A Review of Recent Empirical Studies on Property Price Gradients

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Abstract

This paper reviews the empirical studies that have been conducted on property price gradients. There are basically two different methodologies of estimation and three different assumptions on the spatial structure of an urban area. The two methods are: (1) the hedonic pricing model and (2) the repeat-sales model; and the three assumptions are: (1) the monocentric assumption; (2) the non-monocentric/polycentric assumption; and (3) no a priori assumption about the urban spatial structure. The methodologies and the findings of these previous studies are compared and analyzed to clarify the path for further studies.

Introduction

The value of residential housing has long been shown to be dependent on location. The importance of location on the value of housing was first explained by von Thünen (1826), who stated that if there is a central marketplace in a farming area, where transactions of agricultural products are concentrated, then it saves commuting costs for the farmers to travel between their farmland and the central marketplace. This early spatial theory of agriculture was then modernized by Alonso (1964), who proposed the bid-rent curve. Since then, a large literature, including a vast number of empirical studies, has emerged to test the predictability of urban spatial theory by applying hedonic regressions and repeat sales models.

The classical model, put forward by von Thünen, can be found in many textbooks on urban economics (*e.g.*, McCann, 2001). In von Thünen's model, there is a specific point in the market at which all transactions in agricultural products take place. Farmers need to bring their yields to this marketplace to conduct transactions for profit; and the cost of transportation increases with the distance to the marketplace. As such, von Thünen's model predicts a negative land-rent gradient, by which the rent for farmland will decrease as the distance to the marketplace increases, to compensate for higher transportation costs.

Instead of examining the market for farmland, Alonso's bid-rent model discusses the housing market in terms of a monocentric assumption. A central business district (CBD) is the marketplace at which jobs and other economic activities are concentrated; and each of the households should have at least one member who needs to travel frequently between the residential location and the CBD. The level of utility of each household was expressed as a function of the amount of land (housing) the

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household occupies, the amount of all other goods they own and the distance from which they must travel to reach the CBD. Alonso defined the bid-rent function as the set of prices (the bids) the household would offer for land at different distances to the CBD, holding the utility at a constant level. As such, this model predicts that the bid-rent curve should have a negative slope.

The analysis of the effect of location on the value of housing property was then largely dominated by the bid-rent function. It is common to include the distance to the CBD as an independent variable in empirical studies of property prices. The inclusion is based on the assumption that there is a CBD in the area concerned (*i.e.*, the monocentric assumption). Many studies, both theoretical and empirical, such as those by Muth (1969), Mills (1972), Burrell (1985), and Atack and Margo (1998), have been carried out on the basis of this assumption. However, some empirical studies have failed to show a significant negative coefficient for the distance-to-CBD variable (*e.g.*, Heikkila, et al., 1989). This raises concerns about the validity of this assumption, as well as about using distance-to-CBD as the proxy. There have been numerous attempts to deal with this concern, as listed in Exhibit 1.

One of the explanations for why a non-negative property price gradient is obtained is that the monocentric hypothesis has been wrongly applied in estimating polycentric gradients. For example, Dubin and Sung (1987) showed that if subcenters do exist, then each of them would exert a certain degree of influence on housing values; and that the distance-to-CBD exerts a similar influence on housing values as any one of the subcenters. As an alternative to the monocentric assumption, a large literature exists on polycentric urban spatial structures. Christaller's (1933) central place theory was the first attempt to formulate a theoretical portrayal of multiple market centers. He derived a hexagonal hierarchy of market centers and sub-centers based on the assumptions of demand thresholds and market ranges. His model was reformulated in Lösch (1938) and translated by Lösch (1954) and Baskin (1966). More recently, Papageorgiou and Casetti (1971) put forward the notion of the multi-center bid-rent surface based on the Alonso model; Odland (1978) worked out the conditions for the existence of multi-center cities; Fujita and Ogawa (1982) gave a model of non-monocentric urban land use without any a priori specifications on employment or residential centers. Empirical studies such as those by Sivitanidou (1996, 1997) that examined the effects on property values of the distance to the center and to the sub-center, are based on the polycentric assumption. Nevertheless, the assumption of a monocentric or polycentric city is unnecessary, as there is no way to test the validity of this assumption. On the contrary, the current method of estimation allows price gradients to be studied without the need to make assumptions about the location of the center.

Empirical Models

Two main empirical techniques are used in analyses of property values. One is the hedonic pricing model and the other is the repeat sales model. The hedonic price model is a multiple regression of the price of a heterogeneous good on a number of characteristics associated with each good (Rosen, 1974). The coefficients of the

Exhibit 1
Framework of Studies on Property Price Gradients

Bid-rent curve
(Alonso 1964)

Analytical Studies

Monocentric assumption

e.g., Muth (1969); Mills (1972)

Non-monocentric assumption / Polycentric assumption

e.g., Fujita and Ogawa (1982); Lansberger and Lidgi (1977); Odland (1978); Romanos (1977); Papageorgiou and Casetti (1971)

Empirical Studies

Monocentric assumption

Hedonic regression

Distance to CBD is included in the regression

e.g., (with significant negative price gradient)

Atack and Margo (1998); Mok et al. (1995); Dunse and Jones (1998); Cheshire and Sheppard (1995)

Commuting cost and commuting time are used in place of distance to the CBD

e.g., (with significant negative price gradient)

Burnell (1985) Coulson (1987); Tse and Chan (2003)

Consider the Spatial Autocorrelation

e.g., (with significant negative price gradient)

Carter and Haloupek (2000); Pace and Gilley (1997).

Other attempts to improve model efficiency

e.g., (with significant negative price gradient)

Coulson (1991) Diamond and Gerety (1995) – "GFT model with heterogeneous preference on distance to CBD"; Söderberg and Janssen (2001) – "directional differences are allowed"

Repeat sales model

e.g., (with significant negative price gradient)

McMillen (2003)

Non-monocentric assumption / Polycentric assumption

e.g., (with significant negative price gradients against the centers)

Heikkila et al. (1989) (insignificant gradient against the CBD, but significant against other subcenters); McDonald and McMillen (1990); Sivitanidou (1996, 1997); Dubin and Sung (1987)

No assumption on the urban spatial structure; revelation of price contour by the interacting location and time dummy variables

Hedonic regression

e.g., Chau and Ng (1998); Yiu and Wong (2004)

Repeat sales mode

e.g., Yiu and Tam (2004)

hedonic regression are regarded as the hedonic (implicit) prices of the characteristics. The heterogeneous nature of housing or commercial properties makes property markets a good candidate for the application of the hedonic regression. Physical attributes, neighboring characteristics and locational factors are commonly considered in studies on housing prices. If the monocentric assumption is used, then the distance-to-CBD variable is included.

The hedonic pricing model is widely used as it requires relatively fewer transaction records to estimate the value of housing, and it is more flexible for researchers to use when including different explanatory variables in the regression or when changing the functional form of the model. This advantage, however, is also the major weakness of the hedonic price model. The choice of independent variables and functional form is related to specification bias and inefficiency of estimation (Case, Pollakowski and Wachter, 1991). Studies on the choice of functional form and explanatory variables for hedonic price functions have already given rise to a large body of work (e.g., Cropper, Deck and McConnell, 1988; and Can, 1992).

Another approach of estimation is the repeat sales model, which was first formulated by Bailey, Muth and Nourse (1963). Each observation used in the repeat sales model is a pair of transactions for a single piece of property. This pair-wise feature frees researchers from the difficulty of choosing explanatory variables, as the attributes of each property will be cancelled out in the estimation model. Yet, the repeat sales model is subject to the availability of a large number of transaction records in order to obtain an adequate number of observations on repeat sales (two or more sales of a property) for the estimation. This is not a common trait in most property markets. In addition, the repeat sales model is very sensitive to influential observations (Messe and Wallace, 1997).

Since both techniques possess their strengths and weaknesses, there is no general rule to guide the choice of a methodology for drawing up a housing price index. The decision should be made with respect to the type of analysis that will be conducted (Messe and Wallace, 1997). Yet, judging from the literature on property price gradients, hedonic regression analysis is employed far more often than the repeat sales model. This is because no specific assumption except the location of the CBD is required to include the factor of distance-to-CBD in the hedonic model; while if the distance-to-CBD is included in the repeat sales model, an extra assumption needs to be made in addition to the assumption on the location of the CBD. This additional assumption is that the price gradient is dynamic rather than static; thus, the repeat sales model can estimate the price gradient at each point in time. This assumption may not be true in some studies, especially when those transactions occur within a relatively short period of time.

The objective of this paper is to critically review the assumptions and methodologies adopted in previous studies on property price gradients. Studies based on the monocentric assumption are reviewed next, followed by a discussion of the studies using the non-monocentric assumption, the polycentric assumption and those contain

no assumptions about spatial structure. Suggestions for further studies and concluding comments complete the discussion.

Studies with the Monocentric Assumption

Summaries of the studies that have been reviewed are presented in Exhibit 2. These studies have been analyzed in terms of their estimation method, assumption made on the location of the centre, the data used, and the results obtained.

Using the Distance-to-CBD as the Gradient Variable

Atack and Margo (1998) examined the price gradient of vacant urban land in New York City over a 66-year period, from 1835 to 1900. No housing attributes were included in the hedonic regression, since this was a study of vacant land. The dependent variable is the logarithm of land price per square foot. The independent variables are the distance to the New York City Hall, which is the sole selected CBD; and the dummy variable is whether or not the lot was a corner (boundary) lot. With separate cross-sectional regressions on the data for different years (1835, 1845, 1960, 1870, 1875, 1880, 1885, 1890, 1895 and 1900), the authors showed that, prior to the American Civil War (1861 to 1865), the price gradient was steeper than in the post-war period (after 1865). Improvements in public transportation and a wider spread of economic activities contributed to the fall in the price gradient. The location of the boundary was shown to have a positive effect on the price of vacant land. This historical study showed the effects of the advancement of public transportation and growing prosperity on the price gradient.

Distance-to-CBD is commonly included in hedonic studies of a large area. For example, Mok, Chan and Cho (1995) studied the hedonic price of private housing properties in Hong Kong. They incorporated the Box-Cox Transformation in the model to relax the assumption of the functional form of the model and obtained significantly negative price gradients. However, as they confined their examination to the area within a 300-meter radius of the properties, the results have very limited implications for the monocentric assumption. Dunse and Jones (1998) also attempted to study the effect of location on office rents in the center of Glasgow. They found a significant negative price gradient to a particular street that they argued was the heart of the CBD. Unfortunately, there were several other location-specific dummy variables in their model, such as Central Core, Central Mid, Central Outer and Peripheral. These probably distorted the estimation of the distance-to-CBD. Instead of a two-dimensional distance-to-CBD variable, Cheshire and Sheppard (1998) derived a three-dimensional price contour estimation model, which allowed for different price gradients at different orientations. By allowing differences in topology, accessibility, land use and amenities, this model was a great improvement over the two-dimensional model. Yet, it still relies on a monocentric assumption and a distance-to-CBD proxy.

Using the Cost or Time Required to Commute to the CBD as the Gradient Variable(s)

In the analytical framework of the bid-rent curve, the cost of transportation (commuting) from the property to the CBD, instead of the distance-to-CBD, will be

Exhibit 2
Empirical Studies on Property Price Gradients

Articles	Hedonic (H)/ Repeat Sales (RS)	Monocentric (M)/ Polycentric (P)/	Place of Study	Description of Data	Major Results
Atack and Margo (1998)	H	M	New York, NY	1,127 observations, from 1835 to 1900. Cross-sectional analysis.	Found the change in price gradient in New York City before and after the Civil War. The price gradient before the war was steeper than that after the war.
Burnell (1985)	H	M	Illinois, IL	Observations from 104 suburban municipalities.	Showed that non-residential land use exerted a negative impact on the value of residential housing.
Carter and Haloupek (2000)	H	M	U.S.	349 observations from 1991 to 1992, within eight shopping malls throughout the U.S. Cross-sectional study.	Showed that the WLS correcting for spatial autocorrelation was superior to the hedonic regression without correction for spatial autocorrelation in the sense that the corrected model has a higher R^2 and adjusted R^2, and that the standard errors of the estimated coefficients were also lowered.
Chau and Ng (1998)	H	(A comparison between two railway stations)	Hong Kong, China	70 observations from 1977 to 1992. Panel data analysis.	Estimated the effect of the electrification of the Kowloon-Canton Railway on the housing price gradient. The price gradient flattened following electrification.
Cheshire and Sheppard (1995)	H (with Box-Cox Transformation)	M	Town of Reading and Darlington, U.K.	Listed asking prices of 840 properties around a short period in 1984.	Derived a three-dimensional price contour model of estimation to test the validity of the monocentric assumption. Obtained a highly negative and significant price gradient from the CBD when land attributes were incorporated.
Coulson (1991)	H	M (test of the monocentric assumption)	Pennsylvania, U.S.	406 observations in 1987. Cross-sectional analysis.	Tested the validity of the monocentric assumption. A negative price gradient was found and the monocentric assumption was proven to be valid.

Exhibit 2 (continued)
Empirical Studies on Property Price Gradients

Articles	Hedonic (H)/ Repeat Sales (RS)	Monocentric (M)/ Polycentric (P)/	Place of Study	Description of Data	Major Results
Coulson and Engle (1987)	H	M	Atlanta, Detroit, Houston, Los Angeles, Minneapolis–St. Paul and San Diego	Number of observations not mentioned, from 1974 to 1979. Panel data analysis.	Investigated the rent gradient with the transportation cost to the CBD. The "cost" was comprised of time cost, gasoline costs and other money costs.
Diamond and Gerety (1995)	H	M	Greenville, SC	358 observations from June to September, 1989. Cross-sectional analysis.	Formulated the Generalized Fechner-Thurstone model to estimate the price gradient, given that the consumer preferences on distance to CBD were heterogeneous.
Dunse and Jones (1998)	H	M	Glasgow city center	477 asking rents for office suites during 1994 and 1995.	Significant and negative price gradient from the heart of the CBD.
Heikkila et al. (1989)	H	M	Los Angeles, CA	11,000 observations in 1980. Cross-sectional analysis.	The estimate of the price gradient (the coefficient of the distance to the CBD) was not significantly different from zero. From this, the authors proposed that Los Angeles is not monocentric.
McDonald and McMillen (1990)	H	P	Chicago, IL	159, 176, and 208 observations for cross-sectional regressions for the years 1961, 1971, and 1981, respectively.	Estimated the land value functions in 1961, 1971 and 1981. The results showed that the area around O'Hare Airport has emerged as a major sub-center.
McMillen (2003)	RS	M	Chicago, IL	52,972 observations from 1983 to 1998. Repeat sales model.	Incorporated the price gradient into the Bailey et al. (1963) RS model. A significant negative price gradient was found that supported the view that Chicago is monocentric.

Exhibit 2 (continued)
Empirical Studies on Property Price Gradients

Articles	Hedonic (H)/ Repeat Sales (RS) (with Box-Cox Transformation)	Monocentric (M)/ Polycentric (P)/	Place of Study	Description of Data	Major Results
Mok et al. (1995)	H (with Box-Cox Transformation)	M	Hong Kong, China	1,027 transactions in August 1990 in a zone with a radius of 300 meters.	Significant negative effect of the distance-to-CBD.
Pace and Gilley (1997)	H	M	Boston, MA	506 observations in the 1970s. Cross-sectional analysis.	Showed that the simultaneous autoregression maximum likelihood estimates was superior to the ordinary least squares model, with a 44% decrease in the sum of square errors in SAR MLE.
Sivitanidou (1996)	H	P	Los Angeles, CA	539 observations from 1987 to 1992. Cross-sectional analysis.	Tested the relationship between the values of commercial properties to the "secondary" service center (a positive result was obtained). The results showed that the commercial firms did value access to the service center.
Sivitanidou (1997)	H	P	Los Angeles, CA	201 observations for the 1989 regression and 276 observations for the 1994 regression. Cross-sectional analysis.	Showed the flattening of commercial land value gradients in LA (proposed the conjecture of more dispersed patterns of business locations).
Soderberg and Janssen (2001)	H	M	Stockholm, Sweden	349 observations from 1992 to 1994. Panel study.	Estimated the price gradient within a small area (radius = 5 km), with directional price gradients. The gradient of East was the flattest.

Exhibit 2 (continued)

Empirical Studies on Property Price Gradients

Articles	Hedonic (H)/ Repeat Sales (RS)	Monocentric (M)/ Polycentric (P)/	Place of Study	Description of Data	Major Results
Tse and Chan (2003)	H	M	Hong Kong, China	Transactions of 600 housing estates are randomly drawn in the first half of 2000, cross sectional analysis, with the sub-sample size ranging from 204 observations to 406 observations.	Estimated the price gradient in Hong Kong with the transportation cost and time to the CBD. Negative price gradients (with respect to time and cost) were found.
Yiu and Wong (2004)	H	No assumption of center.	Hong Kong, China	2,095 Transactions from May 1991 to March 2001 in two adjoining districts.	Estimated the price contour in two districts of Hong Kong without relying on a priori assumption of the locations of centers. The results told the change of price gradients over time and implied an evolution of a centre.
Yiu and Tam (2004)	RS	No assumption of center.	Hong Kong, China	17,188 transactions (8,594 pairs) from Sept. 1992 to March 2001 for dwellings along a railway.	Compared several methods of estimating price gradients and develop one more method by the repeat sales model without relying on any assumption of the locations of centers.

optimized in household consumption. The widespread use of distance-to-CBD in the literature is probably the result of the ease of measuring physical distances on a map; or the lack of data on commuting costs.

Coulson and Engle (1987) used differences in commuting cost to explain variations in urban–suburban housing prices in the United States. Although the authors' aim was not to estimate the price gradient, their results showed that the cost of commuting from a suburban area to an urban area has a negative relationship on housing prices.

Burnell (1985) also used commuting cost to determine the accessibility (to the CBD) of residential housing. He assumed that the higher the commuting cost, the lower the accessibility. Based on this assumption, he obtained a positive coefficient for accessibility from the negative relationship between commuting cost and housing value. However, the assumption of a positive relationship between distance and cost may not be valid, especially when the subject area has a well-developed public transportation system. In addition, the cost of commuting may not completely correlate with distance, because of differences in topology and in the transportation facilities provided.

Commuting time is also commonly exploited as a gradient proxy. For example, Tse and Chan (2003) estimated the housing price gradient in Hong Kong by using both commuting cost and commuting time. They used random samples of transaction records for 406 housing estates and private buildings within the first half of 2000. In the cross-sectional hedonic regression, they used commuting cost, commuting time, age of dwelling and two locational dummy variables as the independent variables.[1] They found significantly negative housing price gradients with respect to both commuting cost and commuting time. This supported their assumption that the time spent on transportation is an economic disutility for the household.

It is notable that by using commuting cost and commuting time in the estimation, it is necessary to control for changes in cost due to inflation/deflation over time and for changes in commuting time due to advances in transportation. Tse and Chan's study was based on data within a half-year period and no substantial changes in commuting cost or commuting time took place during this period.[2] Tse and Chan's study was insightful in the use of commuting cost and time; but we are uncertain about the accuracy of their estimated price gradients, as two location dummy variables were included in the set of independent variables and these locational variables were actually highly collinear with commuting time and commuting cost.

Considering Spatial Autocorrelations

The failure of the monocentric gradient in empirical studies has raised questions about the heteroscedasticity of estimations due to spatial autocorrelations. The term spatial autocorrelation is an extension of the concept of serial autocorrelation in the field of time series analysis (Cliff and Ord, 1981). The residuals of a regression are said to be spatially autocorrelated if the value of the residual at location is consistently dependent of the value(s) of the neighboring residual(s). This problem arises because

the neighboring properties share some common attributes of location; for example, common public area, common public car park or common shopping mall. Dubin, Pace and Thibodeau (1999) presented a comprehensive discussion of this problem and described how spatial techniques can be used to improve the precision of estimations. Wiltshaw (1996) confirmed possible limits to the accuracy and efficiency of hedonic price estimates without considering the issue of spatial autocorrelation. Other studies, such as those by Can (1992), Can and Megbolugbe (1997), Pace and Gilley (1997, 1998) and Goetzmann and Spiegel (1997), have considered and/or tested the presence of spatial autocorrelation.

Numerous methods have been proposed to test and correct for spatial autocorrelation. For example, Carter and Haloupek (2000) used the weighted least squares (WLS) method to "spatially randomize" the residuals. They made the assumption that the rent of a store in a mall is negatively related to its distance to the center of the mall. The data set included information on the rents paid by 689 mall stores in eight shopping malls throughout the U.S. The logarithm of rent was the dependent variable and the distance to the mall's center was included in the set of independent variables. The authors first used the ordinary least squares (OLS) method to obtain the hedonic regression result. What they found in the OLS was that the residuals clustered at points along the shopping mall, with large positive residuals near the centers of the malls and large negative residuals at the peripheries. They interpreted these observations on clustering as evidence of spatial autocorrelation. Their model rectifies the spatial error by about 4%.

Pace and Gilley (1997), on the other hand, performed simultaneous autoregression (SAR) on Harrison and Rubinfeld's (1978) data. They also performed an OLS estimation to serve as the benchmark. The logarithm of the transaction price was the dependent variable and distance to the employment center was included in the set of independent variables. When comparing the OLS estimates and the SAR maximum likelihood estimates (MLE), it was observed that the SAR MLE possessed a higher R^2 and that the sum of the square errors of SAR MLE was 44% less than that of the OLS estimation.

However, no studies were found that successfully show a significant monocentric gradient after the rectification of the spatial autocorrelation. Further studies in this area are clearly needed.

Other Attempts to Improve the Efficiency of Models

There are many other attempts to salvage the monocentric assumption. Söderberg and Janssen (2001) carried out estimations of the price gradients of apartments within a small region in Stockholm from the first quarter of 1992 to the last quarter of 1994.[3] Instead of the traditional distance-to-CBD variable, they incorporated interactive dummy variables between direction (east, south and west, with north as the base) and distance. The results showed that the price gradients in all directions were negative, with the eastern gradient the least negative. The authors explained that the eastern area was traditionally the most desirable residential area in Stockholm.

Diamond and Gerety (1995) allowed for heterogeneous consumer preferences when calculating distance-to-CBD, in contrast to the conventional assumption of a homogeneous preference. They put forward their Generalized Fechner-Thurstone model to estimate the price gradient in Greenville, South Carolina.

McMillen (2003) is the first to apply the repeat sales model to estimate price gradient. He studied transactions of single-family houses in the City of Chicago from January 1983 to December 1998. The objective of his study was to test the gradient of return of a monocentric city. McMillen included interactive dummy variables for distance-to-CBD and period of the transaction, in which he made the assumption that the price gradient varied over time. But he included the age of dwellings in the model, which is suspected to be exactly collinear with the period of the transactions. However, he got negative price gradients in this part of analysis. In the second part, he smoothed the time series price index by using the Fourier approach to repeat sales price index. The results supported the negative price gradient in Chicago.

Studies with the Non-monocentric/Polycentric Assumption

The rationale behind the monocentric model is that employment or any other business activities are centralized at the CBD, such that the cost to access the CBD is a major determinant of property values. However, the monocentric assumption has neglected the possible effects, which may not be negligible, of the presence of subcenters or other centers. Therefore, a non-monocentric or polycentric assumption was suggested by Heikkila, et al. (1980). In their study of residential properties in Los Angeles, they included distances-to-CBDs and eighteen other housing attributes in a hedonic regression model. It is interesting to note that while all of the other eighteen attributes are significant with expected signs, the coefficients of the distances-to-CBDs are positive and not significant. The rationale behind their multi-centers setting is that different centers should be responsible for different functions in the city, and that each of these functions should have its value assessed in terms of the nearby properties. Examples of these functions may include employment center, shopping center, recreational center, and so forth.

McDonald and McMillen (1990) studied the change of land value in Chicago between the 1960s and the 1980s. They showed that the conventional CBD of Chicago was still an important employment center; while the area around O'Hare Airport had emerged as another major sub-center for employment.

Sivitanidou (1996) studied the value of office-commercial firms in Los Angeles. She identified a main service employment center and eight sub-centers. She found that office–commercial firms treasured access to the sub-centers, and that the main center did not substitute perfectly for the sub-centers. Sivitanidou (1997) further showed that the effect of the main center and of the group of sub-centers on the value of the office-commercial firms was weakening (i.e., the price gradient from the centers was flattening) in the period between 1989 and 1994. The findings matched more closely with the dispersal of business locations during this period. The findings also support the argument that price gradients are changing over time.

Dubin and Sung (1987) attempted a ray estimation of price gradients. They claimed that the non-directional distance measurement could not reflect the uneven development of the transportation system. They were also concerned about the effects of sub-centers on housing values. Their results showed that the CBD appeared to exert an effect similar to the other sub-centers. Therefore, the presence of sub-centers or other centers should be taken into account in studies on price gradients.

Studies of Urban Spatial Structure without the Monocentric/Polycentric Assumption

The above polycentric studies assume the existence of different centers with different roles and functions. Although Sivitanidou examined the substitutability of the centers, it is not easy to differentiate the role of each sub-center. This problem would be aggravated if the subject area is self-contained (*i.e.*, each sub-center performs almost all the required functions and is almost perfectly substitutable with another). Some studies, for example, those by Odland (1978) and Coulson (1991), tried to formulate the conditions for the existence of a non-monocentric city and empirically test for the monocentric assumption. These studies shed light on choosing the "right" urban spatial structure in studies on property price gradients, as they gave benchmarks for choosing the urban spatial structure a priori to the price gradient analysis. However, the assumption on the locations of centers makes the price gradient estimation tautological.

Using Location Dummy Variable(s). To cope with this problem, a location dummy variable can be used without any assumptions about the location of the centre. For example, Chau and Ng (1998) examined changes in the price differentials of housing between two railway stations in Hong Kong. In 1982, the major railway in Hong Kong underwent electrification, expanding its carrying capacity and shortening traveling times. The estimated coefficient of the interactive dummy variable for time and location was negative, from which the authors concluded that the electrification of the railway flattened the price gradient between the two railway stations. Unfortunately, the study had 70 transactions only, and transactions in certain time periods were arbitrary truncated.

The advantage of using the location dummy variables instead of the distance (or commuting cost, commuting time) to CBD is its simplicity and the relaxation of assumptions. No measurements are needed and no a priori assumptions on the locations of centers are required. Yiu and Wong (2004), who examined the expectation effects of transportation improvement works on housing prices in Hong Kong, used location dummy variables in a hedonic pricing model. They collected 2,095 transactions from May 1991 to March 2001. Without relying on an a priori assumption of the locations of centers, the authors estimated a price contour (a price-distance-time estimation) to explain the temporal structure of the urban space.

Yiu and Tam (2004) further applied the repeat sales model with interactive location and time dummy variables), to estimate price gradient. They extracted transaction records of housing along a major railway in Hong Kong from September 1992 to March 2001. By assuming that the price index of each station changes temporally,

the authors let the location dummies interact with the time dummies. They then obtained the series of price indexes for all of the stations. These locational price indices were used to construct the price contour along that railway. This method permits the data to tell the locations of centers and the evolution of centers over time.

Conclusion

This paper reviewed the results of some existing studies on property price gradients. The previous empirical studies were divided into different groups, according to their underlying assumptions on spatial structure. The findings show that the recent focus on polycentric studies of many metropolitan cities challenges Alonso's monocentric assumption. There are investigations that make no assumption of center but use the estimated price gradient to reveal the spatial structure. They open a new approach to testing the hypotheses of monocentric and polycentric price gradients.

The principles and limitations of the two estimation approaches, *vis-à-vis* the hedonic pricing model and the repeat sales model, were also reviewed. The recent development on the correction of spatial autocorrelation in the estimation has been covered in this study. This study paces the road for further empirical studies on property price gradient.

Endnotes

1. In their model, the authors assumed the existence of a linear relationship between housing prices and commuting costs, and a non-linear relationship between housing prices and commuting time, as well as housing prices and the age of the housing. In making their assumptions, they used the Box-Tidwell transformations on these two variables.

2. Refer to *Hong Kong 2000*, Information Services Department, the Government of the Hong Kong SAR, China.

3. Coulson (1991) had used a similar setting to determine the direction effects on the price gradient. To avoid repetition, only the study of Söderberg and Janssen (2001) is discussed here.

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