systems. *Housing Studies*, 11(3) pp. 387-406.

McMillen, D.P. (2004). Employment subcenters and home price appreciation rates in metropolitan Chicago. In LeSage, J.P. & Pace, K. (eds). *Advances in Econometrics*. *Volume 18: Spatial and Spatiotemporal Econometrics*. pp. 237-257. Elsevier, New York.

McMillen, D.P. (2007): Testing for moncentricity. Chapter 8 in Arnott, R.J. & McMillen, D.P. *A Companion to Urban Economics*. Blackwell.

Meen, G. (2001). *Modelling housing markets. Theory, analysis and policy*. *Advances in Urban and Regional Economics*. Kluwer Academic Publishers.

Meen, G. (2003). Housing, random walks, complexity and the macroeconomy . Ch. 6 in O'Sullivan, T. & Gibb, K. (eds). *Housing Economics and Public Policy*.

Meen, D. & Meen, G. (2003). Social behaviour as a basis for modelling urban housing markets: a review. *Urban studies*, 40(5-6) pp. 917-935.

Mills, E. (1972). *Studies on the Structure of the Urban Economy*. John Hopkins University, Baltimore.

Muth, R. (1969). *Cities and housing*. University of Chicago Press.

Poterba, J.M. (1984). Tax subsidies to owner-occupied housing: an asset market approach. *Quarterly Journal of Economics*, XCIC(4) pp. 729-752.

Roback, J. (1982). Wages, rents and the quality of life. *Journal of Political Economy*, 90, pp. 1257-1278.

Rosen, S. (1974). Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition. *Journal of Political Economy*, 82 pp. 34-55.

Rosen, S. (1979). Wage based indexes of urban quality of life. In Mieszkowski, P. & Straszheim, M. (eds). *Current issues in urban Economics*. John Hopkins University Press, pp. 74-104.

Smith, L.B., Rosen, K.T. & Fallis, G. (1988). Recent development in economic models of housing markets. *Journal of Economic Literature*, Vol 26 pp. 29-64.

Straszheim, M.R. (1974). Hedonic estimation of housing market prices: a further comment. *The Review of Economics and Statistics*. 56 pp. 404-406.

Thompson, M.A. (1997). The impact of spatial mismatch on female labor force participation. *Economic Development Quarterly*, 11(2) pp. 138-145.

Thorsen, I. & Gitlesen, J.P. (1998). Empirical evaluation of alternative model specifications to predict commuting flows. *Journal of Regional Science*, 38 pp. 273-292.

Thünen, J. Von (1825). *Der Isolierte Staat in Beziehung auf Landwirtshaft und Nationalökonomie*. Hamburg.

Tu, Y. (1997). The local housing submarket structure and its properties. *Urban Studies*, 34(2) pp. 337-353.

Vandell, K.D. (1995). Market factors affecting spatial heterogeneity among urban neighborhoods. *Housing Policy Debate*, 6.

Wadell, P, Berry, B.J.L. & Hoch, I. (1993). Residential property values in a multimodal urban area: new evidence on the implicit price of location. *Journal of Real Estate Finance and Economics*, 22 pp. 829-833.

Wegener, M. (1998). Applied models of urban land use, transport and environment: State of the art and future developments. In Lundquist, L., Mattsson, L.G. & Kim, T.J. (eds). *Network Infrastructure and the Urban Environment, Advances in Spatial Systems Modelling*. Springer.

Whitehead, C. (1999). Urban housing markets: theory and policy. In Mills, E.S. & Cheshire, P. (eds). *Handbook of Regional and Urban Economics*. Elsevier Science B.V.

Appendix

Data Sources

Appendix

Data Sources

The papers in the thesis contain information on the relevant datasets. In this part, more detailed information is included in order to supplement the presentations found in the papers.

The empirical work in the thesis is based on three different data-sets, and the information used is gathered from different sources. In order to increase the number of observations and increase the variability in the independent variables, combined or pooled cross- and time-section data are used in all instances. In contrast to pure cross-sections, this demands including time as a variable. The three data sets include only privately-owned or freeholder homes. By freeholder it is meant that the property has a registered title deed. Each house has its own identity number and full proprietary rights are transferred to owners through the sale. Many of the blocks of flats in the study-areas are organized in cooperatives ("borettslag"), and are not characterized as freeholder dwellings. These apartments could make up a different market segment, for instance due to the sharing of loans, insurance etc., and should hence be studied separately. See Paper 6 for a discussion of submarkets in this respect. Also note that a major part of the market for apartments organized as cooperatives was regulated until 1983. These observations could therefore not be used as a basis for hedonic modelling, which assumes competitive markets.

The first data-set is used in Paper 1, and stems from the municipality of Haugesund. It consists of 416 observations of houses sold on the second-hand market in 1980-1987. In all, there were 10667 dwellings in Haugesund in 1980 according to Statistics Norway. Among these 73% were privately owned. The sample consists of the following types of houses: houses in a row, terraced houses and different types of semi-detached or chained houses, and detached houses that are built in series. These houses do not belong to one single category of houses in the official statistics. Not including the detached houses built in series, the proportion of houses belonging to this category was 15.5% in 1980, according to Statistics Norway. One important reason for using the types of houses described here is that the more heterogeneous single family detached houses were only rarely sold during the study period. The considerations regarding separate markets are also relevant here. The houses included in

this sample are fairly equal, are sold relatively frequent, and satisfy specific requirements given by the Norwegian State Housing Bank[1] regarding size of house and costs of building.

In the study period the selling price, date of sale and lot-size were registered in the official land register ("tinglysingsregisteret"). This information is considered reliable. All information about other characteristics of the houses and their location relative to the cbd is gathered from all the existing local real estate agents' descriptions of the houses. In general this information is also considered to be reliable. The data has been registered manually. There may be houses that were sold without using a professional sales agent and that are not included in the sample. There is, however, no reason to believe that there were a large number of people who did not use a sales agent. Finally, the total population size of sold houses in the given category is not known. Given the relatively large number of observations compared to the existing population of the included house types, a large majority of the relevant houses sold on the free market in the relevant period are probably included.

The other two samples are 2788 observations from the Stavanger area (1997 to the first half of 2001) and 1691 observations from the Haugesund area or Haugalandet (1997-2002). The first sample is used in Papers 2, 3, 4, and 5 and the second sample is used in Paper 6. In both of these samples single-family detached houses are used. Of all the houses in Norway, 57.1% were single family detached houses in 2001. In Stavanger, the total share of single family detached houses is 40.6%. The average number in the area, excluding Stavanger was 84%. In Haugesund it was 50%. The average for the area, excluding Haugesund was 90.3%. In 2006, 1889 single-family detached houses were sold in all in Rogaland. All of these numbers were reported by Statistics Norway. Note that there are some rural municipalities that belong to another county than Rogaland in the sample. 522 single-family detached houses were sold in Stavanger, 363 in Sandnes, 167 in Haugesund, and 204 in Karmøy. This type of information is not available for earlier periods. These numbers may indicate the size of the sample compared to the population single-family detached houses that were sold: In Stavanger, the average number of observations pr year is 244, it is 117 in Sandnes, 128 in Haugesund, and 119 in Karmøy.

[1] More information about the Norwegian State Housing Bank, which is the main instrument for governmental implementation of national housing policy in Norway, is available at: <http://www.husbanken.no/Toppmeny/English/Contact%20us.aspx> [read: 2007-02-10]

As described in the papers, the data on housing prices and attributes comes from three sources. One source is a questionnaire produced by Statistics Norway that was sent to everybody who has bought a freeholder dwelling in the given period. According to Statistics Norway, approximately 80% of the questionnaires were returned. The second source is the online Real Estate Registry in Norway, where information on properties in Norway is included. From 1995 this register contains information from the land register ("tinglysingsregisteret") and the so-called GAB-register. GAB is an abbreviation of ground parcel, address, and building. The Real Estate Registry is continuously being updated and improved.

Information on some variables is found in both of these data sources, while information on other variables is found in only one source. In both registers there are observations with missing information on independent variables. There is a tendency that missing information could be more prevalent among the oldest houses in the sample. To some extent lack of information is therefore positively related to the age of the houses. For other variables there are no indications in the data that the samples are not reasonably representative for the total number of transactions. In particular, the possibility of spatial variation in missing information has been searched for. Despite some signs of varying inter-municipality practice in reporting data from transactions to official registers, no substantial tendency of systematic spatial variation in available information has been found.

The reliability of the information has been tested by comparing the two main data sources with the third data source, taken from sales descriptions from the local real estate agents. Simple linear regressions were run between variables that existed in all three datasets. If R^2 and the beta coefficient in the linear regression are 1, there is a perfect fit between the datasets. In this way it was possible to detect some important problems in the first two above mentioned data sources. For this reason postal codes and housing types have been collected from the Real Estate Registry, and the size of the house was collected from the questionnaire.

Information on the lotsize in square meters, postal codes, coordinates, and type of building was collected from the Real Estate Registry. Information on the sales prices, internal living space, if the property included a garage, the age of building, whether it has been rebuilt, and the number of toilets as well as time of sale is collected from Statistics Norway. When missing or erroneous, the information on the sales price, age of house, the existence of a

garage, and whether a house has been rebuilt has been gathered from the Real Estate Registry if available and assumed to be reliable. An example of information that is not found reliable is the following: The existence of a garage may be missing in the data from the questionnaire. The existence of a garage should be registered in the Real Estate Registry. Sometimes the date of when the garage was finished is not included. In these cases the information is not found reliable, since the garage could have been built after the house was sold.

By combining these main two sources of data, the size of the samples have been increased compared to what would have been the case if only one of the sources had been used. The sample that stems from the Haugesund area has also been increased due to information on sales descriptions from several local real estate agents. Information from only one real estate agent was collected for the Stavanger area. The correction for errors in the data and the punching of additional information on explanatory variables that were missing has been performed manually.

With some modifications, the quality of the information should be good. A variable that may be somewhat uncertain is the rebuilt-variable. For instance, Statistics Norway mentions that a new owner does not always know whether a house has been rebuilt earlier. Finally, in some instances, observations that clearly do not belong to the sample have been excluded. Examples are houses with more than 6 toilets, houses with a very low price, and that also have an age of 0 (the house may not be finished when sold) and are very small, in addition to old houses with no toilets (which probably may be characterized as sheds, and what is sold is only the lot).

After completion of this work, if information on some explanatory variables is still missing, such an observation will not be included in the sample. The sample selection is therefore mainly exogenous. It is very common in applied work to ignore observations that have missing information. This may or may not be a problem depending on the reason why the information is missing. If the data on the explanatory variables is missing at random, and given enough variation in the independent variables of the resulting subpopulation, the effect of missing observations is a smaller sample. This makes the estimators less precise, but there will be no bias in the estimated results. There are ways to use the information on observations where variables are missing. These methods are, however, rarely used since the improvement in the estimators is usually very small, and the methods are complicated.

In addition to house prices, and characteristics of houses, information on distances between postal codes has been used. The matrices of physical distances and travelling time were prepared by the Norwegian Mapping authority. The calculations were based on the specification of the road network into separate links, with known distances and speed limits. Distances are given from a data base with an accuracy of ± 2 meters for each link. In calculating traveling times, the fact that actual speed depends on road category has been accounted for. Information on speed limits and road categories is converted into travelling times through instructions (adjustment factors for specific road categories) worked out by the Institute of Transport Economics. The center of each postal delivery zone is determined by using detailed information on residential densities and the road network. Finally, both the matrix of distances and the matrix of travelling times are constructed from the shortest route algorithm. Interzonal distances are measured between zonal centers. In general it is only travelling time that is used in the thesis, based on goodness of fit criteria.

The division of the regions into postal zones corresponds to the most detailed level of information that is available on work locations for the study period. The information is based on the Employer-Employee register, and was provided to us by Statistics Norway. According to Statistics Norway, the division of workers into postal delivery zones is characterized as preliminary. To my knowledge, however, it is the best existing data in Norway for the study period**.** Due to a mismatch between the number of postal codes in the distance matrix and the matrix of information on jobs, some jobs have been relocated to the closest existing postal code. Likewise, there are also some postal codes existing in the house price data, which do not exist in the matrix information on jobs and vice versa. Access to data on zonal population was gained through the Central Population Register in Statistics Norway.