On the functional form of the hedonic price function: a matching-theoretic model and empirical evidence

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Abstract

The key issue in the hedonic price theory is that although the literature emphasises the intrinsic nonlinearity in the relationship between house prices and housing characteristics, very little theoretical guidance is provided regarding the more appropriate mathematical specification for the hedonic price function. Thus, most empirical studies make use of flexible functional forms or simple linear models which possess a direct economic meaningfulness. This theoretical paper attempts to fill this gap by using the Mortensen-Pissarides matching model to show the nonlinearity of the hedonic price function and provide insights on the more appropriate functional relationship between prices and attributes.

Keywords: hedonic price theory, hedonic price function, search and matching frictions

JEL Classification: R21, R31, J63

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1. Introduction

Although the economic theory of hedonic prices (Lancaster, 1966; Rosen, 1974) is well known and not in question,[1] it provides very little theoretical guidance on the appropriate functional relationship between prices and attributes in the hedonic price function (Malpezzi, 2003; Taylor, 2003), and thus in empirical studies researchers have used flexible functional forms, such as Box-Cox functions, or simple parametric models (Anglin and Gençay, 1996).[2]

The hedonic price literature almost unanimously underlines the intrinsic nonlinearity in the relationship between house prices and housing characteristics, though nothing is known a priori about a specific functional form (Anglin and Gençay, 1996; Ekeland, Heckman and Nesheim, 2002, 2004; Parmeter, Henderson and Kumbhakar, 2007; Haupt, Schnurbus and Tschernig, 2010). Nevertheless, while the literature suggests that the equilibrium price function is nonlinear, most empirical studies make use of linear models, thus relying on an influential simulation study by Cropper, Deck and McConnell (1988).[3]

This “puzzle” is due to the absence of theoretical groundwork regarding the more appropriate functional form to use in the hedonic price models (see e.g. Anglin and Gençay, 1996; Malpezzi, 2003). According to Rosen (1974), there is no reason for the hedonic price function to be linear; in fact, the linearity of the hedonic price function is unlikely as long as the marginal cost of attributes increases for sellers and it is not possible to untie packages. Indeed, Ekeland, Heckman and Nesheim (2002, 2004) demonstrate that nonlinearity is a generic property of the hedonic price function. Hence, a linear model would be a special case for the hedonic price function (Kuminoff, Parmeter and Pope, 2008, 2009). However, the nonlinearity is basically a general concept and may imply the use of several kinds of empirical models.

[1] For an exhaustive overview see Sheppard (1999) and Malpezzi (2003).

[2] Often linear, semi-logarithmic or log-log models are chosen. These are characterised as being easily interpretable, and the estimated parameters possess a direct economic meaningfulness (Maurer, Pitzer, and Sebastian, 2004). In particular, in the linear model, the parameters give absolute prices for the unit of the attributes.

[3] Cropper, Deck and McConnell (1988) found that when all attributes are observed, linear and quadratic Box-Cox forms produce the most accurate estimates of marginal attribute prices; whereas, when some attributes are unobserved or are replaced by proxies, linear and linear Box-Cox functions perform best.

As a rule, the use of a particular empirical model rather than another should be indicated by economic theory (Stock and Watson, 2003). Indeed, theoretical models are critical in determining an accurate and consistent econometric model: empirical analysis alone cannot replace conceptual reasoning when estimating the relationships of most economic phenomena (Can, 1992; Brown and Ethridge, 1995).

In order to build a theoretical foundation for empirical models, this paper develops a matching model à la Mortensen-Pissarides (see e.g. the textbook by Pissarides, 2000) and shows that the hedonic pricing equation is nonlinear. In particular, under the realistic assumption of decentralised housing markets with important search and matching frictions (Leung and Zhang, 2011), in this model the equilibrium price function is nonlinear with a closed-form solution. Furthermore, this paper provides empirical evidence for the non-linear effect of housing characteristics on selling price.

Several papers examined the widely used hedonic pricing equation (see e.g. Epple, 1987; Bartik, 1987; Kahn and Lang, 1988; Palmquist, 1988; Brachinger, 2003; Ekeland, Heckman and Nesheim, 2002, 2004). Moreover, there have been attempts to develop a dynamic theory of hedonic prices (Kwong and Leung, 2000; Kan, Kwong and Leung, 2004; Leung, Wong and Cheung, 2007).[4] However, these important contributions did not consider the search and matching frictions. In fact, what distinguishes our paper from the previous efforts is that it is based on a search-matching model, arguably more appropriate for a "matching market" like the housing market.[5]

Also, the proposed housing market matching model allows a major drawback of the standard hedonic pricing theory to be overcome: the assumption of competitive markets. Indeed, in the standard hedonic pricing theory, markets are assumed to be sufficiently thick (i.e. markets with a large amount of trading) so that implicit or hedonic prices, i.e. the shadow prices of the characteristics, are revealed to economic agents through trades that differ only in terms of a single attribute. However, this is hardly true:

[4] In particular, Leung, Wong and Cheung (2007) develop a dynamic theory of hedonic prices based on the general equilibrium asset pricing model *à la* Lucas which holds not only at the steady state but in principle at any point in time.

[5] Peters (2007) develops a suitably modified version of hedonic equilibrium using the limits of Bayesian Nash equilibrium from finite versions of the game to determine the out of equilibrium payoffs. The goal of this paper is to address the realistic situation in which characteristics of traders on both sides of the market are endogenous. This formalisation can be applied to any matching markets (labour, marriage and housing).

markets become increasingly thin when traded goods are increasingly heterogeneous, and the implicit or hedonic prices as well as the "true" market value of the good are not known (Harding, Rosenthal and Sirmans, 2003; Harding, Knight and Sirmans, 2003; Cotteleer and Gardebroek, 2006).[6] In fact, the house price realistically depends not only on the housing characteristics but also on the search and matching frictions and bargaining power of the parties. Indeed, several recent papers have just used the search-matching models to study the housing market (among others, Diaz and Jerez, 2009; Novy-Marx, 2009; Piazzesi and Schneider, 2009; Genesove and Han, 2010; Leung and Zhang, 2011; Peterson, 2012). However, none of these existing works has considered how to take advantage of this approach to derive an appropriate functional form for the hedonic price equation.[7]

The rest of the paper is organised as follows: section 2 presents the housing market matching model; section 3 gives insights on the more appropriate functional form to use in the hedonic price models, while section 4 shows the empirical plausibility of the theoretical result; finally, section 5 concludes the work.

2. A baseline matching model of housing market

We adopt a standard matching framework *à la* Mortensen-Pissarides (see e.g. Pissarides, 2000) with random search and prices determined by Nash bargaining. We believe that the behaviour of the housing market can be properly formalised by the Mortensen-Pissarides matching model. Indeed, the random matching assumption is absolutely compatible with a market where the formal distinction between the demand and supply side is very subtle; whereas, bargaining is a natural outcome of thin, local and decentralised markets for heterogeneous goods.

[6] According to Arnott (1989), the real estate market is thin because of the indivisibility and multi-dimensional heterogeneity of housing units. Although the model is extended to treat costly search, central in Arnott's (1989) modelling framework is the analysis of tenant search and landlord behaviour in a (rental) market with tenant idiosyncratic tastes. Thin (rental) markets are in fact modelled by assuming an idiosyncratic component to household's tastes over housing units. Given such idiosyncratic tastes, tenants search for their preferred unit and are willing to pay a premium for it. This confers monopoly power on landlords, which they exploit by setting rents above costs. In the long run, however, free entry and exit lead to zero profits, with vacancies as the equilibrating mechanism.

[7] Unlike the quoted studies, we follow the standard matching framework *à la* Mortensen-Pissarides without any deviation from the baseline model.

Since we are interested in selling price, the market of reference is the homeownership market rather than the rental market. In this market, if a contract is legally binding (as hypothesised) it is no longer possible to return to the circumstances preceding the bill of sale, unless a new and distinct contractual relationship is set up. In matching model jargon this means that the destruction rate of a specific buyer-seller match does not exist and the value of an occupied home for a seller is simply given by the selling price.

Buyers (*b*) expend costly search effort to find a house, while sellers (*s*) hold $h \geq 2$ houses of which $h-1$ are on the market, i.e. vacancies (v) are simply given by $v = (h-1) \cdot s > 0$.[8] It is therefore possible that a buyer can become a seller, and that a seller can become a buyer. Indeed, buyers today are in fact potential sellers tomorrow (Leung, Leong and Wong, 2006).

The expected values of a vacant house (V) and of buying a house (H) are given by:[9]

$$rV = -a + q(\vartheta) \cdot [P - V] \qquad [1]$$

$$rH = -e + g(\vartheta) \cdot [x - H - P] \qquad [2]$$

where $\vartheta \equiv v/b$ is the housing market tightness from the sellers' standpoint, while $q(\vartheta)$ and $g(\vartheta)$ are, respectively, the (instantaneous) probability of filling a vacant house and of buying a home. The standard hypothesis of constant returns to scale in the matching function, $m = m\{v, b\}$, is adopted (see Pissarides, 2000; Petrongolo and Pissarides, 2001), since it is also used in the (recent) search models of housing market (Diaz and Jerez, 2009; Novy-Marx, 2009; Piazzesi and Schneider, 2009; Genesove and Han, 2010; Leung and Zhang, 2011; Peterson, 2012). Hence, the properties of these functions are straightforward: $q'(\vartheta) < 0$ and $g'(\vartheta) > 0$.[10] The terms a and e represent, respectively,

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[8] Since there is no rental market, this is a reasonable assumption. Alternatively, one could assume that the sellers hold $h \geq 1$ houses of which h are on the market, and that the buyers are the homeless. This case would not change the results of the analysis.

[9] Time is continuous and individuals are risk neutral, live infinitely and discount the future at the exogenous interest rate $r > 0$. As usual in matching-type models, the analysis is restricted to the stationary state.

[10] Standard technical assumptions are postulated: $lim_{\vartheta \to 0} q(\vartheta) = lim_{\vartheta \to \infty} g(\vartheta) = \infty$, and $lim_{\vartheta \to 0} g(\vartheta) = lim_{\vartheta \to \infty} q(\vartheta) = 0$. By definition, markets with frictions require positive and finite tightness, i.e. $0 < \vartheta < \infty$, since for $\vartheta = 0$ the vacancies are always filled, whereas for $\vartheta = \infty$ the home-seekers immediately find a vacant house.

the costs sustained by sellers for the advertisement of vacancies and the effort (in monetary terms) made by buyers to find and visit the largest possible number of houses. If a contract is stipulated, the risk neutral buyer gets a linear benefit from the property, which coincides with the value of the house (abandoning the home searching value) and pays the sale price P to the seller (who abandons the value of finding another buyer). Intuitively, the value of the house, and thus the buyer's benefit, can be higher or lower according to the mix of desired and undesidered housing characteristics (not all characteristics are in fact desired).[11] For the sake of simplicity, we assume that all characteristics are desired. Hence, the greater the housing characteristics, the higher the value of the house (i.e. the buyer's benefit).

The endogenous variables that are determined simultaneously at equilibrium are market tightness (ϑ) and sale price (P). The "zero-profit" or "free-entry" condition normally used by matching models (see Pissarides, 2000) yields the first key relationship of the model, in which market tensions are a positive function of price.[12] By using the equilibrium condition $V = 0$ in [1], we obtain:

$$\frac{1}{q(\vartheta)} \equiv q(\vartheta)^{-1} = \frac{P}{a} \qquad [3]$$

with $\partial\vartheta/\partial P > 0$. This positive relationship is very intuitive (recall that $q'(\vartheta) < 0$): in fact, if the price increases, more vacancies will be on the market.

Instead, the selling price is obtained by solving the following optimisation condition, the so-called *Nash bargaining solution* usually used for decentralised markets (recall that in equilibrium $V = 0$):

$$P = argmax\{(P-V)^{\gamma} \cdot (x-H-P)^{1-\gamma}\}$$

$$\Rightarrow P = \frac{\gamma}{(1-\gamma)} \cdot (x-H-P)$$

$$\Rightarrow P = \gamma \cdot (x-H)$$

[11] Air and noise pollution, bad neighbourhoods are examples of "undesidered" housing characteristics which decrease the value of the house.

[12] The free entry condition for the sellers implies that there is no constraint on the number of sellers. In fact, in the model, anyone holding more than one house becomes a seller and pays the advertising costs.

where $0 < \gamma < 1$ is the share of bargaining power of sellers. Entering into a contractual agreement obviously implies that $x > H$, $\forall \vartheta$ for the buyer. Hence, the selling price is always positive. By using the previous result, i.e. $(x - H - P) = \frac{(1-\gamma)}{\gamma} \cdot P$, in equation [2], eventually we get an explicit expression for the selling price:

$$P = \frac{\gamma \cdot (rx + e)}{r + g(\vartheta) \cdot (1-\gamma)} \qquad [4]$$

with $\partial P / \partial \vartheta < 0$. As regards the economic meaning of equation [4], if the market tightness increases, the effect of the well-known *congestion externalities* on the sellers' side (see Pissarides, 2000) will lower the price (recall that $g'(\vartheta) > 0$).

This simple model is able to reproduce the observed joint behaviour of prices and time-on-the-market (see e.g. Leung, Leong, and Chan, 2002). In fact, with a probability of filling a vacant house of $q(\vartheta)$, the (expected) time-on-the-market is $q(\vartheta)^{-1}$. Hence, from equation [3], the house with a higher selling price has a longer time on the market (since $q(\vartheta)^{-1}$ is increasing in ϑ); whereas, from equation [4], the longer the time-on-the-market (i.e. the higher the market tightness) the lower the sale price.

It is straightforward to obtain from [3] that when P tends to zero (infinity), ϑ tends to zero (infinity), as $q(\vartheta)$ tends to infinity (zero). Consequently, given the negative slope of [4] and the fact that price is always positive, only one long-term equilibrium deriving from the intersection of the two curves exists in the model. Finally, normalising the population in the housing market to the unit, $1 = b + s$, and using both the definition of vacancies, $v = (h-1) \cdot s$, and the value of equilibrium tightness ($\vartheta \equiv \vartheta^* = v/b$), the model is closed in a very simple manner.[13]

3. Hedonic price and functional form specification

The two key equations of the model are the free-entry condition, i.e. equation [3], and the Nash bargaining solution, i.e. equation [4]. Indeed, the latter is none other than the

[13] Given the equilibrium value of market tightness, it is in fact straightforward to solve this system of three equations in three unknowns (*v, b, s*).

hedonic price function of the model. As suggested by the hedonic price theory (Rosen, 1974), the selling price is a (positive) function of (desired) housing characteristics. From [4], in fact, P depends positively on the value of the house, which in turn depends positively on the housing characteristics. Hence, the hedonic or implicit price is positive and the equilibrium hedonic price function has a closed-form solution.

However, unlike the standard hedonic price theory, the sale price of this model depends not only on the housing characteristics but also on the market tensions, bargaining power of the parties and search costs. In particular, market tensions are an endogenous variable of the model. Hence, in order to express the hedonic price function only in terms of exogenous variables we need to combine the equations [3]-[4]. By using a Cobb-Douglas functional form (also used by Novy-Marx, 2009; Piazzesi and Schneider, 2009; Peterson, 2012), i.e. $m = v^{1-\alpha} \cdot b^{\alpha}$, where α is the elasticity of the matching function with respect to the share of buyers, we get the following implicit function for selling price:

$$\left[r + \left(\frac{P}{a} \right)^{\frac{1-\alpha}{\alpha}} \cdot (1-\gamma) \right] \cdot P = \gamma r x + \gamma e \qquad [5]$$

being $q(\vartheta) = \dfrac{v^{1-\alpha} \cdot b^{\alpha}}{v} = \vartheta^{-\alpha}$, $g(\vartheta) = \dfrac{v^{1-\alpha} \cdot b^{\alpha}}{b} = \vartheta^{1-\alpha}$, and $\vartheta = \left(\dfrac{P}{a} \right)^{\frac{1}{\alpha}}$ from [3]. Total differentiation of equation [5] with respect to P and x thus yields:

$$r \cdot dP + \left[\left(\frac{P}{a} \right)^{\frac{1-\alpha}{\alpha}} \cdot (1-\gamma) + P \cdot \left(\frac{1-\alpha}{\alpha} \right) \cdot \left(\frac{P}{a} \right)^{\frac{1-\alpha}{\alpha}-1} \cdot \frac{(1-\gamma)}{a} \right] \cdot dP = \gamma r \cdot dx$$

$$\Rightarrow \frac{dP}{dx} \equiv p = \frac{\gamma r}{\left[r + \left(\frac{P}{a} \right)^{\frac{1-\alpha}{\alpha}} \cdot (1-\gamma) + P \cdot \left(\frac{1-\alpha}{\alpha} \right) \cdot \left(\frac{P}{a} \right)^{\frac{1-\alpha}{\alpha}-1} \cdot \frac{(1-\gamma)}{a} \right]} \qquad [6]$$

As a result, the hedonic price function is non-linear even if the buyer is risk neutral and acquires a linear benefit from the property: in fact, the implicit or hedonic price p depends on x, since $p = f(P)$ and $P = f(x)$. This is in line with the hedonic price literature which suggests that the equilibrium price function should be nonlinear.

The key role of market tightness on the shape of the hedonic price function is straightforward: in fact, the selling price depends on the matching probabilities between seller and buyer which are, intuitively, non-linear (for example, an increase in tightness increases at decreasing rates the probability of finding a home). Also, the equilibrium market tightness depends on housing characteristics through the selling price (see equation 3). In short, unlike the standard hedonic pricing model, housing characteristics affect the selling price both directly and indirectly (through the market tightness). Thus, the combination of these effects leads to the non-linearity of the hedonic price function.

For the sake of simplicity, we use a reasonable and common value of α = 0.5.[14] Hence, the hedonic or implicit price of this model collapses to:

$$\frac{dP}{dx} \equiv p = \frac{\gamma r}{\left[r + \left(\frac{P}{a} \right) \cdot (1 - \gamma) + P \cdot \frac{(1 - \gamma)}{a} \right]} \qquad [6']$$

since the selling price is increasing in the house value (namely, the hedonic price is positive), we may also state that $d^2P/dx^2 \equiv p'(x) < 0$. Hence, this theoretical model also gives a precise statement about the form of the hedonic price function: it in fact suggests an increasing relationship at decreasing rates between selling price and housing characteristics. [15]

4. Empirical testing

In order to test the empirical plausibility of an increasing relationship at decreasing rates between selling price and housing characteristics, we use the benchmark parametric model proposed by Anglin and Gençay (1996), and also considered by Parmeter, Henderson and Kumbhakar (2007), and Haupt, Schnurbus and Tschernig (2010).[16]

[14] See Petrongolo and Pissarides (2001). Indeed, Piazzesi and Schneider (2009) use a very similar value for the U.S. housing market, namely 0.57.
[15] It is straightforward to show that the result holds for any value of α.
[16] Haupt, Schnurbus and Tschernig (2010), in particular, show that the null hypothesis of correct specification of the linear parametric model proposed by Anglin and Gençay (1996), against the alternative of parametric misspecification, cannot be rejected at any reasonable significance level. Furthermore, they also show that the parametric model predicts better than the nonparametric specification proposed by Parmeter, Henderson and Kumbhakar (2007).

The Anglin-Gençay benchmark parametric model is characterised by many binary variables and the relationship between the dependent variable (selling price), the continuous regressor (the lot size) and the discrete variables is represented in terms of relative changes (elasticity).[17] In this empirical analysis, we employ data from their study (also used by Verbeek, 2004). Details about this dataset are reported in the Appendix (now at the end).[18]

Following the benchmark parametric model by Anglin and Gencay (1996), we transform all the quantitative variables (*lot size, bedrooms, bathrooms, stories*) into natural logarithm; whereas, the dummy variables, by definition, cannot be transformed (Maurer, Pitzer and Sebastian, 2004). The econometric model is thus the following:[19]

$$\begin{aligned} ln(P_i) = \beta_0 + \beta_1 \cdot ln(LOT_i) + \beta_2 \cdot ln(BED_i) + \beta_3 \cdot ln(BATH_i) + \beta_4 \cdot ln(STO_i) + \beta_5 \cdot DRI_i \\ + \beta_6 \cdot RER_i + \beta_7 \cdot FIB_i + \beta_8 \cdot GWH_i + \beta_9 \cdot CAC_i + \beta_{10} \cdot PRN_i + \beta_{11} \cdot GAR_i + \varepsilon_i \end{aligned} \quad [7]$$

where P_i is the selling price of the house i; *DRI*, *RER*, *FIB*, *GWH*, *CAC* and *PRN* are dummy variables for driveway, recreational room, finished basement, gas water heating, central air conditioning and preferred neighbourhood; *GAR*, *BED*, *BATH* and *STO* are the number of garages, bedrooms, full bathrooms and stories; and *LOT* is the lot size (in square feet). Finally, ε_i is the stochastic error term.

Neglecting the binary variables,[20] we focus on β_j, with $j = 1,2,3,4$. It follows that with $0 < \beta_j < 1$ the relationship is increasing at decreasing rates, while with $\beta_j > 1$ the relationship is increasing at increasing rates, finally with $\beta_j = 1$ the relationship is linear.

The OLS results show that the coefficients β_j have positive signs and are statistically significant, i.e. $\beta_j \neq 0$. Furthermore, the coefficients β_j range between 0.089 (*number of bedrooms*) and 0.313 (*lot size*), i.e. $0 < \beta_j < 1$, and the null hypothesis of

[17] Data on housing characteristics, in fact, typically consists of one continuous regressor (the lot size) and many ordered and unordered categorical variables (Parmeter, Henderson and Kumbhakar, 2007; Haupt, Schnurbus and Tschernig, 2010).
[18] The STATA file is available at: http://eu.wiley.com//legacy/wileychi/verbeek2ed/datasets.html.
[19] Because of the presence of the value 0, the natural logarithm is not used for the variable number of garage places.
[20] The coefficients for the binary variables give the surcharge which is to be paid relative to a property without those attributes. For more details about the economic interpretation of the effect of dummy variables on the dependent variable in natural logarithmic form see Halvorsen and Palmquist (1980).

$\beta_j = 1$ is rejected at any reasonable significance level, thus confirming the nonlinearity of the hedonic price function. Finally, not surprisingly the null hypothesis of "no omitted variables" can not be rejected at any reasonable significance level (for details about the results see the Appendix).[21]

Hence, an increasing relationship at decreasing rates may be the most appropriate functional form for the hedonic price function (as suggested by the theoretical model).

Finally, this theoretical framework may also be used to study how errors in measuring marginal attribute prices vary with the form of the hedonic price function; in this way, the simulation strategy developed by Cropper, Deck and McConnell (1988), and updated by Kuminoff, Parmeter and Pope (2008, 2009), may take the (equilibria of the) housing market with search and matching frictions into account, thus relaxing the unrealistic assumption of competitive housing markets.[22]

5. Concluding Remarks

The nonlinearity in the relationship between house price and housing characteristics is a recognised starting point for the hedonic price literature, though nothing is known a priori about a specific functional form. Indeed, the economic theory of hedonic prices provides very little theoretical guidance on the appropriate functional relationship between prices and attributes in the hedonic price function. This is a very significant shortcoming for empirical studies, since theoretical models are critical in determining accurate and consistent econometric models and the use of a particular empirical model rather than another should be indicated by economic theory. As a consequence, most empirical studies make use of flexible functional forms or simple models which possess a direct economic meaningfulness. This paper develops a baseline matching model in which the nonlinearity of the hedonic price function emerges as an equilibrium outcome in a market

[21] On the shape of the hedonic price function (precisely, on the estimate of the marginal price of floor space) see the interesting discussion between Coulson (1992, 1993) and Colwell (1993).

[22] In the quoted studies, the marginal bid of consumers (namely, the "true" marginal price paid) for each attribute is obtained by simulations of housing market equilibria. Subsequently, equilibrium housing prices, together with housing attributes, provide the data used to estimate various functional forms for the hedonic price function. Finally, errors in estimating marginal prices are calculated by comparing the consumer's equilibrium marginal bid with the gradient of the hedonic price function.

with search and matching frictions. Furthermore, it provides empirical evidence for the non-linear effect of housing characteristics on selling price.

A drawback of this analysis, however, must be acknowledged: the "gap" between the theoretical model (which derives a complicated non-linear function) and its empirical counterpart (in which many binary regressors are used). It follows that the theoretical model introduces a number of parameters which can not be tested for (above all, the bargaining power of the parties).[23] The explanation (justification) for this difference is that the aim of the empirical part of the paper is to offer clear evidence for the particular shape of the hedonic price function derived from the theoretical model. The empirical model used is in fact a very popular econometric specification. Nevertheless, it would be desirable to verify these results using another dataset and/or a more complex empirical model.

References

Anglin, Paul M., and Gençay Ramazan (1996). Semiparametric Estimation of a Hedonic Price Function, *Journal of Applied Econometrics*, 11(6), 633-648

Arnott, Richard (1989). Housing vacancies, Thin Markets, and Idiosyncratic Tastes, *Journal of Real Estate Finance and Economics*, 2(1), 5-30.

Bartik, Timothy J. (1987). The Estimation of Demand Parameters in Hedonic Price Models, *Journal of Political Economy*, 95(1), 81-88.

Brachinger, Hans Wolfgang (2003). Statistical Theory of Hedonic Price Indices, DQE working paper, 1.

Brown Jeff E., and Don E. Ethridge (1995). Functional Form Model Specification: An Application to Hedonic Pricing, *Agricultural and Resource Economics Review*, 24(2), 166-173.

Can, Ayse (1992). Specification and Estimation of Hedonic Housing Price Models, *Regional Science and Urban Economics*, 22(3), 453-474.

Colwell, Peter F. (1993). Comment: Semiparametric Estimates of the Marginal Price of Floorspace, *Journal of Real Estate Finance and Economics*, 7(1), 73-75.

Cotteleer, Geerte, and Cornelis Gardebroek (2006). Bargaining and market power in a GIS-based hedonic pricing model of the agricultural land market, *American Agricultural Economics Association*, 21255 (2006 Annual meeting, July 23-26, Long Beach, CA).

[23] However, a simple way to measure the important effect of bargaining power with dummy variables can be found in Iacobini and Lisi (2012).

Coulson, Edward N. (1992). Semiparametric Estimates of the Marginal Price of Floorspace, *Journal of Real Estate Finance and Economics*, 5(1), 73-83.

Coulson, Edward N. (1993). Semiparametric Estimates of the Marginal Price of Floorspace: Reply, *Journal of Real Estate Finance and Economics*, 7(1), 77-78.

Cropper, Maureen L., Leland B. Deck, and Kenenth E. McConnell (1988). On the Choice of Functional Form for Hedonic Price Functions, *The Review of Economics and Statistics*, 70(4), 668-675.

Díaz, Antonia, and Belén Jerez (2009). House Prices, Sales and Time on the Market: A Search-Theoretic Framework, Working Paper 09-25 Economic Series, Departamento de Economía, Universidad Carlos III de Madrid.

Ekeland, Ivar, James J. Heckman, and Lars Nesheim (2002). Identifying Hedonic Models, *American Economic Review*, 92(2), 304-309.

Ekeland, Ivar, James J. Heckman, and Lars Nesheim (2004). Identification and Estimation of Hedonic Models, *Journal of Political Economy*, 112(S1), S60-S109.

Epple, Dennis (1987). Hedonic Prices and Implicit Markets: Estimating Demand and Supply Functions for Differentiated Products, *Journal of Political Economy*, 95(1), 59-80.

Genesove, David, and Lu Han (2010). Search and Matching in the Housing Markets, CEPR Discussion Papers, 7777.

Halvorsen, Robert, and Raymond Palmquist (1980). The Interpretation of Dummy Variables in Semi-logarithmic Equations, *American Economics Review*, 70(3), 474-475.

Harding, John P., John R. Knight, and C. F. Sirmans (2003). Estimating Bargaining Effects in Hedonic Models: Evidence from the Housing Market, *Real Estate Economics*, 31(4), 601-622.

Harding, John P., Stuart S. Rosenthal, and C. F. Sirmans (2003). Estimating Bargaining Power in the Market for Existing Homes, *Review of Economics and Statistics*, 85 (1), 178-188.

Haupt, Harry, Joachim Schnurbus, and Rolf Tschernig (2010). On Nonparametric Estimation of a Hedonic Price Function, *Journal of Applied Econometrics*, 25(5), 894-901.

Parmeter, Christopher F., Daniel J. Henderson, and Subal C. Kumbhakar (2007). Nonparametric Estimation of a Hedonic Price Function, *Journal of Applied Econometrics*, 22(3), 695-699

Iacobini, Mauro, and Gaetano Lisi (2012). Measuring the Housing Price Dispersion in Italy, *Economics Bulletin*, 32(1), 811-822.

Kahn, Shulamit, and Kevin Lang (1988). Efficient Estimation of Structural Hedonic Systems, *International Economic Review*, 29(1), 157-166.

Kan, Kamhon, Sunny Kai Sun Kwong, and Charles Ka Yui Leung (2004). The Dynamics and Volatility of Commercial and Residential Property Prices: Theory and Evidence, *Journal of Regional Science*, 44(1), 95-123.

Kuminoff, Nicolai V., Christopher F. Parmeter, and Jaren C. Pope (2008). Hedonic Price Functions: Guidance on Empirical Specification, *American Agricultural Economics Association*, 2008 Annual Meeting, Orlando, Florida, July 27-29, number 6555.

Kuminoff, Nicolai V., Christopher F. Parmeter, and Jaren C. Pope (2009). Specification of Hedonic Price Functions: Guidance for Cross-Sectional and Panel Data Applications, Virginia Tech Working Paper, No. 2009-02, January 2009.

Kwong, Sunny Kai Sun, and Charles Ka Yui Leung (2000). Price Volatility of Commercial and Residential Property, *Journal of Real Estate Finance and Economics*, 20(1), 25-36.

Lancaster, Kevin J. (1966). A New Approach to Consumer Theory, *Journal of Political Economy*, 74(2), 132-157.

Leung, Charles Ka Yui, and Zhang, Jun (2011). Fire Sales in Housing Market: Is the House–Search Process Similar to a Theme Park Visit ?, *International Real Estate Review*, 14(3), 311-329.

Leung, Charles Ka Yui, Kelvin Siu Kei Wong, and Patrick Wai Yin Cheung (2007). On the Stability of the Implicit Prices of Housing Attributes: A Dynamic Theory and Some Evidence, *International Real Estate Review,* 10(2), 66-93.

Leung, Charles Ka Yui, Youngman Chun Fai Leong, and Ida Yin Sze Chan (2002). Time-On-the-Market: Why Isn't Price Enough? *International Real Estate Review*, 5(1), 91-115.

Leung, Charles, Youngman Leong, and Siu Wong (2006). Housing Price Dispersion: An Empirical Investigation, *The Journal of Real Estate Finance and Economics*, 32(3), 357-385.

Lucas, Robert E. (1978). Asset Prices in an Exchange Economy, *Econometrica*, 46(6), 1426-1445.

Malpezzi, Stephen (2003). Hedonic Pricing Models: A Selective and Applied Review, in: *Housing Economics: Essays in Honour of Duncan Maclennan*, T. O. Sullivan and K. Gibbs (Eds.), Blackwell.

Maurer, Raimond, Martin Pitzer, and Steffen Sebastian (2004). Hedonic Price Indices for the Paris Housing Market, *Allgemeines Statistisches Archiv*, 88(3), 303-326.

Novy-Marx, Robert (2009). Hot and Cold Markets, *Real Estate Economics*, 37(1), 1-22.

Palmquist, Raymond B. (1988). Land as a Differentiated Factor of Production: A Hedonic Model and Its Implications for Welfare Measurement, *Land Economics*, 65(1), 23-28.

Peters, Michael (2007). Innis Lecture: Hedonic equilibrium, *Canadian Journal of Economics*, 40(4), 1060-1077.

Peterson, Brian M. (2012). Fooled by Search: Housing Prices, Turnover and Bubbles, Bank of Canada Working Paper 2012-3.

Petrongolo, Barbara, and Christopher A. Pissarides (2001). Looking into the Black Box: A Survey of the Matching Function, *Journal of Economic Literature*, 39(2), 390-431.

Piazzesi, Monika, and Martin Schneider (2009). Momentum Traders in the Housing Market: Survey Evidence and a Search Model, *American Economic Review: Papers & Proceedings*, 99(2), 406-411.

Pissarides, Christopher A. (2000). *Equilibrium Unemployment Theory* (2nd edition), MIT Press Books.

Rosen, Sherwin (1974). Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition, *Journal of Political Economy*, 82(1), 34 - 55.

Sheppard, Stephen (1999). Hedonic Analysis of Housing Markets, in *Handbook of Regional and Urban Economics Volume 3: Applied Urban Economics*, edited by Paul Cheshire and Edwin Mills, Amsterdam: North Holland, 1999, Chapter 41, 1595 – 1635.

Stock, James H., and Mark W. Watson (2003). *Introduction to Econometrics*, 1st Edition, Pearson Education.

Taylor, Laura O. (2003). The Hedonic Model, in: *A Primer on Nonmarket Valuation*, edited by P.A. Champ, K. J. Boyle and T. C. Brown. Dordrecht/Boston/London: Kluwer Academic Publishers.

Verbeek, Marno (2004). *A Guide to Modern Econometrics*, John Wiley and Sons Ltd (2nd edition).

Appendix

Data

The dataset contains 546 observations on sales prices of houses sold during July, August and September (1987) in the city of Windsor, Canada (*source:* Anglin and Gencay, 1996).

The following variables are available:

price (P): sale price of a house
lotsize (LOT): the lot size of a property in square feet
bedrooms (BED): number of bedrooms
bathrms (BATH): number of full bathrooms
stories (STO): number of stories excluding basement
driveway (DRI): dummy, 1 if the house has a driveway
recroom (RER): dummy, 1 if the house has a recreational room
fullbase (FIB): dummy, 1 if the house has a full finished basement
gashw (GWH): dummy, 1 if the house uses gas for hot water heating
airco (CAC): dummy, 1 if there is central air conditioning
garagepl (GAR): number of garage places
prefarea (PRN): dummy, 1 if located in preferred neighbourhood of the city

summary statistics:

Variable	Obs	Mean	Std. Dev.	Min	Max
price	546	68121.6	26702.67	25000	190000
lotsize	546	5150.266	2168.159	1650	16200
bedrooms	546	2.965201	.7373879	1	6
bathrms	546	1.285714	.5021579	1	4
stories	546	1.807692	.8682025	1	4
driveway	546	.8589744	.3483672	0	1
recroom	546	.1776557	.3825731	0	1
fullbase	546	.3498168	.4773493	0	1
gashw	546	.0457875	.2092157	0	1
airco	546	.3168498	.465675	0	1
garagepl	546	.6923077	.8613066	0	3
prefarea	546	.2344322	.4240319	0	1

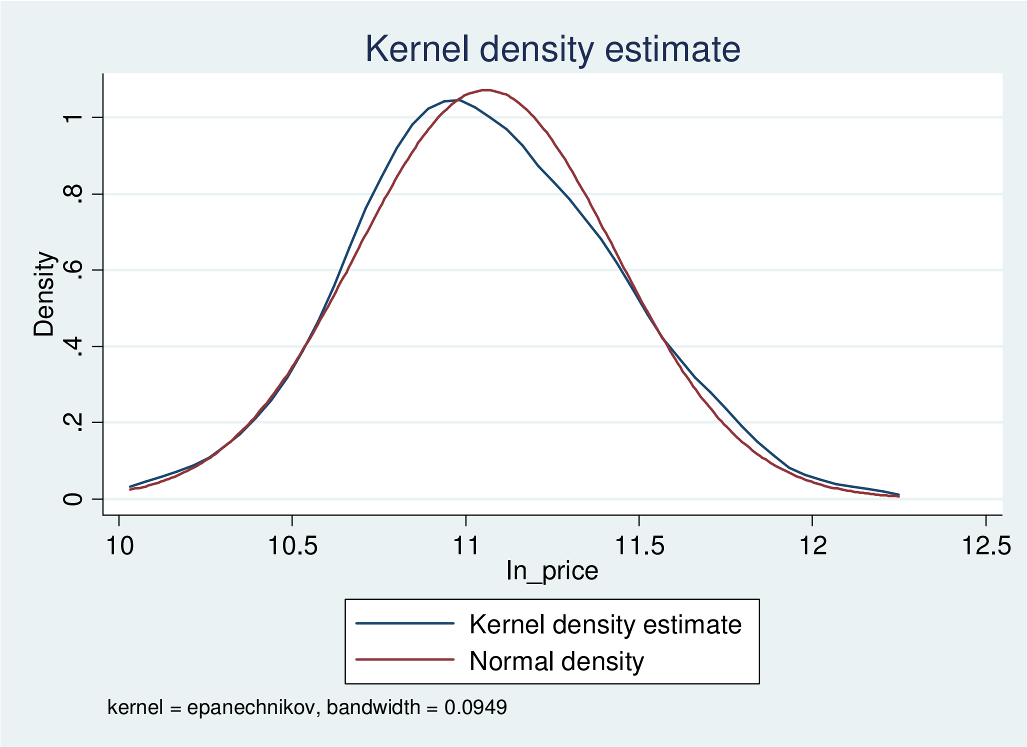
Estimation results

Source	SS	df	MS
Model	51.5755541	11	4.68868673
Residual	23.8376161	534	.044639731
Total	75.4131702	545	.138372789

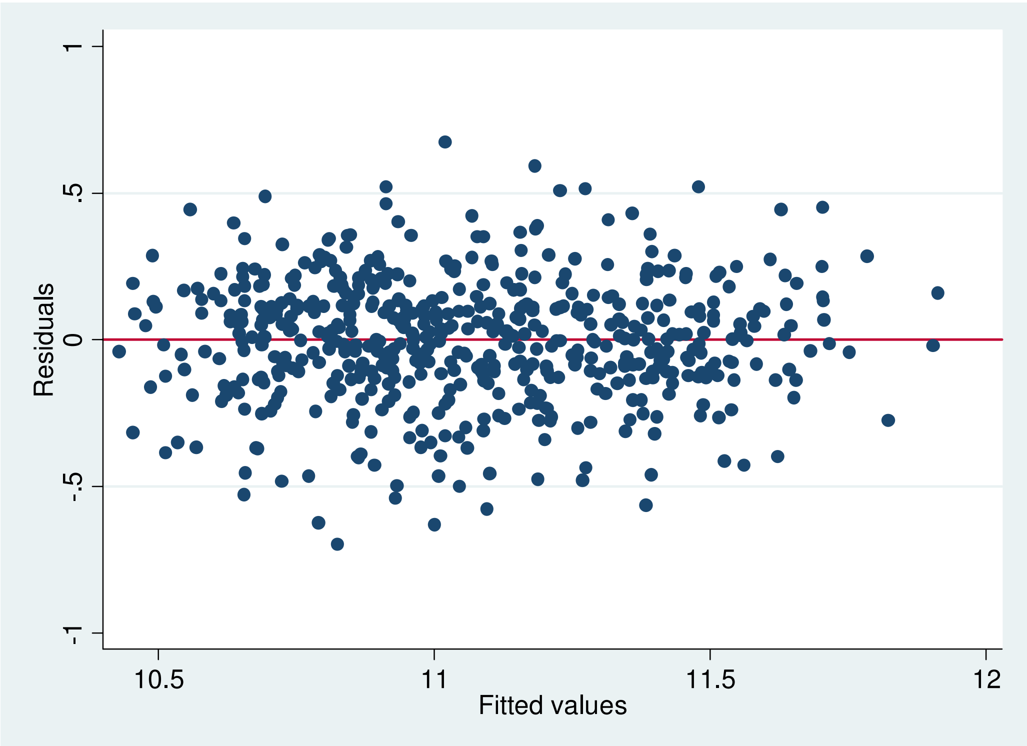
Number of obs =	546
F(11, 534) =	105.03
Prob > F =	0.0000
R-squared =	0.6839
Adj R-squared =	0.6774
Root MSE =	.21128

ln_price	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
ln_lotsize	.3129159	.0269214	11.62	0.000	.260031	.3658007
ln_bedrooms	.0887915	.0437256	2.03	0.043	.0028962	.1746868
ln_bathrms	.2637722	.0312154	8.45	0.000	.2024521	.3250923
ln_stories	.1652339	.024935	6.63	0.000	.1162513	.2142166
driveway	.1095447	.0283597	3.86	0.000	.0538344	.165255

```
     recroom |    .059703   .0261513     2.28   0.023     .0083309    .1110751
    fullbase |   .0956443   .0216553     4.42   0.000     .0531043    .1381843
       gashw |   .1733505    .044116     3.93   0.000     .0866883    .2600126
       airco |   .1707837   .0212669     8.03   0.000     .1290066    .2125608
    garagepl |    .048916   .0115416     4.24   0.000     .0262436    .0715884
    prefarea |   .1296759   .0227795     5.69   0.000     .0849275    .1744243
       _cons |   7.920482   .2191781    36.14   0.000     7.489925    8.351039
------------------------------------------------------------------------------

Ramsey RESET test using powers of the fitted values of ln_price
       Ho:  model has no omitted variables
                 F(3, 531) =      0.76
                  Prob > F =      0.5184


test  ln_lotsize = 1

F(  1,   534) =  651.36
            Prob > F =    0.0000


test ln_bedrooms = 1

F(  1,   534) =  434.27
            Prob > F =    0.0000


test  ln_bathrms = 1

F(  1,   534) =  556.27
            Prob > F =    0.0000


test  ln_stories = 1

F(  1,   534) = 1120.76
            Prob > F =    0.0000
```



Kernel density estimate
Density
0
.2
.4
.6
.8
1
10
10.5
11
11.5
12
12.5
ln_price
Kernel density estimate
Normal density
kernel = epanechnikov, bandwidth = 0.0949



Residuals
-1
-.5
0
.5
1
10.5
11
11.5
12
Fitted values