A Framework For Analysing House Prices Using Time, Space And Quality Criteria[*]

Shanaka Herath[†], Gunther Maier

Research Institute for Spatial and Real Estate Economics
WU Wien

1. Introduction

An increasing number of theoretical and empirical studies have dealt with the determinants of house prices over the last several decades. The hedonic price method (HPM) is undoubtedly one of the most popular and most used methods employed in these studies. Most early hedonic models of house prices typically included several structural characteristics of housing units as exogenous variables. Subsequently, spatial hedonic models emerged with the widespread use of locational and neighbourhood concepts in urban economics. Hedonic models were further expanded recently to include temporal dimension as a result of increasing number of panel applications in real estate and urban economics literature. The extended model which is known as the spatial panel model takes into account both spatial and temporal dynamics of house prices. The purpose of this paper is to combine structural characteristics of houses along with spatial and temporal aspects within a single analytical framework, and put forward an alternative framework to the spatial panel models.

The HPM is also known as the hedonic demand theory or the hedonic regression. This methodology estimates the value of a commodity or alternatively the demand for a commodity. The HPM is used in consumer and market research (e.g. Hirschman and Holbrook, 1982), calculation of consumer price indices (e.g. Moulton, 1996), tax assessment (e.g. Berry and Bednarz, 1975), valuation of cars (e.g. Cowling and

Cubbin, 1972), computers (e.g. White et al, 2004) etc. in addition to real estate economics and real estate appraisal, the topic discussed in this paper. The methodology has recently been used extensively in real estate and housing market research: some of the most applied areas include correction for quality changes in constructing a housing price index, assessment of the value of a property in the absence of specific market transaction data, analysis of demand for various housing characteristics or housing demand in general, and testing assumptions in spatial economics.

The general idea of the HPM is as follows: commodities are characterized by their constitute properties, hence the value of a commodity can be calculated by adding up the estimated values of its separate properties. According to this informal definition, a couple of requirements need to be fulfilled in order to be able to calculate hedonic prices. The first requirement is that the composite good under consideration could be reduced to its constituent parts. The second is there is a value for those constituent parts in the market or at least it is possible to estimate an approximate value.

The idea of hedonic (implicit) prices has its origins in microeconomics. Determination of demand of certain goods - particularly of those that come as composite goods with several intrinsic features or characteristics – becomes increasingly difficult. There were several different applications that considered this "multi-dimensional" nature of houses as a commodity, but Rosen (1974) was the first to clearly refine the concept by mapping out how the hedonic prices represented the joint envelope of bids (from demand) and offers (from supply).

Urban economists demonstrate that not only physical characteristics, but also locational characteristics partly determine the overall level of services offered by a housing unit. Subsequent hedonic papers, therefore, incorporate locational variables explicitly in addition to structural characteristics. A justification for these locational determinants of house prices is very well articulated in the urban economics literature. For instance, most of the scholarly work on urban monocentric models include either distance to the city centre, travel time or travel cost in the model specification to capture these price dynamics generated by location in space. This paper, among other things, examines the widely accepted hypothesis that house price is determined partly by locational characteristics.

Most macroeconomic studies available on temporal dynamics of house prices emphasise on changes of macroeconomic variables and their co-movement with house prices. A new class of hedonic models, spatiotemporal housing models, on the other hand, considers spatial and temporal determinants of house prices simultaneously. In spatiotemporal models, the hedonic model is augmented to include previous values of the dependent and explanatory variables from nearby observations or regions. These spatiotemporal models deal with change of explanatory variables X over time and resulting change in house prices Y, and contain both time as well as space-time lags of the model variables. A detailed account of these spatial and spatiotemporal models is provided by LeSage and Pace (2004) and Anselin et al. (2004).

The main purpose of this paper is to combine structural characteristics, spatial attributes and temporal dynamics of house prices within a single analytical framework. The first part of the paper deals with the research question "what determines house prices?" This section provides a discussion of theoretical and methodological developments related to the hedonic regression, spatial hedonic models, and temporal models of house price dynamics. The latter part of the paper deals with a conceptual composite model that incorporates these three pillars of house price determinants, i.e. structural characteristics of houses, spatial attributes and temporal dynamics. The research question addressed in this section is whether the proposed composite model produces unbiased and consistent estimates of implicit price of characteristics. If the error term of the composite model is stochastic with independent and identically distributed (iid) characteristics, then it provides statistical evidence that house prices are determined by a combination of structural characteristics, spatial attributes and temporal dynamics.

The remainder of the paper is structured as follows: Section 2 presents a brief overview of historical developments related to the methodology as presented in previous literature. It also provides an overview of the urban economics literature on spatial dynamics of house prices based on monocentric and polycentric models. This section also looks at drivers of temporal change of house prices. Section 3 reviews different estimation techniques and issues related to functional form and model specification of the composite model. Section 4 concludes the paper by providing a summery of the discussion.

2. Literature review

2. 1. Housing characteristics and house prices

The number and amount of distinctive features a housing unit possesses determines the quality of services that particular housing unit provides. Since the HPM offers a basis to estimate demand and prices for composite commodities, the method can be applied to estimate house prices taking into account the specific characteristics of housing units. The heterogeneous nature of real estate properties in fact justifies the use of HPM for estimating their value and demand. The HPM has, therefore, been extensively used in real estate and housing market research in the recent past.

There is no consensus among scholars as to who first introduced the method of hedonic regression even though most of the scholars agree that it was Court (1939) who first used the HPM. Accordingly, Bartik (1987), Goodman (1998), Robert and Shapiro (2003) among many others argue that the first actual estimation of a HPM was a hedonic price index for automobiles by A.T. Court (1939). These scholars document that the methodology was popularised by Zvi Griliches in the early 1960s. One reason to consider Court's study as a significant contribution is that it deals with problems of non-linearity and with changes in underlying goods bundles (Goodman, 1998). Robert and Shapiro (2003), commenting on Court's methodology, contend that "…implicit price components for each of a bundle of product characteristics are determined by a regression procedure that expresses the price of a product as a function of the coefficients associated with each characteristic. The price of a new product (or different product) can then be compared with that of the previously existing product when one utilizes these coefficients…" They further highlight that Court (1939) and Griliches (1961) allow for time dependence that does not require any new methodology making it possible to simply use the previous time-independent methodology restricting the regression to two consecutive periods. This will calculate a measure of overall price change for the hedonic commodity.

A second group of scholars pioneered by Colwell and Dilmore (1999) demonstrate that Haas (1922a, 1922b) conducted a hedonic study more than fifteen years prior to A. T. Court even though he never used the term 'hedonic'. Haas analysed price per acre adjusted for year of sale, road type, and city size, using data on 160 sales

transactions gathered from farm sales in Minnesota. The independent variables in the hedonic analysis included depreciated cost of buildings per acre, land classification index, soil productivity index, and distance to the city centre. Colwell and Dilmore (1999) argue that Haas was influential but deny making a comprehensively strong case for Haas as the pioneer to estimate a hedonic model. Surprisingly, their alternative hypothesis is not Court (1939), but Wallace (1926), who used data aggregated by county to calculate comparative farm land values in Iowa.

Many other scholars contributed to the HPM over the years although the HPM is derived mostly from Lancaster's (1966) consumer theory and Rosen's (1974) model. The following section looks at the historical development of the HPM. Houthakker (1952) takes into account the problem of quality variation within the theory of consumer behaviour. He leaves out a multitude of corner solutions necessitated by conventional demand theory and assumes that consumers purchase only a negligible fraction of all goods available to them. This treatment is preserved by many subsequent authors to maintain simplicity in the analysis. This early contribution of Houthakker was later developed and extended by Becker (1965), Muth (1966), and Lancaster (1966) to explicitly take in to account the utility bearing characteristics in the context of consumer behaviour.

Griliches (1958) revived the HPM by further developing Court's work. Griliches's paper embedded technological change and innovation into hedonic prices through quality of goods. This hedonic model on demand for fertilizer contributed to popularise the HPM at the early stage. Demand for fertilizer relates prices and mixes of different components of fertilizer (nitrogen, phosphoric acid and potash) to derive better weights, which in turn are used to develop a series of constant quality fertilizer quantities and prices. Griliches's (1961) work on automobile price indices using automobile models as unit of analysis attracted considerable attention although it was published in an 'inaccessible' publication (Goodman, 1998).

Most important theoretical foundations of the HPM are *Lancaster's consumer theory* and *Rosen's model*. These scholarly works are considered early but significant contributions to the development of HPM. Lancaster (1966) establishes microeconomic foundations for analyzing utility-bearing characteristics and applies that to a range of topics including housing market, financial assets, the labour-leisure

trade off, and the demand for money. In his model quantities of goods and quantities of characteristics are linked by a fixed relationship called "household production function". While households face a budget constraint defined over quantities of goods, they derive utility from the quantities of characteristics these goods do "produce". With this model, Lancaster (1966) focuses on the demand side of the market.

Rosen (1974) integrates the HPM into standard economic theory. Inspired by work of Houthakker (1952), Becker (1965), Muth (1966), and Lancaster (1966), he derives "bid functions" of utility maximizing consumers and "offer functions" of profit maximizing producers and shows that in equilibrium the hedonic price function represents the joint envelope of these functions. In this form Rosen put forward a meticulous explanation of the implicit market and hedonic prices in the context of differentiated products. Using a vector of objectively measured characteristics representing a class of differentiated products, he observes product prices and the amounts of characteristics associated with each good to estimate a set of implicit or hedonic prices. Because of the joint derivation of the hedonic price function from the supply and the demand side, Rosen argued further that the entire set of implied prices guides both consumer and producer locational decisions in characteristics space. His study extends to analyse buyer and seller choices, market equilibrium and the empirical implications of the HPM.

Rosen's theoretical foundation leads to a two step approach, which works as follows: first, a hedonic equation is estimated. Subsequently, the implicit price of a characteristic is derived as the partial derivative of the hedonic equation with respect to that characteristic. Depending on the functional form involved, this derivative has to be evaluated at a particular bundle of characteristics. In this context, the empirically derived prices are embedded in a system of demand and supply equations.

In Rosen's model, income is directly incorporated in the budget constraints of the consumer. This implies that the consumer's marginal willingness to pay for a certain implicit attribute may also change with his income. Buyers bid price (or willingness to pay) for an attribute is a function of the utility level, the buyer's income, and other variables which influence tastes and preferences including education, age etc. An inverse demand function can be estimated by using the marginal price as an endogenous variable in the second-stage simultaneous equation. If it is possible to

trace back the inverse demand function based on the implicit marginal price function, the utility change with respect to certain quality changes can also be measured by integrating the inverse demand.

Lancaster's and Rosen's ideas differ from each other basically in two ways: the functional form of hedonic regression and the answer to the question whether the consumers buy a bundle of goods or separate goods. The fact that a bundle of goods or separate goods are purchased have an impact on the implicit market as follows. The Lancastrian index (1966) is based on the idea that usefulness of goods depends on their characteristics, and goods can be arranged into groups based on their characteristics. Consumers buy goods within groups based on the number of characteristics they possess per dollar. According to Lancaster, the consumer's utility originates from the different characteristics (not just the quantities of the different goods) which the goods themselves provide. Goods are members of a group and some or all of the goods in this characteristic group are consumed in combinations, subject to the consumer's budget. Accordingly, the Lancastrian index is more appropriate for consumer goods.

Rosen's model (1974), on the other hand, has two distinct steps: an initial step involving an estimation of the marginal price for the attribute of interest (by regressing the price of a commodity or good on its attributes), and a second step to identify the inverse demand curve (or the marginal willingness to pay function) from the implicit price function estimated in the first stage. Rosen maintains that there is a range of goods, but that consumers typically do not acquire preferred attributes by purchasing a combination of goods, rather each good is chosen from the spectrum of brands and is consumed discretely. Accordingly, Rosen's model looks appealing to estimate demand for durable goods.

Model specifications in these two theories differ as well. Lancaster's consumer theory assumes a linear relationship between the price of goods and the characteristics contained in those goods. Implicit prices are therefore constant over their range of characteristic amounts, and only a change in the combination of goods consumed is possible. On the other hand, Rosen's model assumes a nonlinear relationship between the price of goods and their inherent attributes. The implicit price is not a constant, but a function of the quantity of the attribute being bought and of the quantities of other

attributes associated with the good (depending on the actual functional form of the equation).

2. 2. Spatial attributes including location and accessibility

The standard urban economic monocentric model developed initially by Alonso (1964) suggests that the principal variable causing variations in constant-quality house prices within a metro area is land price. A typical land rental equation includes distance from the CBD, agricultural land rental, a conversion parameter that depends on transport cost per mile and community income suggesting that distance to the CBD should be included in any house price model. Alonso's model has been empirically tested by many scholars (Ball (1973) and Richardson (1988) provide literature surveys on this topic).

Figure 1 The Monocentric Model by Alonso (1964)
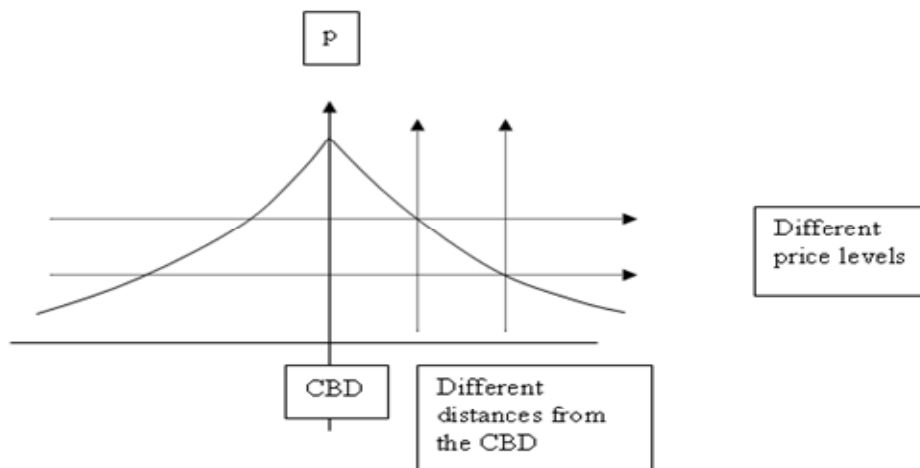
Source: Authors notes

Figure 1 depicts the basic idea behind the monocentric model. The central part of this model is accessibility as a determinant of value of land (or value of houses in the context of this paper). Numerous papers have studied accessibility as a determinant of real estate value. Jackson (1979), for instance, uses trend surface analysis to examine accessibility effects in a study of house prices in Milwaukee. He found that a quadratic accessibility polynomial is preferred in explaining house prices and that

accessibility effects are significant. Rents peak at an area west of the CBD which is well served by expressways.

Despite early dominance of Alonso's model, the existence of contradictory results in the expected signs of the regression model's coefficients and, above all, with regard to the accessibility variable is evident. The multicentric behaviour of the urban spatial structure is probably what has motivated these contradictory results. In a study by Bender and Hwang (1985), the estimated coefficient was positive on distance from the CBD when a regression was estimated for the entire study area of Chicago. When they subdivided the study area into catchment areas for the employment centre of Chicago, the coefficient on distance to the relevant employment centre turned negative. Similarly, Dubin (1992) published that there is lack of empirical support for the capitalization of neighbourhood and accessibility effects probably because of the multicentric nature of the city (polycentric rent gradients).

In monocentric theory, accessibility is measured as the distance, cost or time to the central business district (CBD). In the presence of other sub-centres in addition to the CBD, it becomes more complicated, because the existence of those multi-centres also needs to be taken into account. The polycentric theory that deals with multicentric nature of cities evolved in this context. For example, Dubin & Sung (1987) allow for the existence of non-CBD peaks in the rent gradient by using a spline function to estimate the rent gradient along four rays emanating from the CBD. They demonstrate that centres such as the CBD, universities, and industrial parks do influence rents but this influence is limited to properties in close proximity to the centre. Their estimates show the effect of the CBD was limited to a circle with radius 1.7 miles. The universities affected rents within a circle of one mile radius.

Dubin (1992) states that non-CBD peaks in the rent gradient cause traditional means of capturing accessibility effects to give inconclusive results. He suggests a more flexible means of capturing neighbourhood and accessibility effects: one that allows for multiple peaks in the rent surface. According to Dubin (1992), in addition to polycentric rent gradients, the measurement problems with regard to neighbourhood quality are also possible reasons for inconclusive results. The neighbourhood quality is unobservable and must be addressed through the use of proxy variables. The proxies themselves are measured with error due to the boundary problem, because the

concept of neighbourhood boundaries is vague. Dubin and Sung (1987) also report that multicentric nature poses several challenges with regard to the selection and spatial delimitation of these sub-centres. Dubin (1992) subscribes to a geostatistical model when he omits all neighbourhood and accessibility measures from the set of explanatory variables and instead models the resulting autocorrelation in the error term to avoid above mentioned complexities associated with the analysis.

In addition to the issue of measurement and neighbourhood boundaries, Olmo (1995) put forward other difficulties that emerge with the multicentric theory. One of them is the selection and specification of neighbourhood characteristics. A second problem is that the parameters referring to the neighbourhood characteristics of the model are constant for the whole of the urban space, but a structural change test will show otherwise in the majority of cases.

The presence of spatial autocorrelation is the other important issue in this context: dependence of the neighbourhood characteristics and the accessibility on the location. Implication of this spatial dependence is the spatial heterogeneity and autocorrelation. If the space is omitted from the hedonic model, the estimated coefficients will be biased and inconsistent. Olmo (1995) also suggests that the OLS estimator of the parameters of the hedonic model in the presence of spatial autocorrelation is inefficient. Moreover, models without spatial variables tend to produce wrong standard errors of the estimates of the implicit price of characteristics. To control for these spatial effects, spatial dimension was incorporated into hedonic models by Anselin (1998), Pace et al. (1998), Orford (2000), Bradford et al. (2004), and Brasington (2004) and others.

2. 3. Temporal dynamics of house prices

Even though it is widely accepted that house prices are sensitive to the temporal dynamics, they are hardly incorporated into the hedonic models. Literature related to temporal dynamics of house prices justify adding-in a time variable as a determinant of house prices. Inclusion of temporal dimension allows capturing the time related dynamics of the market such as volatile prices generated by the persistent trend in the economy or the cyclical behaviour.

Most studies on temporal dynamics of house prices are based on national level data. There are a number of studies that examine macroeconomic aspects of the housing market. For instance, Poterba (1991) observes intertemporal fluctuations of house prices in particular cities or regions with shifts in income and construction costs, but provide evidence there is no impact of aggregate demographic effects and user cost variations. Highly cited scholarly work of Mankiw and Weil (1989), and Case and Shiller (1990) maintain there are significant effects of population demographics. There are also a considerable number of papers on house price bubbles. Abraham and Hendershott (1993, 1996), for instance, publish support for speculative bubbles in the housing market.

The scholarly work on temporal changes of house prices belong to two main classes of studies. One class assumes that temporal trend, or the trend of market fundamentals is what drives house prices. Most of these are national level studies that take into account the trend of the national economy, i.e. real income, or trend of main fundamental variables such as construction costs. On the other hand, the second class presumes that cyclical component of the economy explains house prices for a certain extent. These studies consider business cycle movements over time, and investigate whether there is a relation between the business cycles and house prices.

Several studies evaluate temporal changes of house prices using panel data. Most common way of looking at temporal changes of house prices in these models is to assess temporal as well as spatial changes simultaneously. Panel data model of Kim (1993) reported that construction costs, interest rates, metro population, income, income growth and climate have an impact on house prices. Baltagi and Chang (1994), using a panel data set of Boston area predicted that crime rate, air pollution, tax rate, pupil-teacher ratio, proportion of the population in lower status, age of the house and the distance from the employment centres determine median house prices. In a separate study, Mendelsohn et al. (1992) used panel data on repeated single family home sales in Massachusetts and found a significant reduction in housing values as a result of these houses' proximity to hazardous waste sites.

3. Methodology

A caution is in order before proceeding to the section on conceptual model. The conventional hedonic price regression equation with regard to the housing market is either rent or house value against the characteristics of the unit that determine the respective rent or the value of the house. Majority of scholars would argue that rent values do not represent actual value of real estate. On the one hand, the rent values may need adjustments for tax payments, depreciation and other transactions costs etc. On the other hand, rents are based on current demand and supply conditions rather than the actual value of underlying real estate. Since it is almost impossible practically to obtain the actual values of real estate, most studies, in empirical analyses, consider rent values to be proxies for value of the real estate.

The first hypothesis of this study is that house price is determined by its structural characteristics. Section 2 of the paper draws from literature to support the argument that house price is determined by structural characteristics that houses hold. Literature related to the HPM provided the foundation and background knowledge to model this econometric relationship. The model can be extended to incorporate the accessibility variable, distance to the CBD, as a measure to rectify spatial dependence and resulting spatial autocorrelation. This possibility was justified in urban economics literature in general, and in literature related to monocentric model and multicentric model (or polycentric model) in particular. The follow-on hypothesis in the second stage is that the house price is determined by structural as well as locational characteristics. Part 2 of section 2 documents the foundations of this idea. The model can be extended once more with a temporal variable to test the hypothesis whether house price is determined by structural, locational as well as temporal characteristics. Part 3 of section 2 provided details about literature related to this third extension.

The conceptual model

Most of the previous analyses of house prices do not typically take into account the three dimensions, i.e. housing characteristics, accessibility and temporal dynamics jointly so that the estimates produced are likely to be biased. The composite model suggested here will reflect temporal and spatial dimensions in addition to the quality

of the house represented by its intrinsic characteristics (see conceptual model in Figure 2). The estimates of the prospective model, therefore, are likely to be unbiased.

Figure 2 The Conceptual Model
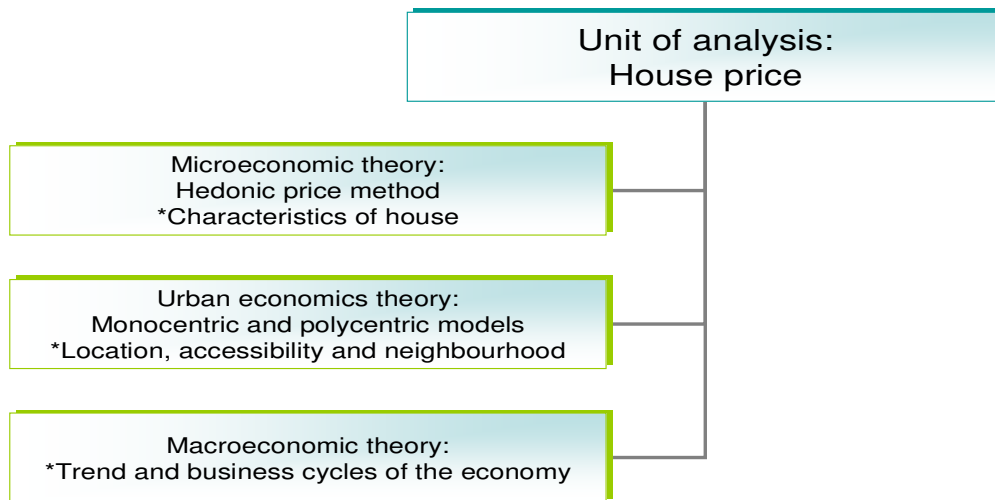
Source: Authors own work

Regression analysis related estimation is the most popular estimation approach among the scholars using the HPM. Multiple regression analysis may either be an OLS regression or a maximum likelihood estimation of the log-likelihood function derived from the hedonic function. Both these estimation techniques try to find a vector of parameters that best matches the values of explanatory variables of observations with the respective observed price. They differ by the criterion they use for identifying the best match. The explanatory variables may be the characteristics values, or mathematical transformations thereof, dummy variables or panel variables making it possible to allow for non-linearity, variable interaction, or other complex valuation situations.

As mentioned before, the conventional hedonic price regression equation with regard to the housing market is either rent or house value against the characteristics of the housing unit that determine the respective rent or the value of the house. The fundamental assumption of regression that the relevant determinants of the dependent

variable (rent, price, or value in this case) are known precisely and in advance is not violated. A classical hedonic equation is as follows:

A sample of n independent observations of house price y_i, $i = 1, \ldots, n$ are linearly related to structural characteristics in a matrix X

$$y_i = X_i \beta + \varepsilon_i$$

$$\varepsilon_i \sim N(0, \sigma^2) \qquad i = 1, \ldots, n$$

In practice, various structural variables are employed based on previous literature, scholars' preference or availability of data. Malpezzi (2003) notes that experience from many studies suggests the following structural variables often appear in hedonic price analyses:

- Number of rooms and type of rooms (bedrooms, bathrooms, etc.)
- Floor area
- Category (single family/ multifamily, attached/ detached, number of floors)
- Availability and type of heating and cooling systems
- Age
- Structural features (presence of basement, fireplaces, garages, etc.)
- Structural material used, and quality of finish

The functional form of the hedonic regression equation can either be in linear, semi-log, or log-log form. Most common is the semi-logarithmic form which has the advantage that the coefficient estimates are proportions of the price that are directly attributable to the respective characteristic. The advantage of the log-log form is that the hedonic regression equation estimates elasticities with respect to each and every characteristic under consideration. Taking logs of the dependent variable also takes into account that prices are non-negative. This property is at odds with normality assumptions in the case of a linear specification.

If the error term of the hedonic regression model is stochastic with independent and identically distributed (iid) characteristics, then it is possible to conclude that house prices are determined by structural characteristics alone. It is highly unlikely that

spatial characteristics and temporal dynamics do not play any role, but this is an indication that the estimated model with structural characteristics has captured most of the variation of house prices.

The second step takes into account the spatial effects. There are alternative ways of capturing spatial heterogeneity and autocorrelation using lattice, geostatistical and semiparametric models. The popular lattice models include spatial lag model and spatial error model. There are also different ways to capture spatial dependence within these models; spatial dependency model and geographically weighted regression model are examples.

Kriging method has been proposed as an instrument to model and estimate house prices in the presence of spatial autocorrelation. Olmo (1995) suggests using the GLS estimator, because the OLS estimator of the parameters is inefficient in the presence of spatial autocorrelation. The GLS estimator is considered BLUE (best linear unbiased estimator), and as Cressie (1991) has shown, the co-variance matrix of the disturbances V has to be known in advance in order to obtain this estimator. This is normally unknown, but it is possible to obtain estimated GLS (EGLS) estimators by substituting V for V*.

An alternative way of capturing the spatial dependence (and the resulting spatial autocorrelation) is to include a spatial variable in the model as an exogenous variable. The simple and obvious way is to include distance to the city centre as an explanatory variable. Based on the monocentric model, the expected coefficient of this variable should be negative. Greater distance to the city centre would mean the price of the house is lower. The extended model with the accessibility variable is as follows:

A sample of n independent observations of house price y_i, $i = 1, \ldots, n$ are linearly related to structural characteristics in a matrix X and to spatial characteristics in a matrix Z

$$y_i = X_i \beta + Z_i \delta + \varepsilon_i$$

$$\varepsilon_i \sim N(0, \sigma^2) \qquad i = 1, \ldots, n$$

If the error term of the extended hedonic regression model is stochastic with independent and identically distributed (iid) characteristics, it is possible to conclude that house prices are determined by structural characteristics and accessibility variables. If this is the case, the notion that "structural characteristics and accessibility variables together explain most of the variation of house prices" will be supported. It is also important to ensure that the differences of coefficients from the previous non-spatial model and the current spatial model are significant. The fact that differences of coefficients from different models are significant suggests inclusion of new variables considerably improves the predictability of the model.

The third step incorporates temporal dynamics of house prices into the extended model. The trend of the economy and the cyclical movements of the economy are considered possible candidates as explanatory variables. The important point to note here is if the investigation is at national level or regional level. The main distinction between the studies cited in the literature section and the present paper is that most previous studies are macroeconomic analyses of house prices while the present study provides a framework to deal with both house prices in a specific country as well as in a specific region. If it is a study dealing with a regional housing market, the trend and the cyclical movements of the regional economy shall be considered. If it is a national level study, the trend of the national economy and national level business cycles shall be considered.

There are several ways to take into account the temporal dynamics of house prices. One way is to include a dummy variable starting from one and go up by one every year. For instance, if there is a list of housing sales transactions from the year 1990 until 2010, the dummy variable for a house that was sold in the year 1990 takes the value 1, a house that was sold in the year 2000 takes the value 11, and a house that was sold in the year 2010 takes the value 21.

There is an alternative way of taking into account the trend and cyclical movements of the economy explicitly using the Hodrick and Prescott (HP) filter (1997). The HP filter is widely used among macroeconomists to obtain a smooth estimate of the long-term trend component of a series. The HP filter is a two-sided linear filter that calculates the smoothed series s of y by minimizing the variance of y around s, subject

to a penalty that constrains the second difference of *s*. In other words, the HP filter chooses *s* to minimize:

$$\sum_{t=1}^{T} (y_t - s_t)^2 + \lambda \sum_{t=2}^{T-1} ((s_{t+1} - s_t) - (s_t - s_{t-1}))^2,$$

Where λ is the penalty parameter that controls the smoothness of the series σ. The larger the λ, the smoother the σ. As $\lambda=\infty$, s approaches a linear trend. Since annual data is used in this analysis, a penalty parameter of 100 is recommended to smooth the series.

It is sensible to consider a fundamental variable such as real GDP, and use the Hodrick & Prescott filter (1997) to decompose the trend component and the cyclical component. Our interest in this study is not only in the trend component of the data series, but also in the cyclical component; therefore both variables are included as explanatory variables in the final composite model. For instance, a transaction that was completed in 1990 will have the relevant decomposed trend value and also the value of the business cycle for that year produced by decomposition mechanism using the HP filter. The composite model is as follows:

A sample of *n* independent observations of house price y_i, $i = 1, \ldots, n$ are linearly related to structural characteristics in a matrix *X*, spatial characteristics in a matrix *Z*, to a trend variable *T*, and to a cyclical variable *C*

$$y_i = X_i \beta + Z_i \delta + T\lambda + C\gamma + \varepsilon_i$$

$$\varepsilon_i \sim N(0, \sigma^2) \qquad i = 1,\ldots,n$$

If the error term of the composite hedonic regression model is stochastic with independent and identically distributed (iid) characteristics, then it is possible to conclude that house prices are determined by structural characteristics, accessibility variables, and temporal dynamics. If the trend variable or cyclical variable is not significant, the particular variable has to be excluded. If the trend variable is significant it is possible to emphasise that the trend of the economy, among other things, determines house prices. It may also be interesting to observe whether the

differences of coefficients from non-spatial and spatial models are significant and how the coefficients change with addition of temporal variables.

4. Summery

The HPM, derived mostly from Lancaster's (1966) consumer theory and Rosen's (1974) model implies that commodities are characterized by their constitute properties, therefore the value of a commodity can be calculated by adding up the estimated values of its separate properties. These hedonic price indices provide a basis to estimate house prices taking into account the quality or the characteristics of a housing unit. Furthermore, the standard urban economic monocentric model developed initially by Alonso (1964) suggests that the principal variable causing variations in constant-quality house prices within a metro area is land price. A typical land rental equation includes distance from the CBD, agricultural land rental, and a conversion parameter that depends on transport cost per mile and community income and hence suggests that distance to the CBD should be included in the house price model. In addition, literature related to temporal dynamics of house prices justify adding-in a temporal variable as a determinant of house prices. The temporal dynamics are hardly incorporated into the hedonic models even though it is widely accepted that house prices are sensitive to them. Inclusion of temporal dimension allows capturing the time related dynamics of the market such as volatile prices generated by cyclical movements of prices.

Most of the previous analyses of house prices do not typically take into account these three dimensions jointly so that the estimates produced are likely to be biased. The conceptual model suggested in this paper will reflect temporal and spatial dimensions in addition to the quality of a house represented by its intrinsic characteristics. The estimates of the prospective model, therefore, are likely to be unbiased. This should be seen as an alternative to the spatial panel or spatiotemporal house price models.

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